Y02A as Praxis: An innovation Model for Coastal Resilience and Adaptation

by Richard Lloyd Hindle

Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

under the supervision of

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Richard Lloyd Hindle, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the school of Design, Architecture, and Building, at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Abstract

This thesis argues that the patent system and patented technologies have a distinct agency in coastal systems and can be operationalized to advance adaptation and resilience efforts. It brings together discourse on coastal resilience and adaptation, the sociotechnical aspect of environmental innovation, histories of the patent system and legal theory, and case studies that reveal the agency of patents in large-scale complex environmental systems. It offers recommendations for strategic integration of patented technologies and the global patent system into the contemporary coastal resilience and adaptation toolkit. The research presented foregrounds the role of inventors, institutions, policy, funding, private research & development, and environmental planning practices operating within coastal zones. It highlights the contributions of these diverse actors to an expanded repertoire of coastal adaptation and resilience technologies. Central to the thesis is the theorization of an innovation model, posited in the conclusion, in which patents, and the patent system, help build adaptive capacities and resilience in coastal systems through integration of spatial planning and design praxis with the Y02A patent classification scheme. The Y02A classification scheme was created (c.2018) to track technologies for adaptation to climate change, including a broad range of technologies related to coastal process and development. Tracking innovation in this emergent sector through the Y02A classification scheme builds adaptive capacity and anticipatory frameworks for the management of sequential innovation in adaptation and resilience sectors, presenting the allied disciplines of environmental design, planning, and engineering, with the opportunity to integrate datasets and novel technologies into praxis, therefore spatializing innovation through real-world projects.

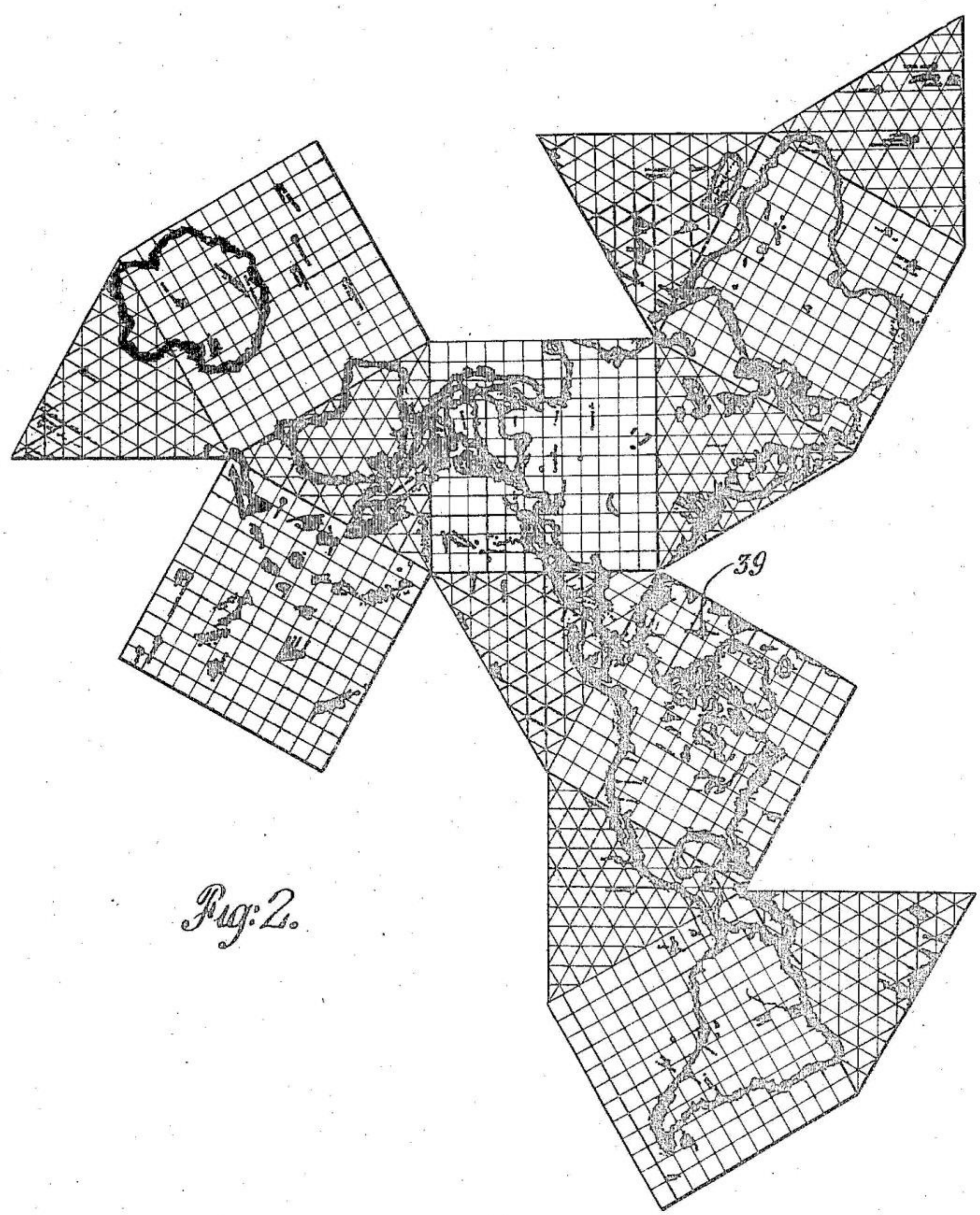

Fig: 2.

INVENTOR
RICHARD BUCKMINSTER FULLER
BY

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Patent US2393676 for "Cartography" Granted to Richard Buckminster Fuller in 1944. The Coordinate system, popularly known as the Dymaxion map, shows the landmasses as islands in a vast ocean.

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Preface: Professional Background and Interest

In many regards this dissertation represents the culmination of my research on environmental innovation revised and refined to address the challenges of coastal adaptation and resilience. As a professor of Landscape Architecture and Environmental Planning at the University of California Berkeley, I have developed a substantive record of research, teaching, and public engagement that explores the role of the patent system, and patented technology, in the built environment across scales and geographies – advocating for an expanded canon of technological precedents and strategies with the design and planning disciplines. Development of this thesis project was undertaken, in collaboration with my advisors Charles Rice (UTS) and Elizabeth Mossop (UTS), with the ambition of translating my established historical and practice-based research into a forward-looking strategy that addresses the complex social, technical, and environmental, process that converge in coastal zones. It represents my best approximation of how the patent system, and novel technologies, integrated with environmental design and planning praxis may address the global challenges facing coastal communities and ecosystems through an expanded field of technological innovation that occurs across environmental sectors.

My research interest in the subject of patents emerged slowly through an inductive research process that began approximately 16 years ago (c. 2007) as a designer/consultant writing technical specifications and guidelines for a novel vegetated building systems under development by the architect Ateliers Jean Nouvel. Having exhausted the all books, peer-reviewed science, and professional journals, and other familiar sources in the Liberty Hyde Bailey Library at Cornell University, I clicked on the newly created *"Include Patent Refences"* button on the web-of-science search page to see what this novel search category might reveal. To my surprise a long list or patents was returned by the search engine, chronicling a history of innovation that was previously unknown to me and not documented in scholarly literature on the subject.

Among the documents I downloaded through subsequent searches was the first known patent for a green wall, titled the "Vegetation Bearing Architectonic Structure and System," invented by Stanley Hart White, Landscape Architect, Professor, and grandfather of modern design theory.[1] It took me a few years, and many research tangents, to realize the layered meaning of Professor White's invention and why it remained entirely unknown in the design community. Today I can confidently say that Professor White, and his prescient green wall system, not only provided a window into the origins of vertical gardens as a technical field, but also revealed the inherent societal value of a patent system that archives, cites, makes public, and otherwise manages sequential innovation. The timing and context of my re-discovery also chronicles a 60-year lag between the initial invention and eventual implementation of the green wall in contemporary cities, thus pointing to the considerable distances that exist between domains of technological knowhow in emergent sectors and the allied disciplines of environmental design and planning. For how could the evolution of core technologies remain such a mystery to the fields from in which they were developed?

Since these early days of discovery my research has evolved into a broader inquiry of patent history, law, technological innovation, and the environment – including original research on the Mississippi River, California Delta, San Pablo Baylands, and the history of patent law as originated in Venice Italy six centuries ago.[2] Unifying these works is the often overlooked, yet latent, relationship of patented technology to known place and geographies – what I now refer to as 'geographies of innovation.' Researching these geographies requires the establishment of linkages between patents, patent law, and the environment, weaving a path through layers of government, policy, economics, and broader innovation studies. From these fragments a picture emerges, often revealing nuanced stories and curious details of how environmental transformation and technological innovation are intertwined, and mediated, to create more complex assemblages. Obviously, my role as professor of Landscape Architecture and Environmental Planning also provides important professional and intellectual context. Having worked professionally on large-scale urban and coastal sites helps ground my research in the

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[1] Richard L Hindle, "A Vertical Garden: Origins of the Vegetation-Bearing Architectonic Structure and System (1938)," *Studies in the History of Gardens & Designed Landscapes* 32, no. 2 (2012): 99–110.

[2] Richard L Hindle, "Inventing Venice: An Urban and Environmental Innovation Model from the Lagoon City," *J. Pat. & Trademark Off. Soc'y 100* (2018): 529; Richard Hindle, "Levees That Might Have Been," Places Journal, 2015, https://placesjournal.org/article/levees-that-might-have-been/; Richard L Hindle, "Patent Scenarios for the Mississippi River," *Journal of Architectural Education* 71, no. 2 (2017): 280–85; Richard Hindle, "Prototyping the Mississippi Delta: Patents, Alternative Futures, and the Design of Complex Environmental Systems," *Journal of Landscape Architecture* 12, no. 02 (n.d.): 32–47, https://doi.org/10.1080/18626033.2017.1361084.

pragmatics of site construction and theoretical horizons of design and planning, helping to inform my research and provide a framework through which to approach this dissertation.

Over the past decade of research, a recurrent theme has emerged through the interrelations between technological innovation, patents, and coastal systems. At first, evidence of the coevolution of technological and coastal systems revealed itself slowly, primarily through detailed research projects and design speculations that built an inductive understanding of the subject area through iterative study and laid the groundwork for development of this dissertation. Establishment of the Y02A classification scheme in 2018, and rollout through 2020, hastened my pace of discovery and galvanized interest in the future technology in the coastal adaptation and resilience sectors. The Y02A initiative provides a deductive, policy driven, framework for my research and provides a distinct opportunity to for governments, planners, designers, and scientists to align innovation and the patent system with the practices and research discoveries that will define the future of coastal systems.

Integration of new site technology into the built environment is among the fundamental practices of the allied professions of environmental design and planning (I.e. landscape architecture, urban design, architecture, regional planning, etc.). Central Park, in New York City, serves as a well-known example of this process as the design by Landscape Architect Frederick Law Olmsted and Calvert Vaux integrated a novel subsurface tile drainage system that was previously untested in a public landscape. The drainage system was developed in England and made possible by the invention of a patented tile fabrication machine before it was tested in agricultural plots in upstate New York and later integrated in the parks infrastructure by sanitary engineer George Waring (c.1856-1857). Today, environmental design and planning disciplines are again chartered to advance urban infrastructure as the professions address the global issues of climate change and sea level rise for which no "instruction manual" or "textbook" exists as a guide – a paradigm that necessitates open ended, flexible, and sociotechnical approaches to the future of technology and the built environment.

As environmental systems and the designed urban landscape become more technologically advanced, performance driven, structurally complex, networked, ecologically hybrid, novel, and integrated, a cohesive strategy is required for the allied disciplines of environmental design and planning to engage the processes of innovation. Patents and the patent system offer one such mechanism through which to comprehend technological change and will play an increasingly important role in the emergent environmental innovation problem space through the management of sequential innovation, development of knowledge infrastructure, projection of future imaginaries, and transfer of technology in this sector. Importantly, these processes may also be operationalized through design and planning praxis to help build a more sustainable, adaptive, and equitable, environment. Many questions remain regarding the invention, prototyping, testing, and implement the environmental technologies of the future, however the work is imperative. This thesis takes the first tentative steps towards integrating environmental innovation, coordinated by the Y02A, into environmental design and planning praxis, raising issues of disciplinary concern through the lens of coastal adaptation and resilience.

Introduction

The parallel genealogy of patented technology and coastal systems spans six centuries and can be observed today in the morphology of anthropogenic coasts around the world. Historically this resulted from the origins of patent law in 15th century Venice where the sociotechnical legal framework of the Venetian Patent Statute of 1474 facilitated urbanization of the *Leguna Venata* through advanced dredge, drainage, and ground stabilization technology, associated with public works in the Venetian territory.[3] More recently the European Patent Office launched the Y02A patent classification scheme (circa.2018/20) to facilitate the diffusion, transfer, and implementation of "Technologies for Adaptation to Climate Change," covering the cross-sectoral innovations in coastal and riverine technology, including flood control, mapping, sensing, human health, infrastructure, etc. The nearly three-quarter million (723,254) patents currently tagged in the Y02A classification chronicle the ongoing parallel evolution of technology, urban, and coastal systems in the context or global climate adaptation and resilience efforts. Given these convergent factors, might the patent system be operationalized to facilitate coastal resilience and adaptation efforts and help build the next layer of coastal infrastructure?

Of course, coastal infrastructure in the contemporary context of resilience and adaptation theory, and praxis, is no longer the fixed heavy dikes, breakwaters, and revetments, of yesteryear. Global adaptation and resilience strategies will require diverse technologies ranging from soft nature based systems, to distributed micro-grids, urban storm water systems, social-networks, artificial marine habitats, mapping software, remote sensing, coral reef restoration, robotics, and yet unforetold inventions that will reformat social, ecological, and technological interactions in coastal regions.[4] This shift in technology is being instigated by a changing environment and also cultural changes in our relationship to water and the ocean.

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[3] Hindle, Richard "Inventing Venice: An Urban and Environmental Innovation Model from the Lagoon City." *Journal of the Patent Office Society*

[4] Jeremy M Hills, Evanthie Michalena, and Konstantinos J Chalvatzis, "Innovative Technology in the Pacific: Building Resilience for Vulnerable Communities," *Technological Forecasting and Social Change* 129 (2018): 16–26; Lynette H L Loke et al., "Complexity for Artificial Substrates (CASU): Software for Creating and Visualising Habitat Complexity," PloS One 9, no. 2 (2014): e87990–e87990; Jana Koerth et al., "A Typology of Household-Level Adaptation to Coastal Flooding and Its Spatio-Temporal Patterns," Springerplus 3, no. 1 (2014): 1–10; Richard JT Klein et al., "Technological Options for Adaptation to Climate Change in Coastal Zones," *Journal of Coastal Research*, 2001, 531–43.

Coastlines are no longer conceived of as thin boundary lines between terrestrial and marine systems, instead they are now understood as an interconnected set of anthropogenic and environmental processes operating within an expanded coastal zone. As contemporary landscape theoreticians such as Anuradha Mathur and Dilip da Cunha point out, the 'terrain' of water extends through, and blurs, geographical boundaries and is deeply intertwined with culture and ecology.[5] Scientist grappling with similar challenges of classification and definition have developed definitions for coastal systems shaped by humans, referring to these complex assemblages as 'coastal anthromes' in which humans are agents of biospheric and geomorphic change, through patterns of settlement, infrastructure, agriculture, technology, and management practices, leading to a widened conception of the coastal zone and human agency within coastal systems.[6] Adaptation and resilience efforts within this expanded coastal zone must embrace the complexity of human agency in coastal systems and develop new tools and technologies through which to address the challenge – collectively representing the scale, scope and opportunities withing this expanded field.

Redefinition of coastal systems is happening concurrent to unprecedented global warming and climate change. The need for an expanded toolkit for coastal adaptation and resilience is therefore timely as climate change and environmental risk radically reconfigure social-ecological-technical systems (SETs) in coastal regions. SETS are ecosystems "defined by the flow and accumulation of energy through the medium of organisms, constructed infrastructure, institutions, and their environment" in which human intention and values have agency and can drive ecological processes alongside non-anthropogenic forces.[7] Catastrophic events such as hurricanes, floods, drought, ecological degradations, subsidence, etc., are catalyzing change in these systems, impacting human and environmental systems alike and leading to irreversible changes in coastal ecosystems. Given the scale and scope of the challenges across these coastal anthromes, questions arise as to the most effective way to advance adaptation and resilience efforts. As decades of research affirms, policy, land use planning, nature-based solutions, and

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[5] A. Mathur, D. da Cunha, and University of Pennsylvania. School of Design, *Design in the Terrain of Water*. Applied Research + Design Publishing, 2014)
[6] Eli D Lazarus, "Toward a Global Classification of Coastal Anthromes," Land 6, no. 1 (2017): 13.
[7] Ariel E Lugo, "Effects of Extreme Disturbance Events: From Ecesis to Social–Ecological–Technological Systems," *Ecosystems* 23, no. 8 (2020): 1726–47.

social infrastructure, will all play a foundational role in in building adaptive capacity and resilience in the coastal zone – effectively addressing the social and ecological elements of the system.[8] However, many questions remain concerning the role of technology in coastal social-ecological-technical systems and how best to coordinate efforts to enact change.

Dynamic environmental and cultural forces are at work in coastal systems, leading to novel assemblages in which risk and climate change are major determinants of innovation. Recent studies show risk and natural disaster catalyze innovation and are integral to recovery and response efforts.[9] The correlation of natural disaster and innovation is an unfortunate reality, but it does indicate a future trend as catastrophic events multiply and innovation is required. It is projected that innovation in the risk mitigation and adaptation sectors will expand rapidly as climate change impacts humanity and environmental risk increases.[10] Emerging from this literature is a sense that technology will be integral to adaptation strategies and that patented technologies will parallel this evolution. The mechanisms through which these new technologies are invented, disseminated, tested, and operationalized promise to expand the agency and scope of resilience and adaptation frameworks by engaging the sociotechnical aspects of coastal systems.

Policy is one mechanism for change that will help calibrate innovation in response to climate change and risk. As the Porter Hypothesis states, environmental regulation and policy may in fact drive innovation and profitability.[11] This is evident across pollution causing industries first researched by Michael Porter, as well as in "green" technologies such as renewable energy such as solar that policy catalyzes innovation.[12] As coastal regions continue to be impacted by

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[8] W Neil Adger et al., "Social-Ecological Resilience to Coastal Disasters," Science 309, no. 5737 (2005): 1036–39; Hakna Ferro-Azcona et al., "Adaptive Capacity and Social-Ecological Resilience of Coastal Areas: A Systematic Review," *Ocean & Coastal Management* 173 (2019): 36–51; Min Kim et al., "Sustainable Land-Use Planning to Improve the Coastal Resilience of the Social-Ecological Landscape," Sustainability 9, no. 7 (2017): 1086; Michael Greg Lloyd, Deborah Peel, and Robert W Duck, "Towards a Social–Ecological Resilience Framework for Coastal Planning," Land Use Policy 30, no. 1 (2013): 925–33; Firas Saleh and Michael P Weinstein, "The Role of Nature-Based Infrastructure (NBI) in Coastal Resiliency Planning: A Literature Review," *Journal of Environmental Management* 183 (2016): 1088–98.

[9] Hongxiu Li, "Innovation as Adaptation to Natural Disasters," 2017.

[10] Qing Miao and David Popp, "Necessity as the Mother of Invention: Innovative Responses to Natural Disasters," *Journal of Environmental Economics and Management* 68, no. 2 (2014): 280–95.

[11] Stefan Ambec and Philippe Barla, "A Theoretical Foundation of the Porter Hypothesis," Economics Letters 75, no. 3 (2002): 355–60.

[12] Kyunam Kim and Yeonbae Kim, "Role of Policy in Innovation and International Trade of Renewable Energy Technology: Empirical Study of Solar PV and Wind Power Technology," *Renewable and Sustainable Energy Reviews* 44 (2015): 717–27.

climate change and new policies and plans are implemented, technology will parallel this process. The origins and evolution of these new coastal technologies are fascinating to ponder as the scale and scope of coastal adaptation and resilience and truly global endeavors.

Patented technology, and the patent system, provide one lens through which to comprehend and analyze the ever-evolving relationship between technology and coastal systems. Innovation in coastal technologies can be traced historically through the global patent archive since dedicated patent classifications have been organizing innovation in this sector for centuries. Extant records of patent documents maintained in archives of the United States Patent and Trademark Office (USPTO), or European Patent Office (EPO) provide a high-fidelity window into the technological innovations that have, or had the potential to, shape coastal systems. In the most recent iteration, the Y02A scheme reformulates this relationship through a strategic focus on climate adaptation. It builds upon long-established classification systems, namely the Cooperative Patent Classification (CPC) and the International Patent Classification (IPC), which have been used globally to categorize technology and track innovation - including coastal technologies organized by the E02B subclass for "Hydraulic Engineering" covering "Man-made devices for using or controlling natural bodies of water."[13] Distinguishing the Y02A is cross-sectoral focus on the core technologies of green infrastructure, human health, water, mapping, environmental restoration, and other technologies related to coastal adaptation and resilience.

The relative newness of the Y02A classification scheme, and general obscurity of the patent system within the discourses of coastal adaptation and resilience, create a unique situation. On one hand, the existence of a global framework for the management and diffusion of innovation in coastal sectors is a provocation, or call-to-action, with the possibility to facilitate positive change in communities and ecosystems. On the other, the mechanisms and processes through which novel adaptation and resilience technologies are invented, tested, and implemented through environmental/spatial design, planning, and engineering praxis remain largely unknown and untried – leaving gaps in knowledge that may slow the pace of innovation.

[13] "CPC Definition - E02B HYDRAULIC ENGINEERING (Ship-Lifting E02C; Dredging E02F)," accessed February 8, 2021, https://www.uspto.gov/web/patents/classification/cpc/html/defE02B.html.

Situated at this juncture, the thesis explores the complexities innovation in this emergent space through detailed analysis of specific cases related to the anticipated scope of coastal adaptation and resilience, highlighting the diverse actors and new networks engaged in the process, and looking towards the future for pathways to operationalize of the Y02A by integrating patent data, innovation studies, and novel technologies, into planning and design praxis.

Outline

The thesis builds an argument for strategic integration of the patent system, and patented technologies, into the praxis of coastal adaptation and resilience planning through theoretical framing, development of six case study chapters that analyze relevant issues, and a conclusion that theorizes working methods for integration of patent data and novel technologies into coastal planning and design praxis. The body of the thesis contains six case study chapters covering the specifics of existing patent/environment entanglements and the opportunities presented by more coordinated approaches. In conclusion the case studies and theoretical framing are synthesized through articulation of an innovation model exploring the unique role of spatial design and planning disciplines in the testing and implementation of climate adaptation technologies.

The six case study chapters proceed as follows. The first three chapters, *Observations and Natural Case Studies, chapters 1-3*, reflect on the current situation in this innovation space, revealing a sometimes messy, incongruent, and largely unknown process of innovation that parallels development of coastal technologies. Through analysis of pilot projects, government policies, business ventures, and other examples, a narrative is developed to elucidate the idiosyncrasies of how new technologies in the coastal sector are developed and issues associated with the inventive process. This includes detailed studies on the invention of coastal infrastructure integrated with oyster habitat, the ongoing search for novel coastal stabilization technology, and the role of corporate interests in the development of artificial reef technology. Each addresses a range of interconnected issues that emerge from coastal innovation that may be raised as part of design praxis, and in the implementation of the Y02A classification scheme, for the adaptation of coastal systems. Since the Y02A is nascent in the longer arch of patent history, many of the precedents and references drawn upon necessarily predate the existence of the classification scheme. This fact does not diminish its potentiality, in fact they help rationalize the need for such framework to exist.

The final three chapters, *Opportunities and Emerging Frameworks, chapters 4-6*, look at the opportunities and potential of integrating the patent system (i.e. Y02A, data, forecasting, infrastructure, law) and innovative patented technologies into environmental design and planning praxis. This includes a survey of new coastal infrastructure paradigms emerging through patented technologies, examples of the successful integration of patent innovation studies into adaptation and resilience planning projects, and a detailed analysis of the Y02A patent classification scheme as a framework for innovation in coastal adaptation and resilience efforts. Collectively the chapters reveal the role of patented technologies, and the patent systems, in coastal innovation, pointing towards establishment of an innovation model that coordinates these efforts through strategic integration of the Y02A scheme in praxis.

Observations and Natural Case Studies (Chapters 1-3)

The first case study (Chapter 1) titled "*Inventing Oyster-tecture: Dimensions of an Innovation Chasm in Coastal Adaptation and Resilience Technologies"* focuses on technological innovation, and development of intellectual property, during coastal resilience design and planning competition programs. Over the past decade the number of design and planning competitions focused on coastal adaptation and resilience has increased as governments and private entities seek solutions to the challenges of climate change. This process has been very successful in highlighting a range of design and planning strategies; however, analysis of the mechanisms through which novel technologies are developed and tested reveals an idiosyncratic process of technological innovation that calls into question how novel technologies are invented, tested, and implemented in the context of coastal adaptation and resilience planning. This chapter analyzes the invention of 'oyster-tecture' systems through the competition process and contrasts it with development of similar technologies developed by inventors outside of the design and planning process.

Oyster-tecture is a compound word (oyster + architecture) coined in 2010 by Kate Orff (SCAPE Landscape Architects) as part of Rising Tides exhibition at the Museum of Modern Art in New York, USA. It refers to the intentional integration of oyster habitat with coastal defense structures designed to mitigate storm surge, stabilize ground, clean waterways, and improve ecological health. The novel planning strategy, and the core technology of oyster-tecture was a breakthrough in planning disciplines – reaching a wide audience and leading to prototype development. Irrespective of the popularity and reach, the process of invention leading to development of core technologies is idiosyncratic to planning and design competition processes. The invention of oyster-tecture is further complicated by the existence of prior-art and pilot projects in the 1990's that reveal an alternate point of origin and lineage of technological innovation. Two disparate points of invention, and their respective timelines, reveal a disjuncture between the initial invention of core technologies for oyster-tecture, uptake of the idea in design disciplines, and adoption of these technologies in the contemporary coastal adaption and resilience sector. From the perspective of innovation studies, this lag represents a unique 'chasm' in the adoption cycle of a new technology. Dimensions of this chasm reveal idiosyncrasies of the innovation process in the design, planning, and coastal resilience planning sectors and a perceived distance between these processes and other established innovation networks. Evidence of a chasm is developed in this chapter through comparison of the inventive process for oyster-tecture to conventional models for the diffusion of innovation, and an analytical narrative timeline that explores the technical, social, and institutional context. Is it possible that integration of innovation studies in planning practice, and the establishment of the YO2A, might help close the chasm?

The second case study (chapter 2) titled "*A wild goose chase? The search for alternative coastal stabilization technologies and the emergence of new actor-networks*" explores the iterative and ongoing quest for systems to mitigate erosion and movement of dynamic coastal edges. Coastal stabilization is a global phenomenon that has paralleled the development of ports, cities, shipping routes, and infrastructure, for millennia. Today, coastal stabilization is again a global issue gaining relevancy through hastened coastal development, sea level rise, increased storm frequency, and other climate change induced threats to coastal communities and ecosystems. The limits of existing technologies such as seawalls, breakwaters, jetties, and groins, necessitates a search for 'alternative' technologies that are cost effective, ecologically beneficial, materially efficient, buildable, innovative, and otherwise address the changes occurring in coastal systems. As the word 'alternative' implies many of these systems are being developed outside, or adjacent to, conventional process for development of coastal infrastructure typically undertaken by government agencies, contractors, and interagency funding sources, thus challenging these established networks through novel pathways for innovation.

Alternative coastal stabilization technologies often emerge through alternative pathways for innovation, involving entrepreneurial innovation, private research and development, patented technologies, competitive grants and awards, and an array of collaborative ventures across private and public sectors. This case study analyzes the various pathways through which alternative coastal stabilization technologies are realized, overlaying the theoretical framework of Actor Network Theory, to highlighting and contextualize the diverse range of inventors, corporations, communities, and institutions, in the implementation of coastal works. Five "alternative" technologies, and their associated networks, are analyzed to gain insights about an innovate process that impacts coastal systems and attempts to instigate changes in process within institutions such as the United States Army Corps of Engineers (USACE). Specific cases included the advent of the "Wave Robber" by Webster Pierce, the" Reaction Breakwater" by Lewis M. Haupt, the "Holmberg System" by Dick Holmberg, Beach Cones deployed in southern Louisiana, and Seascape Artificial Seaweeds pilot project in Cape Hatteras, North Carolina. Each example explores the nuances of the search for alternative coastal stabilization systems and the networks and actors involved in the process, with the aim of identifying mechanisms through which innovative solutions to coastal stabilization are realized. As a case study for coastal adaptation and resilience efforts, it illustrates how patents, and the patent system, engage broad constituencies in a process of change while confronting entrenched power structures.

The third case study (chapter 3) titled "*Corporate Ecologies: the pitfalls and promises of industrialized artificial reef technology*" investigates the interrelation between the patent system and establishment of the artificial reef sectors in Japan and the United States. Artificial reefs have been created in oceans, seas, lakes, and rivers around the world for centuries with the ambition of increasing fish yields, altering species distribution, and altering the ecology of the ocean at grand scales. In general, artificial reefs refer to human-made structures installed in aquatic habitats that serve as a substrate and/or shelter for organisms such as fish, mollusks, and crustaceans. Corporate research and development play an important role in the realization of artificial reefs, linking industry to large-scale environmental processes and the ecological engineering of marine systems. Origins of artificial reef programs in Japan and the U.S. were linked to national policy and funding programs, but also to the patent system which was used to catalyze investment in the newly established sectors. Analysis of this process reveals the role of private industry, policy, and the patent system, in the creation of artificial reefs and brings perspective to this global industrial and ecological entanglement that continues through a dedicated patent class for artificial reefs included in the Y02A patent classification scheme.

Countries around the world, including the United States, Japan, Australia, and others throughout Europe, South America, and Asia have coordinated artificial reef programs to improve marine fisheries – with thousands of hectares and millions of individual reef units currently in operation. Artificial reefs also have a distinct patent class in the Cooperative Patent Classification (CPC) system with a long history of innovation chronicled in patent documents, revealing a complex relationship between private business, technological innovation, and environmental transformation. The policies, funding, and core technologies that constitute these partnerships are important to consider as we approach environmental and ecological engineering challenges in the context of coastal adaptation and resilience efforts as they offer a window into the pitfalls, and promises, or engineering marine ecosystems through corporate investment and strategic partnerships. It also provides an important reference for analogous environmental engineering works that will be developed as nations adapt to climate change and large-scale environmental degradation that no single government entity is equipped to address.

Opportunities and Emerging Frameworks (Chapters 4-6)

The potentiality of integrating the patent system, and patented technologies, into coastal adaptation and resilience planning is far reaching, providing opportunities to expand the toolkit through the adaptive capacities of technological innovation. The final three chapters (4-6) address these issues and opportunities. The fourth case study (chapter 4) titled "*Knowledge Infrastructure for Coastal Infrastructure – utilization of patent innovation searches in the Bay Area Resilience By Design Challenge"* introduces the section, offering an alternate epistemology to chapter 1, "*Inventing Oyster-tecture: Dimensions of an Innovation Chasm in Coastal Adaptation and Resilience Technologies,"* through an analysis of coastal adaptation and resilience planning integrated with prior-art searches and patent innovation research utilizing the knowledge infrastructure of the patent system. The global patent archive is among the world's largest technological database and a robust form of knowledge infrastructure with potential to inform contemporary coastal adaptation and resilience efforts. Patent documents have been archived for six centuries globally and provide a valuable dossier of technological knowledge in every sector of the known Technosphere, including environmental technology. Although the primary function of the patent system is bureaucratic management of innovation and establishment of legal rights for inventors, it also serves as a repository of technical knowledge, providing deep insights about innovation, past discoveries, imaginaries, and future trends. This vast archive may be interpreted, translated, and be used as sources in legal, technical, and non-technical domains alike – including the emerging sectors of coastal adaptation and resilience.

Translation between of technical knowledge in the global patent archive and the development of strategies for coastal adaptation and resilience provides specific opportunities to build on sequential innovation and integrate sociotechnical processes into site design. Detailed analysis of the "Grand Bayway" project developed by the Common Ground Team during the 2017 Resilience by Design Bay Area Challenge provides insights about this process. The Team used patent innovation studies, coupled with a design and envisioning process, to develop innovative strategies for adaptation of the subsided Baylands site. The case offers specifics of how patent innovation studies, patent data, and specific technologies can be integrated into design and planning praxis to inform regional strategies for coastal adaptation and resilience. The Common Ground's team approach as unique among the nine international multidisciplinary teams as it leveraged patent data and knowledge infrastructure to help problems solve.

The fifth case study (chapter 5) title *"New infrastructure paradigms for coastal adaptation and resilience"* explores how new forms of coastal infrastructure relate to new forms of technology chronicled by the Y02A and global patent system. The language and theories of coastal adaptation and resilience have evolved to necessitate novel forms of infrastructure and technology that address the complexity of socio-ecological relationships in coastal zones. This chapter explores the emerging role of patented technologies in decentralized, hybrid, smart, local, and small infrastructure that address issues of adaptation and resilience in coastal systems. These new infrastructure paradigms are highly entrepreneurial, innovative, and nimble, utilizing technologies such as micro-grids, robotics, artificial intelligence, and small-scale distributed systems, to build and prototype critical infrastructure in culturally and environmentally diverse regions – making them highly relevant to strategies for coastal adaptation and resilience. As these new paradigms are innovation driven and may coalesce quickly, they can address a range of emergent coastal issues and bypass entrenched and slower pathways for infrastructure delivery.

A shift away from large-scale and centralized approaches to critical coastal infrastructure reveals alternate pathways for infrastructure delivery and novel technologies developed to address this expanding scope. Innovation is vital within this sector and patented technologies are sometimes developed through prototyping, research, and pilot projects that address a range of coastal issues. This case study explores the evolution of these new infrastructural paradigms and their application in coastal resilience and adaptation, highlighting the inventors, agencies, and role of patents in emergent sectors of coastal infrastructure. The need for an expanded toolkit is timely as climate change and environmental risk reconfigure social-ecological-technical systems (SETs) in coastal regions through catastrophic events such as hurricanes, tsunamis, floods from extreme weather, etc. Infrastructure that supports new social-ecological-technical relationships in coastal region will take diverse forms built through the development of new technologies and through shifting perspectives on coastal infrastructure.

The sixth case study (chapter 6) titled *"The YO2A Patent Scheme as Anticipatory Framework for Coastal Adaptation and Resilience Planning"* explores the adaptive capacity of technology as it contributes to anticipatory governance and planning for probable, plausible, pluralistic, and performative futures. The Y02A patent classification scheme was created by the European Patent Office in April 2018, and rolled out globally through 2020, to organize climate adaptation technologies, including those related to coastal systems, flood control, adaptation of existing infrastructure, human health, and technologies for mapping and sensing the environment.

The YO2A scheme is highly relevant to Coastal planning and design activities as it tags and organizes innovation in a range of coastal and riverine technologies and provides cross-sectoral insight into technological trends - functioning as an anticipatory framework for governance in these emergent sectors. As a mechanism for the management of technological innovation the Y02A scheme also builds adaptive capacity within the coastal adaptation and resilience space through the diffusion of technological information, increased searchability, focused patent classes specifically addressing climate adaptation in coastal, riverine, and urban systems. The Y02A patent scheme has the capacity to help governments, policy makers, planners, and designers prepare for an uncertain future. Analysis of the Y02A scheme's organizational structure and origins in the policy initiatives of the Paris Agreement and Kyoto Protocol are explored in relation to coastal adaptation and resilience efforts. Since no "textbook" or "instruction manual" exist for the adaptation of coastal systems in the face of climate change, the living repository of technology coordinated by the Y02A has the capacity to link the adaptive capacity of technology to site and urban systems through the allied disciplines of environmental design and planning.

Notes for a Conclusion

In the concluding chapter the thesis addresses issues of operationalization and implementation of Y02A technologies through the articulation of an innovation model that addressing the issues and opportunities revealed in the six case studies. As such, the conclusion offers a summary of the findings and offers a recommendation for how the Y02A can be integrated with design and planning practice and operationalized to chart coastal futures. This is theorized to involved the integration of Y02A patent data and metrics into planning and design knowledge infrastructure so it may inform development and management of coastal systems at geographical scales, building innovative coastal systems through pilot projects, testing, and implementation of novel Y02A technologies, and development of core technologies from withing the fields of environmental design and planning to establish technological frontiers and core technologies in adaptation and resilience sectors.

Methodology

Source material for this project is built from a deep reading of patents and environment. Born in the epoch of the Anthropocene, it is premised on the idea that innovation does not only happen inside a factory, or from Silicon Valley startups, it extends into complex and large-scale environmental systems more networked, hybrid, and degraded than ever before in history. Thus, it seeks novel ways to leverage the process of innovation for positive environmental and societal outcomes. Given the intersectional nature of the topic, I have developed unique research methods that are now integrated into this thesis. In summary the research methods involve two distinct yet highly interconnected processes. In the first, a range of textual, image, and classification searches yield primary patent document that are then correlated with environmental systems, known geographies, and inventors, to build a composite understanding of the actors engaged in this unique type of environmental work. In the second, parallel deep readings of environmental history and theory are collated with patent law and the history of global patent infrastructure. These seemingly disparate primary research processes yield a range of source material that bring together science and technology studies, theories of spatial planning and design, urban history, obscure patents, contemporary design projects, and stories of inventors from around the world, collectively operating within a broader and protracted coastal adaptation resilience space. Together these research processes provide a range of materials that aggregate to a much larger picture of the sociotechnical processes that shape our environment through innovation.

Patent documents and data used in this thesis are compiled using publicly accessible search engines including those offered by the European Patent Office (EPO) Espacenet search engine (https://worldwide.espacenet.com/), United States Patent and Trademark Office (USPTO) website (https://www.uspto.gov/), and Alphabet Companies, Google Patent Search (https://patents.google.com/). At times I have also employed the use of propriety patent search services such as Wisdomain Actionable Patents (https://www.actionablepatents.com) to manage the bulk data and analyze text, however these proved too costly and cumbersome to maintain as they work best with contemporary searches in well-established sectors of technology such as medicine and telecommunications. Publicly accessible patent searches provide all users with powerful tools for discovery, yet often specialized research requires some prior knowledge of the patent system's unique organizational structure. In this context the Y02A is particularly important, as it creates a user-friendly organizational structure for climate adaptation technologies, helping to speed up discovery. In development of this thesis patent searches were conducted using the Y02A scheme and more traditional keyword, citation, and classification searches within the CPC, IPC, and USPC.

Patent searches yield a wealth of primary documents, metadata, bibliographic information, and timelines, that I use to reconstruct environmental histories and narratives regarding the relationship between technology and the environment. Much of the original work associated with this research process involves correlating patent documents and data with specific geographies, pilot projects, and built works. The outcomes of this initial net-casting phase are usually unknown, as it requires time consuming surveys of environmental history, policy, theory, and law, that often lead into new subject areas that challenge my assumptions and expand the scope of my work. Most of the source material gathered during this process includes government reports, contracts, case law, corporate history, local news media, policy papers, peer-reviewed literature, and other esoteric or arcane sources. For example, my interest in the subject of artificial reefs led me first through the history of reef technology and science to the establishment of an entirely new patent class. Along the way it necessitated I learn aspects of Japanese patent law, read congressional hearings, and inform myself on national policy, to make connections between policy, technology, and the advent of artificial marine ecologies. Having evolved from my prior work in this area, this type of research brings together the sociotechnical aspect of environmental innovation, histories of the patent system and legal theory, and case studies that reveal the agency of patents in large-scale complex environmental systems. In this process I have sought ways that designers, planners, and governments can utilize these precedents and mechanisms to improve the environment and society.

Concurrent to the penning of the dissertation the European Patent Office serendipitously implemented the Y02A classification scheme (circa 2018-2020), covering the cross-sectoral technologies of climate adaptation and mitigation. This timely example of convergent evolution provides an important institutional framework for my established ongoing research, helping to situate this dissertation within global initiatives for technological innovation in the coastal adaptation and resilience sectors. Establishment of the Y02A patent classification scheme follows from broad policy directives originating with the Paris Agreement and Kyoto Protocol with the goal of building adaptive capacities through technological innovation. These initiatives cut a clear transect through coastal adaptation and resilience sectors and are interwoven with this thesis as appropriate.

Arrival of the Y02A during the formative stages of the thesis simultaneously bolstered, and complicated, the research process. Existence of a global policy driven initiative to focus the patent system on adaptation technologies creates an important touchstone for the thesis, and a new way to search and interpret innovation. For example, entirely new classes of technology were created as part of the Y02A, making it easier to find and reference new technologies in previously non-existent sectors. For example, Y02A30/60 – "Planning or developing urban green infrastructure" establishes a new classification scheme for urban infrastructure by reorganizing existing related patents and creates a system to organize future innovations, helping to build technical capacity in previously obscure sectors of technology. Strategic reorganization also complicates certain research tasks, as any of the cases discussed in the thesis predate the existence of the Y02A. For example the new class Y02A10/26 covering "Artificial reefs or seaweed; Restoration or protection of coral reefs" makes it easier to identify new coral reef technologies, but entirely razes the prior classifications for reefs made of automobile tires, thus making it difficult to conduct searches and analyze technology in now arcane subject areas.

Other research tools are also important to note, especially digitized books, government documents, legal transcripts, used as primary source material that Is made available through the United States Library of Congress (https://www.loc.gov/) , Hathi Trust Digital Library (https://www.hathitrust.org/) , internet Archive (https://archive.org/) and Alphabet companies Google Books (https://books.google.com/) which make it possible to find obsolete and obscure references required for this research project, especially those usurped or overwritten by the ongoing revisions to patent law and environmental history that dominate other sources. Collectively these resources provide nuanced histories of invention in the context of environmental policy, planning, and transformation through technological means, which in combination with the bureaucratic systems and records of the patent system provide this thesis with a wealth of primary sources.

Climate change, and discourse on coastal adaptation and resilience situate the research in a contemporary context. Extensive prior work has been conducted in areas or coastal sustainability, policy, economics, urban planning, as well as through design speculation and analysis. This includes important contributions by researchers such as Alan Berger, Billy Flemming, and Carolyn Kousky, Kristina Hill, Guy Nordenson, Catherine Seavitt Nordenson, Jeff Carney, Traci Birch, Elizabeth Mossop, Henk Ovink, Bruce Glavovic, Fadi Mousad, Nate Kaufmann, Peter C Bosselmann, Timothy Beatley, and long list of others that provide scale, scope, and strategic insights for coastal design and planning.[14] Once versed in these prior works, the Y02A patent classification scheme, and key findings of this thesis, can be understood as an ever-evolving addendum, or technical appendix, to coastal design and planning strategies already in process.

Methods developed in the thesis are highly contextual, yet not wholly unique within design discourse. Sigfried Gideon (1888-1868), the famed architectural historian and theorist, utilized patent sources to weave together an "anonymous history" in the book *"Mechanization Takes Command"* exploring the impacts of industrialization manufacturing and machine culture on daily life.[15] At the time of publication in 1948 architecture and design were grappling with rapid modernization and standardization of construction systems, making primary patent

[14] Kousky, Carolyn, Billy Fleming, and Alan M. Berger, eds. *A blueprint for coastal adaptation: Uniting design, economics, and policy*. Island Press, 2021.
Berger, Alan M., et al. "Theorizing the resilience district: Design-based decision making for coastal climate change adaptation." Journal of Landscape Architecture 15.1 (2020): 6-17.
Masoud, Fadi, ed. *Terra-sorta-firma: Reclaiming the Littoral Gradient*. Actar D, Inc., 2021.
Kauffman, Nate, and Kristina Hill. "Climate change, adaptation planning and institutional integration: A literature review and framework." Sustainability 13.19 (2021): 10708.
Bosselmann, Peter C. *Adaptations of the metropolitan landscape in Delta Region*s. Routledge, 2018.
Beatley, Timothy. Blue urbanism: exploring connections between cities and oceans. Washington, DC: Island Press, 2014.
Mossop, Elizabeth, ed. Sustainable coastal design and planning. CRC Press, 2018.
Nordenson, Catherine Seavitt, Guy Nordenson, and Julia Chapman. *Structures of coastal resilience*. Island Press, 2018.
Nordenson, G., Seavitt, C., Yarinsky, A., & Bergdoll, B. (2010). On the Water: Palisade Bay. New York: Hatje Cantz.
Birch, Traci, and Jeff Carney. "Regional resilience: building adaptive capacity and community well-being across louisiana's dynamic coastal–inland continuum." *Louisiana's Response to Extreme Weather: A Coastal State's Adaptation Challenges and Successes* (2020): 313-340.
Glavovic, Bruce, et al., eds. *Climate change and the coast: building resilient communities*. CRC Press, 2014.
de Graaf-van Dinther, Rutger, and Henk Ovink. "The five pillars of climate resilience." *Climate Resilient Urban Areas: Governance, design and development in coastal delta cities* (2021): 1-19.
[15] Giedion, Sigfried, *Mechanization Takes Command a Contribution to Anonymous History*. Oxford Univ. Press 1948.

sources an appropriate reference for discussion of cultural architectural theories. Other lesser works in design use similar methods involving patent source materials. For example, a beautifully illustrated volume of the Italian journal, *Rassegna*, explores the interplay of design and patents with essay on the patented works of Le Corbusier and the role of innovation in the creation of architectural spaces and elements.[16] Of course, there are also troves of books, articles, and manuscripts exploring patent innovation studies within specific technology sectors as within cultural studies and humanities. Exemplary among these is the research of Mario Biagioli, Professor of Law and Communication at the University of California Los Angeles (UCLA), who has written extensively of the politics, history, representation, and legal interpretation of patents and the patent system.[17] Distinguishing the research and methods used in this thesis are the connections made between patent innovation, physical geography, coastal systems, and forward-looking climate practices in environmental design and planning. In this manner the thesis builds arguments through examination of prior-art, analysis of technologies impact on environmental systems, and outlines critical linkages between these cases, environmental policy, and framework of the Y02A patent classification in the context of coastal adaptation and resilience praxis.

[16] Gregotti, Vittorio (Editor) 46 *Rassegna* (Patent and Design) - Quarterly year XIII, 46/2 - June 1991
[17] Biagioli Mario et al. *Making and Unmaking Intellectual Property: Creative Production in Legal and Cultural Perspective*. University of Chicago Press 2011.

Geographical and Environmental Dimension of Patents and the Patent System

Establishment of the Y02A classification scheme is not the first time the patent system has been operationalized to help develop technologies with geographic, urban, and environmental dimensions, although it is certainly the first with a planetary scope aiming to address the wicked problems of climate change. In 1421 the Florentine government issued the first true patent to the eminent architect Filippo Brunelleschi for a ship designed to move heavy materials on the River Arno for construction the Duomo of Florence, helping to solve one of three engineering challenges associated with the building project and establishing a legal precedent for the "patent bargain" between inventors and the state.[18] This myth-of-origin inextricably links the processes of urbanization and infrastructure development to the history of patent law. The anomaly of Brunelleschi's Florentine patent established legal precedent that informed contemporaneous patent experiments in Venice, where some of the earliest precedents were those employed in public works utilizing novel technologies. Fifty-three years later the Venetian State formalized patent law with the Venetian Patent Statute of 1474, codifying the patent bargain to incentivize the sharing of new inventions in exchange for protection of intellectual property within Venetian territories.

The advent of patent law modernized the Venetian economy but was similarly entwined with environmental transformation and urbanization. The environmental flux of the Venetian lagoon created fertile ground for innovation, and in part led to establishment an equally resilient legal framework – patent law - that incentivized the evolution of technology and industry within Venetian territories.[19] Many of the earliest examples of patents issued in Venice, including those predating the formal patent statute of 1474, were issued for "mud" technologies and other forms of coastal infrastructure integral to innovative public works.[20] This included systems used for ground stabilization, reclamation, drainage, and dredging.[21] Perhaps the grandest and most conspicuous features of the urban landscape resulting from this process are the canals of Venice,

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[18] Frank D Prager, "Brunelleschi's Patent," *J. Pat. Off. Soc'y* 28 (1946): 109–109.

[19] Hindle, "Inventing Venice: An Urban and Environmental Innovation Model from the Lagoon City."

[20] Roberto Berveglieri, *Le Vie Di Venezia: Canali Lagunari e Rii a Venezia: Inventori, Brevetti, Tecnologia e Legislazione Nei Secoli XIII-XVIII* (Cierre, 1999).

[21] Salvatore. Ciriacono, *Building on Water : Venice, Holland and the Construction of the European Landscape in Early Modern Times* (New York, N.Y. ; Oxford: Berghahn Books, 2006).

built in part with innovative technology developed in partnership with private inventors through the granting of patent rights.[22] Leveraging of the patent system in public works meant that innovative technologies could be tried and tested as Venice urbanized the lagoon, revealing the distinct agency of the patent system in the production of the urban landscape, and situating environmental innovations in a specific location with a "distinctly local and immediate notion of utility" as opposed to the consumer technologies that glut the patent system of today.[23]

By engaging to social dimensions of innovation the Venetians were able to problem solve using diverse actors, helping to build some of the most advanced urban infrastructure of the renaissance in a dynamic coastal geography. Technology was integral to the republic, and incentives of patents, and the patent system, contributed to technology transfer to the city as the world's leading inventors brought new discoveries from countries such as France and the Netherlands.[24] Expert review panels, geographically specific scopes of work, and support for prototyping new technologies was also part of the Venetian effort to build the city.[25] As a political act, the Venetian patent statute decoupled invention from privilege, class, and guilds, liberating inventors and democratizing ingenuity, and allowing broad constituencies to engage the processes of innovation, as anyone could be granted a patent for their invention. According to Mario Biagioli, a leading scholar of law, science, and technology, this paralleled "the demise of political absolutism, the development of liberal economies, and the emergence of the modern political subject."[26] These ideas spread through Europe and the Americas and were later constitutionalized. Some legal scholars even argue that all patent law is in essence only an amendment to the original Venetian patent Statute.[27]

Other examples exist of patent offices engaged in initiatives with geographical, atmospheric, and technological dimensions. In England, drainage of the fens in the 16th century was achieved through innovative technologies and skilled experts from the European continent,

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[22] Berveglieri, Le Vie Di Venezia: Canali Lagunari e Rii a Venezia: Inventori, Brevetti, Tecnologia e Legislazione Nei Secoli XIII-XVIII.
[23] Mario Biagioli, "Patent Republic: Representing Inventions, Constructing Rights and Authors," *Social Research*, 2006, 1129–72.
[24] Klaas van BERKEL, "Cornelius Meijer Inventor et Fecit': On the Representation of Science in Late Seventeenth-Century Rome," 2002.
[25] Berveglieri, Le Vie Di Venezia: Canali Lagunari e Rii a Venezia: Inventori, Brevetti, Tecnologia e Legislazione Nei Secoli XIII-XVIII.
[26] Biagioli, "Patent Republic: Representing Inventions, Constructing Rights and Authors."
[27] Craig Allen Nard and Andrew P Morriss, "Constitutionalizing Patents: From Venice to Philadelphia," *Review of Law and Economics* 2, no. 2 (2006): 223–321.

including the Netherlands and Venice, to the British Isles. Patent rights granted by the Crown were integral to this process of technology transfer, leading to an influx of innovation and inventors.[28] This led to a modest technology boom in following years, with 1/5th of all patents from 1620-1640 awarded for drainage technologies to raise waters and reclaim ground.[29] In America, similar patterns can be observed with the patent office engaged strategically in the process of environmental transformation. The first meteorological studies in the United States were commissioned jointly by the Patent Office and Smithsonian Institute in 1855, helping to promote advances in agricultural technology and the science of climate.[30] The data, standards, and instrumentation developed by the Smithsonian Institute during this venture led to the creation of the a formal national weather system known as the Signal Service (1870-1891).[31] The patent office's involvement in this meteorological research venture was also fruitful, building upon a track record of agricultural innovation that eventually led to the creation of an independent Department of Agriculture in 1862 and publication of pioneering works of agrometeorology such as "Meteorology and its Connection with Agriculture" in 1857.[32] In this expanded role we see a patent office broadly concerned with the technology, data, germplasm, and cartography, that would transform western states into a vast agricultural territory.

Organization of the US patent office was central to its focus on agriculture, environment, and territorialization. From 1790 to 1849, the Patent Office was operated by the Department of State, however the increasing rate of patent submissions and an explosion of domestic concerns overwhelmed the State Department and led to the creation of the Department of Interior in 1849. The Department of Interior was formed through a strategic reorganization of the USPTO, General Land Office, Census Bureau, and Bureau of Indian Affairs and charged with the management of "home" affairs, including wilderness areas and new US territories. The combined

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[28] Clive Holmes, "Drainage Projects in Elizabethan England: The European Dimension'," Eau et Developpement Dans VEurope Moderne (Paris, 2004), 2004, 87–102.

[29] W.H. Price, The English Patents of Monopoly, Harvard Economic Studies (Harvard University Press, 1906),

[30] Patent Office. United States. Bishop, William D., Henry, Joseph, Hough, Franklin B., Coffin, James H., Smithsonian Institution., Results of Meteorological Observations, Made under the Direction of the United States Patent Office and the Smithsonian Institution from the Year 1854 to 1859, Inclusive, Being a Report of the Commissioner of Patents Made at the First Session of the Thirty-Sixth Congress. Vol. I-II: Pt. 1. (Washington: Govt. Print. Off., 1861).

[31] NATIONAL ACADEMY OF SCIENCES-NATIONAL RESEARCH COUNCIL WASHINGTON DC and Hoyt Lemons, "Physical Geography" (US Government, 1953), https://apps.dtic.mil/sti/pdfs/AD0017348.pdf.

[32] Joseph Henry, Meteorology in Its Connection with Agriculture., p. 455-492, 419-[552; 461]-524 incl. diagrs., illus.tables. ([Washington, D. C., 1857), //catalog.hathitrust.org/Record/012307539.

interests of the Department of Interior made it the de facto department of the west, playing a vital role in the expansion and development of western states. Richard Andrews, an environmental policy scholar, has argued that in an ideal world, the integration of interior, patent, land, and census departments might have provided the "foundation for integrated planning and management of the nation's environment."[33]

As history shows, the sociotechnical aspects of innovation and organization of the patent systems have environmental implications and can be operationalized to enact environmental works at a grand scale, draining lands, building productive agricultural systems, urbanizing lagoons, tracking data, and altering deltaic landscapes, by integrating sociotechnical aspects of innovation large-scale works of urbanization and development. The Y02A is the latest iteration, conceived to address the global challenges of climate adaptation with a strategic focus on green & blue urban infrastructure, coastal systems, agriculture, and technologies for mapping and sensing the environment, etc., built from a contemporary perspective of ecology, sustainability, and intelligence. Among the many challenges facing this initiative is the translation of technology into actionable projects that impact the lives of coastal populations. This "last mile" problem highlights the potential contribution of the allied professions of environmental design and planning to this endeavor as both end user, and producer, of new technologies.

[33] R N L Andrews, *Managing the Environment, Managing Ourselves: A History of American Environmental Policy* (Yale University Press, 1999)

Framing

Operationalization means to put something into operation or use. In the context of coastal resilience and adaptation operationalization means the real-world application of planning frameworks/theories and tangible benefits for coastal communities and the environment. According to recent compendium on urban resilience for risk and adaptation governance focusing on the on applications of resilience planning theory and practice, "operationalising resilience is arguably one of the most impactful global issues for the future research as it implies to link the concept about what urban resilience is and what urban resilience ought to be."[34] A broader survey of literature reveals an array of established pathways to operationalize resilience and adaptation goals in the coastal systems and the built environment. In summary this includes funding, policy, land-use planning, design competitions, theorization of decision-making units, and grass roots organizing, etc., that effectively translate theory into practice.[35] Although the list of operational pathways is robust, and evolving, research in this area largely overlooks the role of technological innovation. This is surprising as global policy initiatives such as the 2015 Paris Agreement of Climate Change make explicit provisions for technological innovation and technology transfer with tangible implications for coastal adaptation and resilience efforts.

Obviously, these pathways continue expand and are not without controversy. Some argue that the theoretical frameworks for adaptation and resilience are too poorly defined for use in site-specific situations and ecosystems.[36] Others cite the need for stronger institutions for projects to be realized.[37] Specific industries, such as building sectors, may also struggle to implement overly theoretical resilience planning and policy initiatives that challenge industry

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[34] Ombretta Caldarice, Grazia Brunetta, and Nicola Tollin, "The Challenge of Urban Resilience: Operationalization," in *Urban Resilience for Risk and Adaptation Governance* (Springer, 2019), 1–6.
[35] Alan M Berger et al., "Theorizing the Resilience District: Design-Based Decision Making for Coastal Climate Change Adaptation," Journal of Landscape Architecture 15, no. 1 (2020): 6–17; Britta Horstmann, "Operationalizing the Adaptation Fund: Challenges in Allocating Funds to the Vulnerable," Climate Policy 11, no. 4 (2011): 1086–96; Helen Lochhead, "Resilience by Design: Can Innovative Processes Deliver More?," Procedia Engineering 180 (2017): 7–15.
[36] Marcus Sheaves et al., "Principles for Operationalizing Climate Change Adaptation Strategies to Support the Resilience of Estuarine and Coastal Ecosystems: An Australian Perspective," *Marine Policy* 68 (2016): 229–40.
[37] Sierra C Woodruff et al., "Adaptation to Resilience Planning: Alternative Pathways to Prepare for Climate Change," *Journal of Planning Education and Research,* 2018, 0739456X18801057; Md Shamsuzzoha, Md Rasheduzzaman, and Rajan Chandra Ghosh, "Building Resilience for Drinking Water Shortages through Reverse Osmosis Technology in Coastal Areas of Bangladesh," Procedia Engineering 212 (2018): 559–66.

conventions and use ambiguous terminology.[38] In the context of this dissertation, one area of further consideration is the role of actors and agents operating within coastal social-ecological-technical systems (SETs), and the mechanisms through which to engage the process of innovation in coastal works. Presciently, the Y02 patent classification scheme aims to operationalize technical aspects of global climate policy through the management of complex societal and technical responses to climate change – building adaptive capacity while catalyzing innovation.

According to the European Patent Office description "This class (Y02) covers selected technologies, which control, reduce or prevent anthropogenic emissions of greenhouse gases [GHG], in the framework of the Kyoto Protocol and the Paris Agreement, and also technologies which allow adapting to the adverse effects of climate change."[39] As noted in the United Nations Framework Convention of Climate Change (UNFCCC) program page, The Paris Agreement includes provision for advancing technology development and transfer of technology to build capacities in climate resilience. This includes a framework for enhanced technological capacity within climate adaptation and mitigation sectors through leveraging intellectual property and technology transfer.[40] Accordingly, the Y02 scheme initially focused on carbon technologies and climate mitigation, however the categories of climate adaptation technology continue to expand and now include an broad range of urban and environmental technologies related to the built environment and coastal systems – presenting a distinct opportunity to advance technological capacity in these sectors.

Fundamentally, the Y02A scheme aims to link the socio-technical aspects of innovation to the process climate adaptation. The invention and diffusion of technology is, and will be, integral to operationalizing resilience and adaptation goals through the integration of novel technologies into real world project that impact coastal communities and ecosystems. We needn't look any further than smart-cities and the "Internet of Things" approach to urban

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[38] Margaret H Kurth et al., "Defining Resilience for the US Building Industry," *Building Research & Information* 47, no. 4 (2019): 480–92.

[39] "Espacenet – Patent Classification," accessed February 8, 2021, https://worldwide.espacenet.com/patent/cpc-browser#!/CPC=Y02A.

[40] Chen Zhou, "Can Intellectual Property Rights within Climate Technology Transfer Work for the UNFCCC and the Paris Agreement?," *International Environmental Agreements: Politics, Law and Economics* 19, no. 1 (2019): 107–22; Matthew Rimmer, "Beyond the Paris Agreement: Intellectual Property, Innovation Policy, and Climate Justice," Laws 8, no. 1 (2019): 7.

problem solving to realize how deeply integrated technology has become with sustainability measures and cities.[41] In the context of coastal adaptation and resilience this represents an exciting new frontier, translating theory into action through novel technology.

The complex phenomenon of technological and infrastructural change is not an abstraction, in fact is permeates people's daily lives in, or away, from coastal regions. Take for example the current transformations to cities and urban life undertaken by digital technology companies such as Uber, Amazon, Google, etc., who are reformatting transportation, logistics, and modes of production, in the United States and globally to serve their missions. The new technologies, and their delivery method, are brought to the urban realm through processes beyond the conventional scope of the allied urban disciplines and therefore appear as disruptive, with many cities often caught off-guard by fleets of new amateur taxi drivers, electric scooters, and online shopping. A 2018 New York times article titled "Tech Envisions the Ultimate Start-Up: An Entire City" highlights the issue clearly by spotlighting the role large technology companies such as Uber, Amazon, and Google play in development of the contemporary American city and their vision for future.[42] The issue has recently reached a precipice with SideWalk Labs, an Alphabet Company, attempting to build an entire urban district in Toronto Canada, and later abandoned the project due to privacy concerns and public resistance.[43] Innovation driven urbanism has infiltrated contemporary society, challenging conventional approaches to infrastructure while simultaneously revealing the capacity for step change through technological innovation in the hardware and software that we use to build cities.

The Y02A exist as a provocation that these step changes may also occur in core environmental technologies and climate adaptive infrastructure such as green infrastructure, coral reef restoration, plastic pollution mitigation, and a range of other sectors covered by the classification scheme. Patents and the global patent systems have well established relationships

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[41] David Perez Abreu et al., "A Resilient Internet of Things Architecture for Smart Cities," *Annals of Telecommunications* 72, no. 1–2 (2017): 19–30; Michael Batty et al., "Smart Cities of the Future," The European Physical Journal Special Topics 214 (2012): 481–518; Ruben Sánchez-Corcuera et al., "Smart Cities Survey: Technologies, Application Domains and Challenges for the Cities of the Future," *International Journal of Distributed Sensor Networks* 15, no. 6 (2019): 1550147719853984.
[42] Emily Badger, "Tech Envisions the Ultimate Start-Up: An Entire City," The New York Times, February 24, 2018, sec. The Upshot, https://www.nytimes.com/2018/02/24/upshot/tech-envisions-the-ultimate-start-up-an-entire-city.html.
[43] "Alphabet's Sidewalk Labs Scraps Its Ambitious Toronto Project," Wired, accessed November 13, 2020, https://www.wired.com/story/alphabets-sidewalk-labs-scraps-ambitious-toronto-project/.

to invention and diffusion of new technology and are arguably the most robust institutional mechanism form the management of sequential innovation. Western patent law was founded on the principles that patents would incentivize invention and disclosure of new technologies to improve society.[44] Critics argue that the patent system inhibits innovation, or is exploited and does not achieve its stated goals due to red tape, therefore inhibiting certain innovations.[45] Yet, many have forgotten that the origins of patent law and the "patent bargain" (i.e. a quid pro quo in which the inventor discloses an invention in order to receive patent protection from the state) on which the system was founded were highly egalitarian and have been employed in public works since their inception.[46] Irrespective of contemporary debates on the subject, the patent system is the oldest institutional and bureaucratic framework for the management of sequential innovation – playing a role in innovation in all sectors of technology.[47] Operationalizing the patent system in service of global climate adaption efforts is one step in a broader societal change, with upsides for the creation of knowledge infrastructure and coordination of innovation in emergent environmental sectors such as those converging in coastal anthromes.

The benefits of invention, disclosure, and cataloging new technologies is manifold. The disclosure of new inventions leads to the creation of knowledge infrastructure which is vital to emerging and established sectors of technology alike. Technological innovation, and by proxy the patent system, ask open ended questions about the future of technology and provide institutional framework to organize, categorize, and disseminate knowledge.[48] Since the inception of patent law categorization of technology has kept pace with technological innovation to effectively collate and disseminate technological information and the preservation of patent rights.[49] Archiving and diffusion of technical information is essential to the system. As with other

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[44] Suzanne Scotchmer, "Patents as an Incentive System," in *Economics in a Changing World* (Springer, 1996), 281–96.

[45] Adam B Jaffe and Josh Lerner, Innovation and Its Discontents: How Our Broken Patent System Is Endangering Innovation and Progress, and What to Do about It (Princeton University Press, 2011).

[46] Mario Biagioli, "From Print to Patents: Living on Instruments in Early Modern Europe," *History of Science* 44, no. 2 (2006): 139–86; Biagioli, "Patent Republic: Representing Inventions, Constructing Rights and Authors"; Mario Biagioli, "Patent Specification and Political Representation: How Patents Became Rights," *Making and Unmaking Intellectual Property: Creative Production in Legal and Cultural Perspective*, 2011, 25–40.

[47] Nard and Morriss, "Constitutionalizing Patents: From Venice to Philadelphia."

[48] Carlo Belfanti, "Guilds, Patents, and the Circulation of Technical Knowledge: Northern Italy during the Early Modern Age," *Technology and Culture* 45, no. 3 (2004): 569–89.

[49] Heather J E Simmons, "Categorizing the Useful Arts: Part, Present, and Future Development of Patent Classification in the United States," Law Libr. J. 106 (2014): 564–564; MF Bailey, "History of Classification of Patents," J. Pat. Off. Soc'y 28 (1946): 463.

complex and adaptive systems, technological innovations develop and progress in distinct ways leading to novel combinations and permutations. This adaptive quality is highly desirable as the vanguard of technology is continuously redefined. Aptly, the patent system is theorized to operate like a "process of recombinant search over technology landscapes" in which iterative processes of revision and investigation lead to novel inventions.[50] Integral to this conceptualization is the process of query, recombination, and redefinitions through which discovery occurs and new categories of technology emerge such as those integral to coastal adaptation and resilience and others now organized through the Y02A classification scheme. Coordinating the diffusion of innovation in coastal adaptation and resilience technologies may help bridge the innovation chasm and greenlight actionable technology as new policies and plans are implemented. Importantly, innovations can then be further leveraged and fast-tracked in critical sectors such as green technology.[51] As coastal adaptation and resilience policies and plans proliferate, so too will the need for innovation.

However nascent, knowledge regarding the unique role of intellectual property in resilience and adaptation is gaining. For example, in the context of smart cities researchers have observed that regions with smart cities plans have higher incidence of innovation generally and an increase in the patenting of specific technologies for smart city applications.[52] The fact that smart cities develop more smart city technologies is an important revelation. The findings link established research on the geographical determinants of innovation to the process of invention that will define future smart cities.[53] Evidence also exists that an effective patent system facilitates resilience through the transfer of environmentally sensitive technology from advanced economies to least developed countries.[54] This means that technologies developed in one region can effectively be transferred to other regions as needed which is vital given the scale and scope

[50] Lee Fleming and Olav Sorenson, "Technology as a Complex Adaptive System: Evidence from Patent Data," *Research Policy 30, no.* 7 (2001): 1019–39.
[51] Eric L Lane, "Building the Global Green Patent Highway: A Proposal for International Harmonization of Green Technology Fast Track Programs," *Berkeley Technology Law Journal*, 2012, 1119–70.
[52] Caragliu and Del Bo, "Smart Innovative Cities: The Impact of Smart City Policies on Urban Innovation."
[53] For an expanded discussion on "geographies of innovation" see Feldman and Florida Maryann P Feldman and Richard Florida, "The Geographic Sources of Innovation: Technological Infrastructure and Product Innovation in the United States," Annals of the Association of American Geographers 84, no. 2 (1994): 210–29; Harald Bathelt, Maryann Feldman, and Dieter F Kogler, *Beyond Territory: Dynamic Geographies of Innovation and Knowledge Creation* (Routledge, 2012).
[54] Azam, "Climate Change Resilience and Technology Transfer: The Role of Intellectual Property."

of the global climate crisis and necessity for new forms of critical infrastructure. The Y02A classification scheme, and provisions for technological innovation in the Paris Agreement, take steps to better coordinate diffusion of technical knowledge, creating a distinct opportunity to expand technical capacities.

Of course, open-source mechanisms and intellectual property will both play a role in adaptation and resilience technology. This does not diminish the importance of either, in fact they operate complimentary to each other. In many cases, innovation within the adaptation and resilience problem space will undoubtedly be shared, disseminated, and operationalized though open source, and open innovation, mechanisms. Based on observations in contemporary popular media and peer-revied literature, this will likely lead to advances through the sharing of data sets, planning methodologies, social networks, and application of new technologies such as artificial intelligence promoted by Open Ai , Code For Change, and Code for Change.[55] In general an 'Open Source model' refers to collaborative mode of production in which innovation is shared more openly and an 'Open Innovation models' refers to a process in which a firm integrates ideas from inside and outside to innovate.[56] Preliminary research into the role of such open source methods in climate mitigation technology does outline clear pathways for technology transfer using Open Innovation and Open Source methods through licensing agreements of Intellectual property Rights (IPR) and creation of General Public Licenses (GPL) in addition to conventional licensing and sharing of technology through patent pools, patent commons, and alternative structures such as Equitable Access Licensing and clearing houses for eco-technology.[57] Importantly, all of these modified arrangements are built on models for shared and distributed intellectual property that do not negate the need for management of sequential innovation and inventors rights, such as those managed by the traditional patent system.

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[55] "Code for America," Code for America, accessed March 10, 2023, https://codeforamerica.org/; "OpenAI," accessed March 10, 2023, https://openai.com/; "Code for Change," accessed March 10, 2023, https://codeforchangenepal.com/.

[56] For an in-depth description see: H.W. Chesbrough, Open Innovation: The New Imperative for Creating and Profiting from Technology, G - Reference, *Information and Interdisciplinary Subjects Series* (Harvard Business School Press, 2003).

[57] Krishna Ravi Srinivas, "Role of Open Innovation Models and IPR in Technology Transfer in the Context of Climate Change Mitigation," *Diffusion Of Renewable Energy Technologies: Case Studies Of Enabling Frameworks In Developing Countries-Technology Transfer Perspective Series*, 2011, 147–58.

Future Technologies for Future Coasts

Coastal resilience and adaptation frameworks establish new theoretical horizons for the nature of social-ecological-technical interactions in coastal systems. However, the translation of resilience and adaptation theory into tangible technologies is underrepresented in literature. In other "innovation rich" sectors the invention of new technology is well documented and theoretical models have been developed to help comprehend this process. For example, in the fields of biomedical technology knowledge translation and theoretical framework of the Knowledge To Action (KTA) model is explored as a pathway to invention.[58] The KTA model hypothesizes the translation of inquiry and knowledge synthesis into actionable tools and technologies. Other researchers in the same field theorize that author-inventor relationships are central to the process of biomedical invention as new technologies are developed through innovative publications/research that led to new discoveries.[59] In this formulation of inventive process key authors in a particular area of expertise are also key inventors as indicated by publication lists and patents. Irrespective of the pathway to invention, the theoretical framing seeks the same outcome, namely, the identification of a need or purpose for an invention and the creation of a means that can satisfy this need or purpose.[60] In context of coastal adaptation and resilience, the pathways to action are often conceived of primarily through the professional lens of planning, architecture, and design, however the problem space can also be approached through productive partnership with technology and the processes of innovation. The establishment of the Y02A exists as a framework to support these activities, and a provocative call-to-action for practitioners, researchers, and communities.

The value of engaging innovation in the resilience and adaptation sector is twofold. Firstly, new technologies are developed, and secondly the categorization of these discoveries lead to the codification of knowledge and increased linkages between ideas. A general theory of invention suggests that searching is the essential framework for discovery involving the iterative

[58] Joseph P Lane and Jennifer L Flagg, "Translating Three States of Knowledge–Discovery, Invention, and Innovation," *Implementation Science* 5, no. 1 (2010): 1–14.
[59] ECM Noyons et al., "Exploring the Science and Technology Interface: Inventor-Author Relations in Laser Medicine Research," Research Policy 23, no. 4 (1994): 443–57.
[60] W Brian Arthur, "The Structure of Invention," *Research Policy* 36, no. 2 (2007): 274–87.

and recursive stages of stimulus, net casting, categorization, linking, and discovery.[61] Other researchers suggest that novelty or newness is essential to the process of invention and the combinatory process and refinement of existing technologies are fundamental to the creation of new technologies.[62] Central to the combinatorial process is context and prior knowledge. In this context the patent is known to serve as a "carrier" of innovation leaving "footprints" for the development of new technology.[63] Invention of a new technology is important within itself, but the process of invention also contributes to knowledge infrastructure and the evolution of innovations in diverse sectors and across spatial scales.[64] Most of what is known in relation to these knowledge infrastructures is derived from innovation rich sectors of technology and industry. But, in the context of the Anthropocene, these knowledge infrastructures are theorized to have the capacity to contribute to "large-scale, long-term, anthropogenic environmental change." [65] Leveraging knowledge infrastructure may also help solve intractable problems such as those converging in coastal regions globally by linking the iterative process of invention to the dynamics of coastal systems.

Reformatting the enmeshed technological systems of coastal anthromes to achieve adaptation and resilience goals will require cross-sectoral strategies, ranging from coordinated blue/green infrastructure investment to new crop management practices, social media, and distributed reverse osmosis systems.[66] Translation of adaptation and resilience theory into applicable technologies may fill this gap and imagine new forms of coastal infrastructure and an expanded coastal infrastructure toolkit. Adaptation and Resilience literature indicates the need

[61] Patrick G Maggitti, Ken G Smith, and Riitta Katila, "The Complex Search Process of Invention," Research Policy 42, no. 1 (2013): 90–100.

[62] Deborah Strumsky and José Lobo, "Identifying the Sources of Technological Novelty in the Process of Invention," Research Policy 44, no. 8 (2015): 1445–61.

[63] Hyejin Youn et al., "Invention as a Combinatorial Process: Evidence from US Patents," Journal of the Royal Society Interface 12, no. 106 (2015): 20150272.

[64] Frank Moulaert and Abdelillah Hamdouch, "New Views of Innovation Systems: Agents, Rationales, Networks and Spatial Scales in the Knowledge Infrastructure," *Innovation: The European Journal of Social Science Research* 19, no. 1 (2006): 11–24.

[65] Paul N Edwards, "Knowledge Infrastructures for the Anthropocene," *The Anthropocene Review* 4, no. 1 (2017): 34–43.

[66] Justin Joyce et al., "Coupling Infrastructure Resilience and Flood Risk Assessment via Copulas Analyses for a Coastal Green-Grey-Blue Drainage System under Extreme Weather Events," *Environmental Modelling & Software* 100 (2018): 82–103; Shamsuzzoha, Rasheduzzaman, and Ghosh, "Building Resilience for Drinking Water Shortages through Reverse Osmosis Technology in Coastal Areas of Bangladesh"; Ranjan Roy et al., "Resilience of Coastal Agricultural Systems in Bangladesh: Assessment for Agroecosystem Stewardship Strategies," *Ecological Indicators* 106 (2019): 105525.

for innovation and an expanded repertoire of coastal technologies.[67] Therefore, building technological pathways from, and within, the sector is a natural progression of the social, scientific, and planning/design frameworks emerging from coastal networks.

Integrating technological and social change into future planning frameworks requires anticipation of the unknown and acknowledgment that new technologies emerge through complex sociotechnical processes as we progress towards an uncertain future.[68] Anticipatory frameworks for managing acceleration and complexity are essential in sectors ranging from national defense to emergent technologies.[69] Anticipatory governance is defined as "a broad-based capacity extended through society that can act on a variety of inputs to manage emerging knowledge-based technologies while such management is still possible. It motivates activities designed to build capacities in foresight, engagement, and integration – as well as through their production ensemble."[70] Beyond the technological, anticipatory governance is integral to social-ecological resilience and suggest that effective management of this process can lead to increased ecological knowledge.[71] A central tenant of anticipatory governance is the recognition of values associate with emergent technologies and their role in society in sectors ranging in scale from nanotechnology to geoengineering.[72] Foresight is integral to anticipatory governance as institutions establish future trajectories for investment and innovation.[73] Technological innovation and patent trends offer distinct insights about future environmental scenarios while simultaneously revealing the role of the patent system of adaptive governance and new knowledge infrastructures.

However optimistic, the desire for coastal innovation does reveal a paradox in that we must invent new technologies and social structures while realizing that technology and culture is

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Julie L Davidson et al., "Interrogating Resilience: Toward a Typology to Improve Its Operationalization," *Ecology and Society* 21, no. 2 (2016); Klein et al., "Technological Options for Adaptation to Climate Change in Coastal Zones."[67] Klein et al.

[68] Carla Alvial-Palavicino, "The Future as Practice. A Framework to Understand Anticipation in Science and Technology," TECNOSCIENZA: *Italian Journal of Science & Technology Studies* 6, no. 2 (2016): 135–72.

[69] Leon Fuerth, "Operationalizing Anticipatory Governance," Prism 2, no. 4 (2011): 31–46.

[70] David H Guston, "Understanding 'Anticipatory Governance,'" *Social Studies of Science* 44, no. 2 (2014): 218–42.

[71] Emily Boyd et al., "Anticipatory Governance for Social-Ecological Resilience," Ambio 44, no. 1 (2015): 149–61.

[72] Risto Karinen and David H Guston, "Toward Anticipatory Governance: The Experience with Nanotechnology," in Governing Future Technologies (Springer, 2009), 217–32; Rider W Foley, D Guston, and Daniel Sarewitz, "Towards the Anticipatory Governance of Geoengineering," *Geoengineering Our Climate*, 2015.

[73] Jose M Ramos, "Anticipatory Governance: Traditions and Trajectories for Strategic Design," *Journal of Futures Studies* 19, no. 1 (2014): 35–52.

responsible for many of the declines of coastal ecological health and process. Bruce Glavovic refers to this *problematique* as the "coastal innovation paradox" in which we must innovate for our future survival but must also recognize how past innovations and systems have led us to the present situation.[74] This paradox is ripe within the proposal to leverage patent innovation to advance coastal adaptation and resilience, however an alternative reading of patent history and an analysis of case studies presented in this thesis showcase the positive contribution of innovation to our coastal future.

The paradoxical nature of coastal innovation has the potential to instigate change in both the technologies and culture of coastal regions. New decision-making units, cultural efforts, and democratic processes are spearheading changes in coastal environments and new technologies will parallel these initiatives. This involves a critical reassessment of coastal infrastructure to embrace concepts modularity, flexibility, and autonomy, etc.[75] Paradigm shifts are afoot and readily observable in international design and planning competitions, pedagogical initiatives, and student work at leading universities, and in coastal masterplans produced by government agencies. At this juncture in history a distinct opportunity exists to leverage the patent systems, and patented technology, to advance and operationalize these new paradigms in planning and design praxis. As is argued in this thesis, the patent system offers a distinct form of agency in coastal systems and can contribute to democratic and technological modes of coastal adaptation and resilience by engaging diverse constituents, flattening pathways for innovation, coordinating innovation, and broadening the toolkit of coastal technologies.

[74] Bruce C Glavovic, "Coastal Innovation Paradox," *Sustainability* 5, no. 3 (2013): 912–33.
[75] Bruce C Glavovic, "Coastal Innovation Imperative," *Sustainability* 5, no. 3 (2013): 934–54; Louisa Marie Shakou et al., "Developing an Innovative Framework for Enhancing the Resilience of Critical Infrastructure to Climate Change," Safety Science 118 (2019): 364–78; Bradley Cantrell, Laura J Martin, and Erle C Ellis, "Designing Autonomy: Opportunities for New Wildness in the Anthropocene," *Trends in Ecology & Evolution* 32, no. 3 (2017): 156–66.

1. Inventing Oyster-tecture: Dimensions of an Innovation Chasm in Coastal Adaptation and Resilience Technologies

The invention of oyster-tecture is a natural case study in how innovative environmental technologies are developed, shared, and adopted through the coastal adaptation and resilience design/planning competition process. Few innovation studies exist in this specific sector but proliferation of high-profile coastal adaptation and resilience competitions, ongoing public discourse, financial expenditures, and environmental imperatives, make it necessary to consider how innovative technologies are integrated into praxis through design and planning competitions. The competition process, typified by hastened timelines, emphasis on high profile teams, and media attention given to visionary proposals, creates a unique situation with the capacity to advance novel planning strategies and develop innovative solutions to coastal adaptation and resilience. However, when contrasted with conventional models for invention, involving the conceptualization of new technology, development of prototypes, scientific evaluation, diffusion, patenting, and prolonged research and development, we can observe how the idiosyncrasies of the design and planning process may complicate logical steps in sequential innovation and may, in fact, overlook established technologies by favoring expediency.

Oyster-tecture is a compound word (oyster + architecture) coined in 2010 by Kate Orff (SCAPE Landscape Architects) as part of Rising Tides exhibition at the Museum of Modern Art (MOMA, NYC) and popularized through further development during the Rebuild by Design Competition. It refers to the intentional integration of oyster habitat with coastal defense structures designed to mitigate storm surge, stabilize ground, clean waterways, and improve ecological health. The 2010 coining of the term and subsequent development of oyster-tecture prototypes were widely publicized, referenced, and mimicked, in design discourse and popular media. Yet, a review of patents and pilot projects in this sector reveals that core technologies and conceptual tenets for integrations of oysters and other marine organisms with coastal infrastructure existed prior, having evolved through research, and prototyping in the 1980's - 1990's (figure1). This lag in real world application, and distance between siloed inventor groups, indicate a distinct innovation chasm. The contours of this chasm are important to consider as innovation is a central tenet of adaption and resilience theory, and incongruences may impede the development of other important technologies in the coastal adaptation and resilience sector.

To understand the dimensions of the innovation chasm this chapter puts into dialogue the process of "invention" within design and planning competitions and compares this to conventionally understood processes for invention and diffusion of innovation. The chapter analyses of the project narrative, detailed timelines, and the history of patent innovation to explore the technical, social, and institutional context of oyster-tecture. Dimensions of the unique chasm created during development of core technologies, reveal idiosyncrasies of the innovation process in the design, planning, and coastal resilience planning sectors and document how, in fact, conventional mechanisms for technological innovation outpace "speculative" technologies developed during the design and planning competition process. As knowledge gains related to coastal adaptation and resilience technologies through establishment of the Y02A classification scheme, it is hypothesized that issues of siloed invention and ambiguities with technological scope, may narrow the chasm by providing an organizational structure and clearly identified subject heading for related forms of coastal infrastructure.

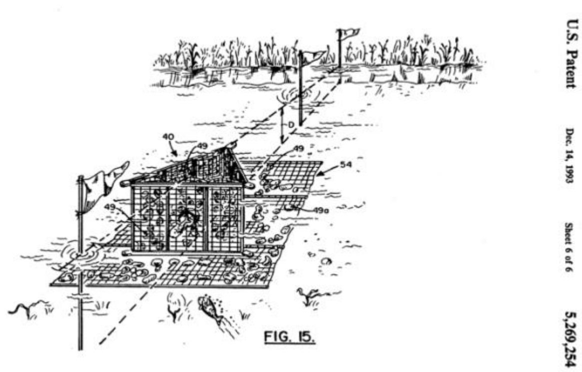

Figure 1: An early oyster-tecture patent US5269254A "Method and apparatus for growing oyster reef," 1993. (Source: European Patent Office, https://www.epo.org/en)

Diffusion of Innovation and Permutations of the 'Chasm'

To understand the idiosyncratic origins of oyster-texture it is important, firstly, to understand conventions of how innovative ideas and technologies originate and spread. The 'diffusion of innovation' is a widely cited theory that aims to explain how, why, and through what processes innovations are adopted through social networks, providing a cornerstone for innovation studies. According to Everett Rogers, originator of the popular theoretical model for diffusion of innovation, Information about new ideas and technologies moves along communication channels and through distinct social networks, facilitating adoption of the new technology sequentially within and among social groupings. These social groupings are made up of innovators, early adopters, early majority, late majority, and laggards, who contribute to the process of invention and adoption of new technologies. Through these social networks new technology is theorized to move in a predictable manner, exhibiting sequential progress from awareness, interest, evaluation, trial, and ultimately adoption. Collectively this process is known as the diffusion of innovation.[76]

The diffusion of innovation brings together elements of society, geography, time, and technology, to comprehend how innovation spreads. Early Studies on the diffusion of innovation emerged from research on specific complexes of innovation such as the maize or horse complex, which offered insights about innovation in specific domains. Other veins of research in the field can be traced back to anthropological studies on innovation and the metropolis which aimed to show the influence of the city on its satellite areas, thus documenting networks of city planners and amateur radio enthusiasts sharing information about new technologies through their communication channels to a broader audience.[77] Among these early studies Everett Rogers's original research is canonical, documenting how the network of agricultural extension offices in Iowa identified novel technologies and facilitated the diffusion of agricultural innovation through networks of farmers. Key elements of this original research are particularly useful to consider in the context of coastal adaptation and planning competitions as they involve unique institutional partnerships, geographical locations, novel technologies, and social networks, as is observed in other studies on diffusion.

Since publication of the "Diffusion of Innovation" in 1962, numerous research papers, revised models, and theoretical reframing have been published on the subject of diffusion of innovation, and future trends suggest ongoing interest in multigenerational, multinational, and sectors specific insights on the diffusive process.[78] Critics of the theory, as framed by Rogers,

[76] Everett Mitchell. ROGERS, *Diffusion of Innovations*. (Pp. xiii. 367. Free Press of Glencoe: New York; Macmillan, New York: London, 1962).
[77] Elihu Katz, Martin L Levin, and Herbert Hamilton, "Traditions of Research on the Diffusion of Innovation," American Sociological Review, 1963, 237–52.
[78] Nigel Meade and Towhidul Islam, "Modelling and Forecasting the Diffusion of Innovation – A 25-Year Review," *International Journal of Forecasting, Twenty five years of forecasting*, 22, no. 3 (January 1, 2006): 519–45, https://doi.org/10.1016/j.ijforecast.2006.01.005.

point out that early concepts of diffusion emphasize the individual and overlook the role of institutions and multi-actor relations to the process of diffusion and adoption.[79] Yet, nearly 60 years of subsequent research and debate continue to clarify and refine the diffusion of innovation to integrate these factors. This body of literature now includes widely cited studies on the diffusion of innovation within subject areas as diverse as policy entrepreneurialism, health care, language teaching, etc.[80] Unifying these studies is a focus on social networks, communication channels, and adoptive processes that describe how innovation spreads through social groups – providing insights about how new ideas are lost or delayed within and between social groups and at steps in the adoptive process. Of particular interest to the specific case of oyster-tecture are the lags, delays, and incongruencies in the process through which innovative technologies get lost or overlooked.

The concept of a "chasm" was coined by Geoffrey Moore in his book "Crossing the Chasm" to explain how innovations get lost in the technology adoption cycle – building upon the theory framework of diffusion of innovation. According to Moore, the chasm is the adoption gap between a social group, such as the early adopters (visionaries) and early majority, that encumber progress of an innovation to a mainstream social group or market. Although Moore's initial thesis focuses on the marketing of high-tech products and their positioning, pricing, and distribution, the term "chasm" has been appropriated widely and now refers to gaps in the development and adoption of technology and has been reframed through numerous case studies to explain gaps in innovation that emerge within social and technological systems.

The flexibility of the idea has allowed for reinterpretation and the "chasm" now takes diverse forms across sectors to comprehend how to hasten the rate of innovation and adoption of new technologies. The contours of the chasm form differently across sectors. For example, in sustainability sectors it is theorized that a "green chasm" exists due to the extended timespans that exist between early adoption and widespread acceptance of new technology, resulting from extended development cycles and sudden changes in market conditions and policy. Researchers

[79] Stephen L Vargo, Melissa Archpru Akaka, and Heiko Wieland, "Rethinking the Process of Diffusion in Innovation: A Service-Ecosystems and Institutional Perspective," *Journal of Business Research* 116 (2020): 526–34.
[80] Michael Mintrom, "Policy Entrepreneurs and the Diffusion of Innovation," American Journal of Political Science, 1997, 738–70; Numa Markee, "The Diffusion of Innovation in Language Teaching," *Annual Review of Applied Linguistics* 13 (1992): 229–43; Mary Cain and Robert Mittman, "Diffusion of Innovation in Health Care," 2002.

hypothesized that long innovation cycles in green Technological Innovation Systems (TIS) in combination with a lag known as the "catch-up cycle model" showed that these two obstacles present in green innovation led to the "discontinuation of latecomer's catch-up and enhanced forerunner's enduring leadership." [81] In other sectors, such as telehealth, the chasm takes another form, theorized to result from high levels of innovation and incongruence in the diffusion of innovation and development of working prototypes with commercial market application. Researchers believe this results from the structurally complex, networked, inter-organizational structure of the telehealth industry which makes it hard for innovations to gain wide adoption among all partners.[82] Other research in the healthcare information technology space suggest that the main challenge to adoption of new technology is an implementation chams resulting from a multidimensional problem with design, management, organization, and assessment of new technologies.[83] Of course it is important to note that the dimensions of the chasm take shape differently across geographies and social groups in response to everything form market conditions to policies, knowledge networks, and disciplinary structure.[84] Emerging from a review of chasm literature is that the phenomenon is widespread, multidimension, and persistent.

The contours of an innovation chasm take shape from the structure of the social group, institutional organization, and mechanisms of the technological adoption cycle, policy context, and geography. Although an innovation chasm may emerge in different forms, proof of a chasm is substantiated by evidence of delay in the adoption cycle or discontinuities between the rate of innovation and the pace of adoption. Researchers in this area often use a variety of source materials to describe these lags, including patent innovation timelines, analysis rates of adoption and implementation, and description of social, policy, and professional context to define the

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[81] Sang-Jin Ahn and Ho Young Yoon, "'Green Chasm'in Clean-Tech for Air Pollution: Patent Evidence of a Long Innovation Cycle and a Technological Level Gap," *Journal of Cleaner Production* 272 (2020): 122726.

[82] Sunyoung Cho, Lars Mathiassen, and Michael Gallivan, "Crossing the Diffusion Chasm: From Invention to Penetration of a Telehealth Innovation," *Information Technology & People*, 2009.

[83] Nancy M Lorenzi et al., "Crossing the Implementation Chasm: A Proposal for Bold Action," *Journal of the American Medical Informatics Association* 15, no. 3 (2008): 290–96.

[84] Bilgehan Yildiz, Murat Ustaoglu, and Ahmet Incekara, "Investigating Turkey's EV Technology Adoption Level: How Would Turkey Cross the Chasm Through Policies?," *Review of Contemporary Business Research* 3, no. 1 (2014): 11–34; Cinderella Dube and Victor Gumbo, "Diffusion of Innovation and the Technology Adoption Curve: Where Are We? The Zimbabwean Experience," *Business and Management Studies* 3, no. 3 (2017): 34; Qinghai Li and Ping Deng, "From International New Ventures to MNCs: Crossing the Chasm Effect on Internationalization Paths," Journal of Business Research 70 (2017): 92–100.

unique characteristics of a chasm - documenting bottlenecks in innovation within fields as diverse a biology, e-learning, and data science.[85] Coastal adaptation and resilience planning competitions offer a unique case among these studies as they arise from distinct planning processes involving government, institutional partners, designers, consultants, and community groups, engaged in developing visions for coastal development.

Coastal Resilience Planning Competitions as a Unique Catalyst for Innovation and Diffusion

Over the past two decades design and planning competitions focused on coastal sustainability, adaptation, and resilience, have gained relevancy, frequency, and exposure through awareness of climate change and sea level rise. Essentially these coordinated events aim to develop design and planning solutions that address coastal issues and present visions for the future of the built environment. Although no universal format exists for coastal adaptation and resilience competitions, they are often developed through invited or open calls for teams, including planners, landscape architects, architects, designers, engineers, community members, and an array of consultants, to develop solutions for specific project scopes, regions, or in response to specific issues such as increased storm surge, sea level rise, or coastal development paradigms. The desired outcome of these costly, yet impactful programs, are implementable projects and future strategies that address coastal resilience issues and develop further funding, political stake, and publicity. Today, competitions are occurring more frequently as high-level strategic plans are implemented by government and private sectors in response to specific environmental risks that galvanize funding, policy, and public concern.

Timelines and impetus for coastal adaptation and resilience competitions vary internationally, nationally, and locally. In the United States, and elsewhere, the issue of coastal adaptation and resilience has gained urgency in the early 2000's through increased awareness and tangible changes to the environment. Catastrophic events such as hurricane Katrina in 2005, and Superstorm Sandy in 2012, impacted the Gulf Coast and East Coast of the United States and brought environmental risk and resilience to the fore. These 'natural' disasters instigated a range

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[85] Irina Elgort, "E-Learning Adoption: Bridging the Chasm," 2005, 181–85; Alon Y Halevy et al., "Crossing the Structure Chasm.," 2003; Alan H Goodman and Thomas L Leatherman, "Traversing the Chasm between Biology," *Building a New Biocultural Synthesis: Political-Economic Perspectives on Human Biology*, 1998, 1.

of plans, pilot projects, discourse, and debate on the issues of climate change.[86] Resilience and Adaptation design/planning competitions emerged as a viable, and highly visible, response to these environmental threats, offering future potential solutions, catalyzing discourse, and instigating changes in policy and funding for related issues. The impacts of this process have been far reaching – initiating changes in layers of governance and planning. For example, researchers analyzing the Louisiana Coastal masterplan and resilience efforts in the state offer the following narrative to explain the impacts of recent catastrophic events as catalyst for change in coastal planning:

> *"Following devastating disasters such as Hurricanes Katrina in Louisiana and Hurricane Sandy on the eastern seaboard, there has been an emphasis on developing strategies to reduce flood risk to communities through building-, community-, and region-scale design and planning. Specifically, following the success of Rebuild by Design and the 100 Resilient Cities initiative, the US Department of Housing and Urban Development (HUD), supported by the Rockefeller Foundation, developed the National Disaster Resilience Competition to provide significant support and resources toward resilience. NDRC was a two-phase competitive process awarding $1 billion to help communities across the US recover from prior disasters and develop replicable frameworks to withstand future shocks. The competition encouraged "American communities to consider not only the infrastructure needed to become resilient, but also the social and economic characteristics that allow communities to quickly bounce back after disruption""* [87]

National and international organizations are now focusing their efforts on coastal adaptation and resilience, and the list of high-profile coastal adaptation and resilience competitions continues to grow and today represents a significant part of how regions, cities, and communities adapt to a changing environment. Broad consensus exists that coastal adaptation and resilience projects and the design competition process leads to innovative solutions and that unique structure of the events catalyzes novel strategies. Of course, these innovations operate in domains are social, technical, and environmental, engaging layers of governance and finance to build these capacities – a process catalyzed by climate change. As a recent article on the relationship of natural disasters to innovative planning projects states; "out of disasters can come opportunities for innovation. Post-Sandy, a range of new initiatives, tools,

[86] Louise K Comfort, "Cities at Risk: Hurricane Katrina and the Drowning of New Orleans," Urban Affairs Review 41, no. 4 (2006): 501–16.
[87] Traci Birch and Jeff Carney, "Delta Urbanism: Aligning Adaptation with the Protection and Restoration Paradigm in Coastal Louisiana," *Technology| Architecture+ Design* 3, no. 1 (2019): 102–14.

policies, governance frameworks and incentives are being tested, including competition processes like Rebuild by Design. Design is seen as a key tool for dealing with complex problems by creating integrated strategies to build resilience, sustainability, and livability."[88] The general concept behind building coastal resilience through design competitions is that the competition process drives social, technical, and environmental, innovation and are important mechanisms through which regions and cities adapt to a changing environment – providing high visibility solutions for an uncertain future.

Critics of the competition process point out that the "resilience-through-competition" is not a panacea. Emphasis on works of high-profile design firms and issues of equity and inclusion are often cited for hamstringing tangible solutions and leading to unrealistic expectations and solutions. Billy Fleming, a leading voice on the subject, points out that the pioneering resilience planning competition " Rebuild By Design " (discussed fully later in the chapter) undertaken in the New York Metropolitan region following Super Storm Sandy in 2012 seemingly revealed as many problems as it solved, calling into questions issues of equity, planning, funding, and even the validity of proposals developed by the teams who lacked technical capacity to resolve aspect of the proposed plan. In a review of the highly publicized competition process, Fleming states that certain elements of design proposals may in fact cause "unnecessary risk of disaster and undercut the credibility of landscape architects" and their teams, arguing that "Expertise is as much about knowing what you cannot do as it is what you can do."[89] This pointed critique casts doubts about proposals developed during design competition cycles as many of the strategies put forward by elite universities and design firms may be unrealistic or hastily conceived. In general, it reflects the notion that competitions sometimes prioritize bold visions over grounded local solutions that engage broader constituencies and sociotechnical processes. It also calls into question the technological capacities of the allied fields of environmental design and the mechanisms through which innovative solutions are developed and implemented in the coastal adaptation and resilience space. The development of Oyster-tecture systems offers one such

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[88] Lochhead, "Resilience by Design: Can Innovative Processes Deliver More?"
[89] Billy Fleming, "'Rebuild by Design' in New York City: Investigating the Competition Process and Discussing Its Outcomes," Ri-Vista. *Research for Landscape Architecture* 15, no. 2 (2017): 200–215.

example through which to expand this critique and foreground the role of diverse actors in development of novel technology.

Although imperfect, issues of equity, community, ecology, and feasibility, continue to instigate revision of the competition process and progress has been made. This includes new frameworks for evaluation of coastal adaption proposals developed through planning and competition processes and protocol to ensure the engagement of communities as well as an equitable distribution of resources.[90] Research is also emerging on the efficacy of the competition process on the delivering on its promises, including studies on competitions as a catalyst for green infrastructure solutions.[91] Collectively the research and reflection on almost two-decades of coastal adaptation and resilience competitions substantiates the efficacy of the process in delivering novel solutions and innovative strategies for resilience while highlighting the need for revised strategies that address social aspects, policy, and funding mechanisms for project realization.

Research and revisions to the “resilience-through-competition” model are laudable, however they remain incomplete. One area that is substantively overlooked in this body of literature, and within the competition process at large, are detailed analysis of the mechanisms through which new technologies are integrated with and evaluated within adaptation and resilience projects and the competition process. This is a surprising omission given the close relationship between technology the realization of tangible resilience plans. Notable Exceptions included the “Resilience Rd” project in Australia which focused on delivery of technical solutions for homeowners, and the Land Art Generator competition that explores the intersection of renewable energy technology, design, and society.[92] Undoubtedly coastal adaptation and residence competitions are also platforms for the development and application of novel technology but a detailed analysis of oyster-tecture documents an idiosyncratic process of invention that fundamentally alter the diffusion of innovation in the sector and call into question

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[90] Daniella Hirschfeld, Kristina E Hill, and Ellen Plane, “Adapting to Sea Level Rise: Insights from a New Evaluation Framework of Physical Design Projects,” *Coastal Management* 49, no. 6 (2021): 636–61.
[91] Robert Šakić Trogrlić et al., “Rebuild by Design in Hoboken: A Design Competition as a Means for Achieving Flood Resilience of Urban Areas through the Implementation of Green Infrastructure,” *Water* 10, no. 5 (2018): 553.
[92] “Land Art Generator,” accessed June 2, 2023, https://landartgenerator.org/index.html; “Resilience Rd,” Suncorp, accessed April 26, 2022, https://resilience.suncorp.com.au/resilience-rd/.

how technological knowhow is shared through the teams, organizers, and other groups involved in project development.

The advent of Oyster-tecture in design competitions, exhibitions, and coastal resilience planning projects – a narrative timeline and analysis

Oyster-tecture was developed through institutional framework of museums, galleries, design schools, and competitions cycles, leading to real-world pilot projects and a large-scale installation in 2021-2024. This circuitous path, and extended timeline, are central to understating how the technology was develop and the social channels through which it travelled. The "Rising Currents" (2010) design exhibition, hosted by PS1 and the Museum of Modern Art (MOMA, NY), brought together leading design teams to develop strategies for sea level rise in the New York Metropolitan region. The design phase (November 16, 2009–January 8, 2010) was followed by an exhibition on display through October 2010 at MOMA. Four teams were selected to participate, including a team by Lead by Kate Orff and SCAPE landscape Architects. The teams project site was located the Gowanus/Red Hook/Governors Island area of the city and served as the context for development of proposals. The SCAPE team developed speculative proposals for bio-engineered coastal structures integrated with oysters that would stabilize ground, filter water, and renew the waterfront – a proposal referred to in the final program documentation and exhibition as oyster-tecture.

Concurrent to, and following, the exhibition a series of preliminary prototypes were developed in collaboration with the consulting team member SeArc from Tel Aviv, Israel. According to Kate Orff, "SCAPE has designed an Oystertecture pilot project as a means of pushing the big vision of the MoMA exhibit into real world applications. This project consists of 14 fuzzy rope panels as well as test panels made by SeArc Ecological Marine Consulting, a marine engineering firm headquartered in Tel-Aviv, Israel. These panels were installed at an active industrial pier in Brooklyn and are designed to attract and host existing mussel larvae."[93] The test panels were used, in part, to validate claims that elements of the oyster-tecture scheme and develop a working model for living edge strategies for the shoreline of New York. Installation and

[93] Kate Orff, "Shellfish as Living Infrastructure," *Ecological Restoration* 31, no. 3 (2013): 317–22.

monitoring of the project established a proof of concept that was later built upon through further design iteration.

Results from the study were mixed, as the panels did not recruit oysters as originally intended, and instead recruited only mussels and other ubiquitous marine organisms commonly found on docks, lines, and other marine structures in the NY region. Irrespective of the success of the first prototypes the exhibition images and concept of oyster-tecture gained international attention through the widespread media coverage.[94] A book documenting the Rising Currents design competition was published by the Museum of Modern Art in 2011, including a chapter on oyster-tecture, which timestamps the printed origins of the compound word oyster-tecture and also the basic conceptual tenets of integrating shellfish habitat with coastal infrastructure and cultural programs.[95] The high profile publication and projects reached a wide audience within the social networks and communication channels of design and planning circles, through which the concept was rapidly adopted in academic discourse, professional practice, and pedagogy. This is readily observed in design blogs, student proposals, and dissemination in professional publications, including a TED talk by Kate Orff and coverage by the popular podcast '99% invisible.'[96]

A few years later in the wake of Super Storm Sandy in 2012 the Rebuild by Design competition created opportunities to further develop the oyster-tecture concept. The SCAPE led team was selected for the competition, ultimately leading to the construction of "living breakwaters" in 2021-2024, including social and physical infrastructure for oyster reef restoration in Staten Island. Rebuild by Design was a four-stage, interdisciplinary design competition aimed at improving the resilience of the New York region after Hurricane Sandy in 2012. The multi-stage competition was developed in partnership with U.S. Housing and Urban Development (HUD), Municipal Art Society, Regional Plan Association, NYU's Institute for Public Knowledge, The Van Alen Institute, and support from The Rockefeller Foundation and other

[94] "Oyster-Tecture," 99% Invisible (blog), accessed September 23, 2021, https://99percentinvisible.org/episode/oyster-tecture/; "Reviving New York Harbor With Oysters: Why Hasn't This Happened Yet?," Bloomberg.Com, September 11, 2012, https://www.bloomberg.com/news/articles/2012-09-11/reviving-new-york-harbor-with-oysters-why-hasn-t-this-happened-yet.
[95] *Rising Currents: Projects for New York's Waterfront* (The Museum of Modern Art, n.d.),
[96] Kate Orff, "Kate Orff: Reviving New York's Rivers -- with Oysters! | TED Talk," accessed June 2, 2023, https://www.ted.com/talks/kate_orff_reviving_new_york_s_rivers_with_oysters; "Oyster-Tecture"; "Oyster-Tecture and the Gowanus Canal | ArchDaily," accessed June 2, 2023, https://www.archdaily.com/165568/oyster-tecture-and-the-gowanus-canal.

philanthropic partners. One hundred and fifty (150) international teams applied, and ten (10) finalists were selected – including SCAPE. Each team was comprised of engineers, planners, architects, landscape designers, and scientists, thus balancing areas of expertise with community stakeholders. The 10 final teams spent three months doing in-depth research, and from this process 41 site concepts and research strategies were explored. The design phase included community stakeholders and local government who contributed to final proposals. From this process a series of actionable projects were funded for construction, including the living breakwaters project in Staten Island designed by the SCAPE Team.[97]

The essential tenet of oyster-tecture, developed during the MOMA Rising Currents exhibition - that bivalve mollusk species, such as oysters and mussels, could be used to help restore marine habitats and provide living infrastructure in coastal adaptation strategies - was refined by the SCAPE team as part of the Rebuild By Design Competition. During this process of revision the systems changed drastically in both material form and function. Morphing from its initial form as a woven "fuzzy rope" mesh structure created during the "Rising Current" pilot project, into chemically modified concrete breakwater structures with complex surface geometry designed to create habitat for marine species. Again, Scape LLC worked with SeArc on development of the ecological infrastructure. According to Kate Orff the idea developed collaboratively through a series of prototype panels and concrete mixtures. "The SeArc test panels are made from ECOncrete, their own proprietary material. This type of concrete is different in composition of regular concrete such that it is a more suitable substrate for marine organisms. SeArc's structures also experiment with surface texture and the overall design in the interest of creating coastal infrastructure that is more biologically productive."[98] The revised structural systems were then complemented with social infrastructure to cultivate and monitor oysters as part of the living breakwater system.

From the initial "fuzzy rope" trials to the development of test panels for living breakwaters, we see the evolution of the oyster-tecture concept through research and development supported by the Resilience by Design competition and the real-world projects

[97] "Hurricane Sandy Design Competition – Rebuild by Design," accessed June 2, 2023, https://rebuildbydesign.org/hurricane-sandy-design-competition/.
[98] Orff, "Shellfish as Living Infrastructure."

resulting from this process. It is important to note the role of the team members of SeArc whose ongoing research into breakwater prototypes and material composition were deterministic in the final form of the living breakwater systems and led the creation of intellectual property by members of the company.

SeArc Patents, Publications, and Technologies of living Breakwaters

Development of the living breakwaters prototypes was complemented by a series of scholarly articles and patented technologies by the SeArc and the related corporate entity, Econcrete Tech LTD, founded in 2012 by Dr Ido Sella and Dr. Shimrit Perkol-Finkel (1975-2021). The research publications focused on the use or concrete as ecologically enhanced infrastructure and the role of coastal structures in the health of marine habitats, including specific studies of their patented ecological concrete mixtures.[99] From 2013 -2021 SeArc also developed a patent portfolio of technologies related to bioengineered coastal structure under the corporate name Econcrete Tech LTD. This includes patent ecological concrete and related molding processes used in the fabrication of 'living breakwaters" – the latter-day value engineered version of oyster-tecture. This intellectual property originates through work undertaken during the Resilience by Design Competition and related works, and reveals details of the material mixtures, form making processes, and composition, of the collaboratively designed living breakwater technology (table 1).

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[99] Laura Airoldi et al., "Corridors for Aliens but Not for Natives: Effects of Marine Urban Sprawl at a Regional Scale," *Diversity and Distributions* 21, no. 7 (2015): 755–68; Sella Ido and Perkol-Finkel Shimrit, "Blue Is the New Green – Ecological Enhancement of Concrete Based Coastal and Marine Infrastructure," *Ecological Engineering* 84 (November 2015): 260–72, https://doi.org/10.1016/j.ecoleng.2015.09.016; Shimrit Perkol-Finkel and Ido Sella, "Ecologically Active Concrete for Coastal and Marine Infrastructure: Innovative Matrices and Designs," in *Proceeding of the 10th ICE Conference: From Sea to Shore–Meeting the Challenges of the Sea*. ICE Publishing, London, 2014, 1139–50; Shimrit Perkol-Finkel et al., "Seascape Architecture–Incorporating Ecological Considerations in Design of Coastal and Marine Infrastructure," Ecological Engineering 120 (2018): 645–54; Shimrit Perkol-Finkel et al., "Conservation Challenges in Urban Seascapes: Promoting the Growth of Threatened Species on Coastal Infrastructures," *Journal of Applied Ecology* 49, no. 6 (2012): 1457–66.

Number	*Publication Date*	*Assignee*	*Title*
US D841,185	*Feb,19,2019*	*ECONCRETE TECH Ltd*	*Tide Pool*
US 2021/0171399	*pending*	*ECONCRETE TECH Ltd*	*Cast Mold Forming Compositions And Uses Thereof*
US 9,538,732	*Jan. 10, 2017*	*ECONCRETE TECH Ltd*	*Methods And Matrices For Promoting Fauna And Flora Growth*
US20230073789A1	*23, March 2023*	*ECONCRETE TECH Ltd*	*Interlocking ecological armoring units and uses thereof in forming a costal barrier*

Table 1: Patents Developed by SeArc and Econcrete as Part of the SCAPE Team

The patent citations networks associated with each of the patents reveal important details regarding the technical specifications but also evolution of technology in the field. Of these patents, (US 9,538,732) "Methods And Matrices For Promoting Fauna And Flora Growth" is interesting to discuss as it is the substrate to be used in the living breakwaters and associates the core technology with a clear patent innovation landscape.[100] According to the patent abstract "The invention provides a marine infrastructure comprising a concrete matrix having a pH of less than 12 for use in promoting the growth of fauna and flora in aquatic environment, and methods for promoting the growth of fauna and flora in aquatic environment". In essence the patent refers to a concrete mixture that is modified to promote biological growth, including the growth of oysters and other mollusks. Analysis of the patent citation networks reveals a history of patent innovation in related technologies.

The patent cites 21 patents as prior art including modified concrete mixtures to promote algal growth other marine organisms (table 2). Several of the prior-art patents are worthy of further discussion to help establish context. The patent EP0134855A1 "Concrete blocks for use underwater for algal culture" was granted in 1983, covering mixtures for reef establishment using coal ash to modify the pH.[101] The Japanese patent JP2002000112A "Artificial shore reef" submitted in 2002, covers breakwater structures built using concrete mixed with biomass to establish artificial oyster reefs.[102] And US7144196B1 'Biologically-dominated artificial reef' granted in 2006, covers the reef units built with biologically active concrete to promote the

[100] Shimrit Finkel and Ido Sella, Methods and matrices for promoting fauna and flora growth, US9538732B2, filed February 13, 2014, and issued January 10, 2017.
[101] Tetsuo Suzuki, Concrete blocks for use underwater for algal culture., EP0134855A1, filed September 15, 1983, and issued March 27, 1985.
[102] Makoto Kito et al., Artificial Shore Reef, JP2002000112A, filed June 26, 2000, and issued January 8, 2002.

growth of oysters and other marine organisms.[103] From the citation network of prior art, a complex picture emerges of the technical innovations associated with living breakwaters and the concrete mixtures used to form the structure with related innovations dating back to the 1980's.

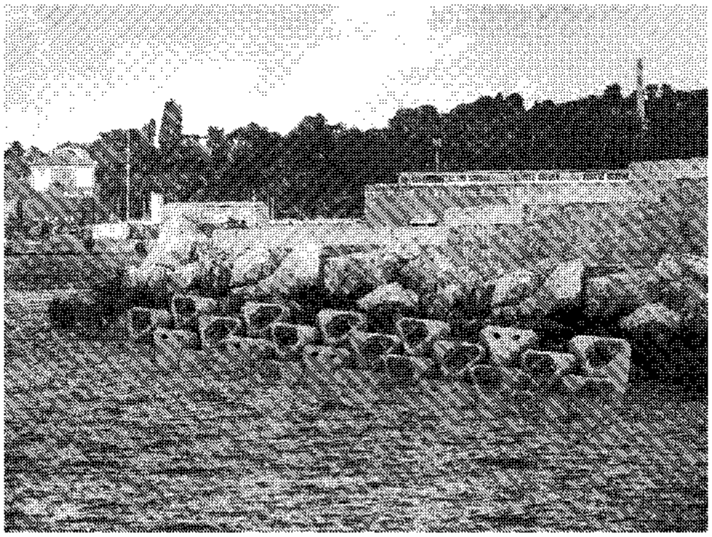

Figure 2: US20230073789A1 "Interlocking ecological armoring units and uses thereof in forming a costal barrier." (Source: European Patent Office, https://www.epo.org/en)

A more recent patent by SeArc and Econcrete Tech LTD is also revelatory as it covers the composite form of the living breakwater and is the unit commonly used in project renderings by the SCAPE team. The patent US20230073789A1 "Interlocking ecological armoring units and uses thereof in forming a costal barrier" was submitted 02-02-2021 and assigned to Econcrete Tech LTD (figure 2). The patent states: "The invention provides a marine infrastructure unit having a polyhedral structure with at least four faces; wherein said unit is formed of concrete and wherein at least one face of said unit comprises at least one tidal pool indentation; for use in building a marine infrastructure and promoting fauna and flora growth in marine environment."[104] Importantly, the units described by the patent are those commonly used in project renderings; however they are not used in the final project buildout, which is ostensibly composed of large rip-rap boulders and the designed "tide pool" units covered by Patent USD841,185 (figure 3).[105]

Reflecting on this process establishes a clear timeline for the advent of oyster-tecture technology that began with "fuzzy rope" pilot projects and ultimately translated into "living breakwaters". The intellectual property originated by SeArc and Econcrete Tech LTD evolved from the unique contingencies of the design competition process. In summary, the original

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[103] Matthew D. Campbell, Robert L. Beine, and Steven G. Hall, Biologically-dominated artificial reef, United States US7144196B1, filed December 28, 2005, and issued December 5, 2006.
[104] Ido Sella and Barak Saar, Interlocking Ecological Armoring Units and Uses Thereof in Forming a Costal Barrier, US2023073789A1, filed February 25, 2021, and issued March 9, 2023.
[105] Ido Sella, Shimrit Finkel, and Adi Neuman, Tide pool, USD841185S, filed July 11, 2017, and issued February 19, 2019.

oyster-tecture concept was conceived of circa 2009-2010 as part of the Rising Currents competition and reached design and museum audiences through concurrent gallery exhibitions, online media sources, and a book chapter in 2011. At this time a series of "fuzzy rope" pilot projects were initiated by SCAPE LLC and SeaArc. This early work laid the groundwork for further development of the concept and core technologies during the Resilience by Design competition in New York. This prolonged research and development phase resulted in a funded project "living breakwaters" being constructed in Staten Island. Intellectual property and peer reviewed studies of the core technology were developed from 2013-2021 by SCAPE team member SeArc and their corporate partner, Econcrete Tech LTD.

During this process we can observe an 'inverted' sequence of invention and diffusion of innovation in which the core technological concept was visualized, popularized, tested, and then invented through dedicated research and development. In essence, the exhibiting of oyster-tecture and communication of the idea through competition social channels facilitated the diffusion and adoption of oyster-tecture in advance of developing the core technology. This 'inverted' process challenges conventional models for the diffusion of innovation in which invention necessarily precedes adoption through social groupings. Further confounding the issue is the existence of prior-art and established prototyping within this technological field – helping to define the idiosyncratic chasm that defines the invention of oyster-tecture.

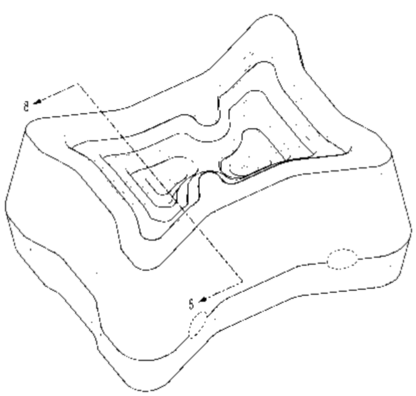

Figure 3: *Design Patent USD841185 "Tide Pool" (Source: European Patent Office, https://www.epo.org/en)*

Prior-Art: patent innovation landscape of Oyster-Architecture outside of the competition framework

The technological origins of oyster-tecture can be traced to two key patents by Sherwood Gagliano and August Muench respectively. In essence the patents disclose the art of integrating oysters with coastal structures to mitigate erosion, restore habitat, filter water, and stabilize ground – establishing prior art in this field. They build upon sequential innovations in oyster cultivation, and coastal infrastructure to define a new hybrid form of bioengineered coastal structure including patented technologies for such systems dating to the early 1970's. Prototyping and development of the technologies by Gagliano and Muench have distinct geographical, social, and technical characteristics leading to their development and adoption. The system developed by Gagliano emerged from research on land loss in southern Louisiana and observations about the role of oysters in stabilizing delta sediments. The system developed by Muench evolved through observation of the impacts of seawalls in the Tampa Bay region and the hands-on development of oyster reefs for habitat restoration. Collectively, thirty-three (33) patents cite the initial patents by Muench and Gagliano, revealing an innovation landscape that spans more than two decades and is interconnected with ongoing innovations in the field of bioengineered coastal structures.

To establish these timelines and origin points, patent searches were conducted to find technologies that represent conceptual and technical precedents for oyster-architecture. This included a broad search for early patents that integrated living organisms into coastal infrastructure, and a more refined search that looked at specific technologies for the growth of oyster reefs within coastal infrastructure structures such as seawalls, breakwaters, jetties, etc. The Keyword, citation, and classification searches were conducted on through the European patent office (www.worldwide.espacenet.com) and through Google (www.patents.google.com) to net-cast and search for related patents.

Keyword searches were conducted using the following combinations, seawall+oysters, breakwater+oyster, oyster+sediment. These searches yielded a range of result that were further filtered by reverse date search (oldest-new) to establish chronology. From this process the patent US5007377A "Apparatus and method for marine habitat development" was identified as among the earliest technology for integrating oyster reefs habitats with coastal infrastructure.[106] A secondary search was then conducted using patent citations further expanding the list of related technologies, revealing novel structures for open water oyster cultivation dating back to the early 19th century. Among these citations was a unique patent from 1992 "Method and

[106] August A. Muench, Apparatus and method for marine habitat development, US5007377A, filed February 6, 1990, and issued April 16, 1991.

apparatus for growing oyster reef" (US5269254A) that aims to intentionally integrate oyster reef cultivation in coastal infrastructure for sediment accretion and ground stabilization.[107]

A final patent classification search was conducted to find hybrid technologies that are categorized simultaneously in international classification (A01K) Animal husbandry; Care of birds, fishes, insects; Fishing; Rearing or breeding animals, not otherwise provided for; New breeds of animals, and (E02B) Hydraulic Engineering; Man-made devices for using or controlling natural bodies of water; Artificial bodies of water. This yielded more than 3,000 unique patents, many of which are for devices such as fish ladders or cultivation devices not directly related to coastal infrastructure and others are highly interrelated through their hybrid approach to bioengineering of marine structures. One of the earliest identified examples is US3888209A "Artificial Reef" patented in 1973 which is designed to mitigate coastal erosion through the growth of sabellarid worms on an engineered reef structure – providing evidence of the first known "living breakwater."

Three patents resulting from these searches are discussed below as early antecedents of oyster architecture and bioengineering of marine structures. They reveal, through further biographic research, a timeline of novel marine ecological structures originating in the early 1970's and specific integration of oysters into coastal infrastructure in the 1990's. Although the searches are by no means absolute, they do suggest the emergence of an innovation landscape that continues to evolve today through development of new technologies and further refinement of materials. In the context of oyster-tecture they represent prior-art that expand the historical timeline of sequential innovation in this sector.

Possible explanations for the omission of this prior art in the SeArc/Econcrete patent portfolio include span a spectrum of procedural and organizational idiosyncrasies in the U.S. patent system. Firstly, prior-art searches for U.S. patents are initially conducted by lawyers, not subject area experts, and re used to prove novelty as well as delineate the scope of invention. This means that only a curated list of prior-art patents is provided in support of a new patent application, and these citations can sometimes be seemingly incomplete or include unrelated

[107] Sherwood M. Gagliano and Mark H. Gagliano, Method and apparatus for growing oyster reef, US5269254A, filed July 6, 1992, and issued December 14, 1993.

patents as related to the claims. In areas of ambiguity, such as those related to the definition of ecological coastal infrastructure, patent lawyers and examiners may not establish linkages and focus a narrower scope. A second possible explanation is that patent classifications for hybrid coastal infrastructure, such as living breakwaters and oyster-tecture is highly differentiated, and therefore span across subclasses of the CPC or IPC classifications, leading to potential ambiguities, or bias, in how an invention is organized, cited, and interpreted. As a point of refence, the Y02A classification scheme partially address this issue, as it provided new climate adaptation classifications including those for coastal tech and artificial reefs, consolidating innovation in disparate, yet convergent, sectors under an easily identified subject heading. It is therefore conceivable that similar technologies invented today would more readily be associated with related prior art in the adaptation sector.

August Muench: the “first” patented oyster-tecture system

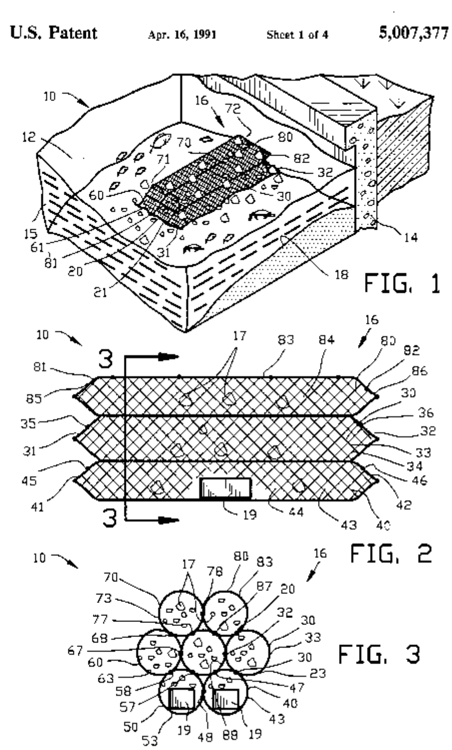

Figure 4: US5007377A “Apparatus and method for ***marine habitat development,"*** *1991. (Source:European Patent Office, https://www.epo.org/en)*

Keyword searches identified the earliest known patent for the intentional integration of oyster with coastal infrastructure. The system called “Apparatus and method for marine habitat development” (US5007377A) was granted to Inventor August A. Muench, Jr. on April 16, 1991. According to the abstract the patent discloses “An improved apparatus and method is disclosed for the development of a marine habitat through the growth of mollusks.” The system aims to integrate oyster habitat with seawalls to improve habitat, clean water, and enhance intertidal ecology. The structural system involves a plurality of retaining members having a mesh wall these members are interconnected and retain adult mollusks within the structure adjacent to seawalls and culverts. The system is designed to be integrated with marine structures such as sea walls, where the habitat of oyster has been degraded by placement of the wall, thus forming a hybrid structure to catalyze the establishment of ecological communities – including the climax mangrove community that is observed to establish late successional artificial reefs.

According to August (Gus) Muench he came up with the idea in 1986 after losing a crab trap filled with oyster shells. When he retrieved the trap later that year it was covered with oysters and had captured enough sediments that a mangrove had established itself.[108] Muench and his wife Elizabeth, incorporated Oyster Reef Designs, Inc., on the 23rd of October 1989 in Ruskin, FL. Ultimately Oyster Reef Design Inc went on to create numerous seawall oyster reefs all through the Tampa Bay region, especially in the little manatee river area where the Muench family lived. [109] The invention was reduced to practice from 1986-1989 through a series of initial prototypes, and a patent was filed on February 6th, 1990. In a recorded video interview archived at the University of South Florida Digital Commons, Muench describes the process of discovery and the ecological succession that underpin the technology.

"I started a company called Oyster Reef Design, and we got a patent on seawall reefs. We put reefs in; they grow oysters. It started out as a fish habitat, and then I found out that, well, through succession, oysters are going to grow on that. Oysters give off sediment; they spit out silt and clay; the sediment falls down between the oysters, and then that fills up. The oysters keep going until they get to the point called mean high-water line. That mean high water line is where the oysters stop growing, okay, and that's where your red mangrove seeds come in and get caught and start growing. So, where I started that fish habitat, the seawall reefs led to oyster growth; the oyster growth led to mangroves—that's the succession of it. Then the bird life came in. That's where the reds, the whites, and blacks, and buttonwood all start, and spartina… so looking at the seawall reefs that I created—that came about by accident. I was throwing old crab traps off the dock, and I watched the little fish go through it—swim through this old crab trap just like you walk through a door, and so, I said, "That's habitat!" So I said, "Well, maybe I can make something," so I came up with, uh, creating seawall reefs from using polyethylene fencing,

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[108] Tampa Publishing Company, "Sowing the Seeds of Life," *Tampa Bay Times*, accessed September 17, 2021, https://www.tampabay.com/archive/1990/10/28/sowing-the-seeds-of-life/.
[109] "August Muench Oral History Interview," accessed September 17, 2021, https://digital.lib.usf.edu/SFS0050335/00001.

which is just a skeleton, like a skeleton of a sponge, and, therefore, the oysters, or barnacles, whatever grows on that, creates a living rock, you might say. It’s all porous.” [110]

From the interviews, news reports, company filings, and patent we can reconstruct a timeline and narrative of the evolution of oyster-habitats integrated with coastal infrastructure in southern Florida. The geographical scope of the work was seemingly isolated to the Tampa region. According to the audio recording oyster reefs were installed private waterfront lands and Madeira Beach, Boca Ciega Bay, and the Madeira Beach Middle School, through grants by the Tampa Bay Estuary Program. Invention of the technique emerged from local practices and observation and was enacted through the corporate entity, and patented technology.

Gagliano: Early field test and patents

Similar experiments with constructed oyster reef were occurring in southern Louisiana around the same time. Patent citation searches reveal an early system for the construction of oyster reefs in ground stabilization and to increase sediment accretion. The US patent for “Method and apparatus for growing oyster reef” (US5269254A) was granted to Inventors Sherwood M. Gagliano and Mark H. Gagliano on December 14th, 1993, and filed by the inventors on July 6th, 1992. According to the abstract the patent discloses “A method for forming an oyster reef, includes setting seed oysters on cultch material, placing the cultch material containing the seed oysters in water permeable panels to form a vertical permeable wall of cultch material through which water may flow, and placing the panels in water having favorable conditions for oyster growth. The apparatus includes water

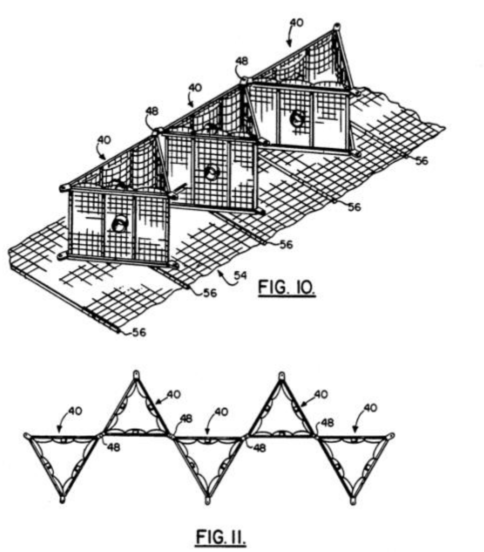

Figure 5: “Method and apparatus for growing oyster reef” US5269254A. (Source: European Patent Office, https://www.epo.org/en)

[110] “August Muench Oral History Interview.”

permeable panels for holding cultch material in a vertical permeable wall to expose the entire column or wall of cultch to water having favorable conditions for oyster growth, and blocks formed from the panels." In essence the permeable oyster cultivation system may be positioned in coastal areas to capture sediment and stabilize ground through the growth of oyster reefs in combination with the material assembly.

Dr. Sherwood Gagliano is credited as one of the first scientists and geographers to document land loss in Louisiana and a pioneer of deltaic restoration.[111] His early research on the geomorphology of Mississippi Delta revealed the extents of sediment loss and habitat destruction in the Mississippi delta.[112] During these studies Sherwood collected data from a range of sources, including oyster farmers and fishing camp owners. These observations led to the realization of rapid land loss in Louisiana. In 1980 (or earlier) Dr Gagliano started building experimental oyster reefs to stabilize and capture delta sediments. According to a quote from his obituary in the New Orleans Advocate the oyster program "started as a father-son high school science project in 1982 between my son, Mark Gagliano," and leading to the creation of a company to design, build, and install oyster reefs.[113] Gagliano's company Coastal Environments Inc has been building and installing the patented Reef BLK system since it was patented in the 1990's.

Edmund Boots: early pioneer in biologically dominated coastal infrastructure.

An origin point for living breakwater can also be identified in patents dating to the early 1970's. The US patent for an "Artificial Reef" (US3888209A) was submitted by the Inventor Edmund R Boots on November 14th, 1973, and granted on June 10th, 1974. It likely represents the first technological system designed to accrete sediment and stop erosion by cultivating marine organism on an artificial breakwater structure. According to the abstract the patent discloses "A method and apparatus for preventing erosion of a beach, including an artificial reef

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[111] MARK SCHLEIFSTEIN | Staff writer, "Dr. Sherwood 'Woody' Gagliano, 'Paul Revere' of Coastal Land Loss, Dead at 84," NOLA.com, accessed September 17, 2021, https://www.nola.com/news/environment/article_8574789a-c965-11ea-8e4d-eb4bafe9881e.html.

[112] Sherwood M Gagliano and Johannes L Van Beek, Geologic and Geomorphic Aspects of Deltaic Processes, Mississippi Delta System (Coastal Resources Unit, Center for Wetland Resources, Louisiana State University, 1970).

[113] writer, "Dr. Sherwood 'Woody' Gagliano, 'Paul Revere' of Coastal Land Loss, Dead at 84."

for subsurface placement adjacent a shoreline and made up of a base reef set on the seabed and an upper reef preformed and mounted to the base reef or formed in situ on the base reef by a sabellarid marine organism thereby forming a composite reef to build up accretion of sand on the shore side of the reef and to prevent erosion of a beach."[114] Among the references for the patent is mention of a 1968 article from the Natural History Magazine, titled "The reef builders" in which the lifecycle and environmental transformation of the reef forming worm is described in depth, including their capacity to stabilize beaches through the accretion of sands and sediments. Although the patented system does not aim to build reefs through oysters, it is significant for the integration of marine organisms with coastal infrastructure to stabilize beaches and mitigate erosion.

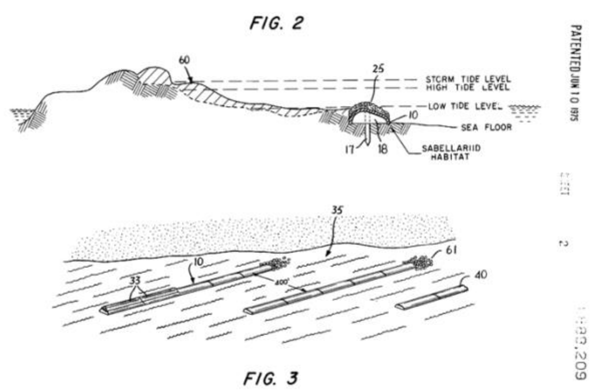

Figure 6: US3888209A "Artificial Reef," 1974. (Source: European Patent Office, https://www.epo.org/en)

A biographical sketch of the inventor in the book "The beaches are moving" states that "Mr. Edmund Boots, an 88-year—old retiree who is said to have invented the traffic light, claims to have the "ultimate solution" to stopping Florida's erosion." According to the account Mr. Boots noticed that the local Riomar Reef near Vero Beach was made by sabellarid worms, and that this worm reef blocked erosion. Through further research it was discovered that the Riomar Reef acted like a breakwater by cutting off erosion, thus establishing the concept for the sabellarid worm reef invention. The system involved construction of a concrete archway that would serve as a stable base for the sabellarid reef. The eight-foot-wide "underwater worm boardwalk" would thus become a hybrid habitat and coastal infrastructure. According to Mr. Boots, it "could be built for $1 million a mile" and he founded the Sabecon Reef Association to conduct this work. "[115]

[114] Edmund R. Boots, Artificial reef, US3888209A, filed November 14, 1973, and issued June 10, 1975.
[115] Wallace. Kaufman and Orrin H. Pilkey, *The Beaches Are Moving the Drowning of America's Shoreline : With a New Epilogue, Living with the Shore* (Durham, N.C: Duke University Press, 1983), https://doi.org/10.1515/9780822382942.

The Sabecon Reef Association actively promoted the idea of a Sabellarid reef during the planning ad review period of a breakwater project in Indian River County, Florida. The environmental impact statement for the project reveals that the Army Corps of Engineers (USACE) was presented with the project 1976 during the initial phases of the feasibility study but it was never implemented. According to Army Corp accounts, Mr. Boots had observed reefs protecting the beach near his home and worked with manufacturers to design a protype artificial reef for sabellarid worms and developed plans to build a test section. [116] An associated research study from 1973 at the University of Florida by A.J. Metha confirmed the value of the sabellarid reef in beach nourishment and stabilization.[117] Unfortunately a full-scale pilot project was never realized.

Discussion: Dimensions of the Chasm in oyster-tecture and Adaptation and Resilience Planning

The emergence of oyster-tecture as a viable approach to ecologically informed coastal infrastructure was an exciting breakthrough in coastal adaptation and resilience planning as the idea was widely praised in popular media, catalyzing interest in ecological infrastructure in coastal and the allied disciplines of environmental design tasked with developing solutions to the emergent threats of climate change and seal level rise. However, the recent popularization and adoption of the concept through the coastal adaptation and resilience competition process stands in contrast to prior art in the field as documented in patented technologies and pilot projects, revealing a temporal lag, geographical siloed and disconnect groups, between those involved in the initial technological development by scientists and individual inventors in the 1990's and the late adoption of the related technology in design/planning fields. The social, temporal, and technical dimension of this innovation chasm are distinct, as documented prototyping, and patent innovation timelines, exhibitions, and competition materials associated with advent of oyster-tecture provide critical insights for how innovative ideas and technologies are disseminated and adopted.

[116] United States. Army. Corps of Engineers, Indian River County Beach Erosion Control: Environmental Impact Statement, 1981.
[117] Walter G Nelson and Martin B Main, "Criteria for Beach Nourishment: Biological Guidelines for Sabellariid Worm Reef," 1985.

The two earliest oyster-tecture patented systems by Gagliano and Muench evolved through a conventional process of observation, research, testing, prototyping, and eventual development of a technology. These technologies, although implemented locally, have not been widely adopted and were essentially lost to an innovation chasm between the visionary early inventors and a wider adoption. This likely results from the complexity and timescale of environmental works and the geographically specific scopes in combination with discrete social networks that limited their rate of diffusion. In the context of contemporary coastal adaptation and resilience it is also significant that research and pilot projects are developed by specific and often siloed social and professional groups operating within team structures.

Comparatively, the process of invention that led to the coining of the term "oyster-tecture" in the design/planning fields, and development of prototypes varies distinctly from these cases. The concept was developed by Kate Orff and SCAPE Landscape Architects during the Rising Tides Competition, hosted the Museum of Modern Art in 2010. Thereafter test panels were conducted to complement the exhibition and establish proof of concept. In the wake of Super Storm Sandy in 2012 the Rebuild by Design competition provided a platform for further development of the oyster-tecture concept and leading to development of living breakwaters in Staten Island, NY and the development of innovative concrete mixtures patented by team members.

In the translation from concept to prototype we can see the difficulties that result from rapid conceptual development and a hastened process of invention necessitated by the project timeline. The tension between an innovative concept and development of a new technology is clearly articulated in a 2013 article by Kate Orff titled "Shellfish as Living Infrastructure" in which the author discusses the promise of using shellfish to build coastal structures and restore habitats, tentatively outlining the technological and social strategy of oyster-tecture while pointing to pilot project and nascent prototypes to validate claims. This tension is further articulated in a response from Roger Mann in the journal of Ecological Restoration in which he discusses the complexity of establishing oyster reefs and the opportunities for collaboration as a sort of "reality check" for designers and a call to action for the ecological restoration community.

[118] These articles are interesting to consider, as they both assert aspirational ideas regarding the use of shellfish to build coastal infrastructure yet fail to identify a robust list of prior-art or precedent through which to contextualize the debate. In this context the Y02A patent classification scheme is valuable, as it can provide context to debates and prior-art studies for new infrastructural ideas.

Traditional studies on the diffusion of innovation within the coastal adaptation and resilience planning sectors are essentially nonexistent. Of course, innovative works of design and planning are created and documented, and wide consensus exists that planning processes, such as competitions, symposia, and exhibitions, lead to innovative and creative solutions to the issue of coastal adaptation and resilience. However, the mechanisms through which new technologies are invented, tested, and widely adopted remain poorly understood and undocumented. Given the dearth of innovation studies within the coastal adaptation and resilience planning and competitions one may assume that adoption of novel techniques and technologies follow a conventional model. However, as the invention of oyster-tecture reveals, adoption can precede invention – calling into question the nature of technological innovation within the coastal resilience and adaptation competition process.

The specific case of oyster-tecture reveals a disjuncture in the development of core technologies and its broader adoption in the design and planning communities. This chasm is hypothesized to result from several factors, including an epistemological gap in the design competition processes, siloed social networks, and opaque mechanisms for the diffusion and adoption of technology in the coastal adaptation and resilience sectors. The invention of Oyster-tecture reveals the need for integration of innovation knowledge infrastructure with planning processes to better coordinate advances in the sector with real world projects. This may be accomplished through the integration of the Y02A patent classification scheme with planning process.

[118] Roger Mann, “Restoring Nature’s Coastal Architects: A Reality Check,” *Ecological Restoration* 31, no. 3 (2013): 323–24.

Table 2: Patent citations for (US 9,538,732) "Methods And Matrices For Promoting Fauna And Flora Growth."

Number	Publication Date	Assignee	Title
US556436A	1896-03-17	J.G. Pohle	Apparatus for Elevating Liquid
EP0134855A1	1985-03-27	Hokuriku Estate Co., Ltd	Concrete blocks for use underwater for algal culture
US5564369A	1996-10-15	Barber; Todd R.	Reef ball
US6186702B1	2001-02-13	Michael Scott Bartkowski	Artificial reef
JP2002000112A	2002-01-08	Oriental Giken Kogyo Kk	Artificial shore reef
WO2004031096A1	2004-04-15	Madelaine Joy Fernandez	Composition suitable for aquatic habitat repair, replacement and/or enhancement
US20060147656A1	2006-07-06	Mathieu Theodore J	Simulated coral rock and method of manufacture
US7144196B1	2006-12-05	Ora Technologies, LLC	Biologically-dominated artificial reef
US20090269135A1	2009-10-29	Louis Arvai	Coquina Based Underwater Mitigation Reef and Method of Making Same
AU2010100170A4	2010-05-20	Craig Campbel Stuart	Artificial Marine Aquarium Live Rock
US8312843B2 *	2012-11-20	Ora Technologies, LLC	Artificial material conducive to attract and grow oysters, mollusks or other productive and/or stabilizing organisms

US4508057A *	1985-04-02	Tokyu Musashi Mfg. Co., Ltd.	Algal culturing reef unit, artificial reef unit and artificial culturing and fishing field unit
JP2000157095A *	2000-06-13	Nkk Corp	Creation or improvement of alga bank
JP2001352848A *	2001-12-25	Sumitomo Osaka Cement Co Ltd	Seaweed bed propagating bank and method for forming the same
JP4016014B2 *	2007-12-05	南和産業株式会社	Formwork block and manufacturing method thereof
JP2006223297A *	2006-08-31	Yasunari Sakat	Method for treating surface of cement-based cured product for adhesion of seaweed, raft method by underwater exposure of porous material bagged in net, hanging method, mat method, and fish or shellfish-living environment-maintaining method in seaweed bed or artificial fishing bank by these method
JP2008263928A *	2008-11-06	Japan Science & Technology Agency	Dredged soil block for installing beach bedrock
CN101439939B *	2011-07-20	北京科技大学	Low alkalinity gel material for preparing concrete artificial reef and preparation thereof
CN101475348B *	2011-09-21	首钢总公司	Artificial reef preparation with metallurgy slag as principal raw material
WO2010121094A1 *	2010-10-21	Livefuels. Inc.	Systems and methods for culturing algae with bivalves
CN101671132B *	2011-10-12	北京科技大学	Fish reef cementing material containing nano-tailings and preparation method thereof

2. A wild goose chase? The search for alternative coastal stabilization technologies and the emergence of new actor-networks

Stabilization of the coastline has paralleled the development of ports, cities, shipping routes, and military sites, for millennia. Today, coastal stabilization is a global issue gaining relevancy through widespread coastal development, increased sea level rise, storm surges, and other climate change induced threats to coastal development. However, the logic of rigidly armoring dynamic coastal systems is widely criticized as appreciation grows for coastal processes and the environmental impacts of rigid structures become clear. The limits of existing technologies, and the ongoing coastal changes occurring globally in the context of climate change, necessitate a search for alternative technologies. This proverbial "wild goose chase" has led to the advent of diverse range of novel processes for coastal stabilization while simultaneously revealing the challenge of innovating within complex environmental systems. Irrespective of the challenges, the search for novel coastal stabilization technologies reveals a range of inventors, new technologies, corporations, communities, awards organizations, and institutions, engaged in the invention prototyping, and implementation of coastal works.

As the word "alternative" implies the search for novel coastal stabilization technologies inherently challenges entrenched techniques and protocols developed over centuries - engaging diverse human and non-human actors in coastal systems, forging new networks, and leading to establishment of new technological assemblages operating within coastal Anthromes. Their novelty, failures, and success, make these new assemblages interesting to consider as we approach the wicked problem of global sea level rise with no established government or private sector entity fully prepared to address the scale and complexity of this emergent global issue. Reflecting on this process through the lens of actor network theory reveals patent documents, as their associated rights, as important intermediaries through which innovative solutions to coastal stabilization techniques are realized. Research on patented technologies therefore highlights the actors-networks engaged in this process of instigating change, and challenging entrenched interests of agencies such as the United States Army Corps of Engineers (USACE), who hold near monopolies on coastal works in the United States.

The process of change in complex coastal stabilization infrastructure is incremental yet ongoing. As is observed in the advent of oyster-tecture and living breakwaters in chapter 1, the process involves layers of planning, institutional partnerships, policy, funding, and invention to shift the needle on large-scale coastal infrastructure projects towards more ecological and process-based systems. Of course, design and planning competitions are not the only mechanism through which innovation occurs and instigates change. Coastal constituencies are broad, culturally diverse, and geographically disparate, yet entwined with the processes of coastal adaptation. Within this network, or assemblage, local knowledge, university research, individual inventors, private development, industrial partners, professional organizations, and governance, all play a potential role in coastal innovation. In this chapter, six individual examples explore the dynamic between the advent of novel technologies and the USACE through technology exchange and patent rights. This includes an overview of the pioneering works of James Buchanan Eads in the Mississippi River Delta, and 5 lesser-known works by others, that have realized a range of novel coastal stabilization systems and expanded the network of coastal agents.

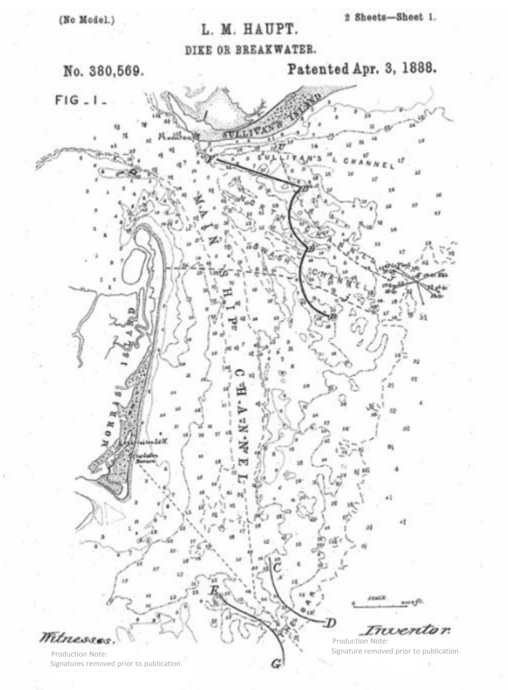

Figure 7: US 380569 "Dike Or Breakwater" popularly known as the Reaction Breakwater which excavates channels and stabilizes shorelines through the controlled forces of water. (Source: European Patent Office, https://www.epo.org/en)

What are alternative coastal stabilization technologies?

Alternative, or innovative, coastal stabilization devices are those that are considered by engineers, and other experts, to be “non-traditional.” In general, these alternative devices are understood as a broad and assorted mix of technologies, methods, and structures, for stabilizing (i.e. erosion protection, armoring, sediment capturing, etc.) that deviate from traditions and best practices in coastal engineering established over centuries. Historically the fields coastal and civil engineering has focused on a relative narrow list of technologies to address the issue of coastal stabilization, utilizing terminology such as rigid, fixed, armoring, and defense, to establish design criteria. Irrespective of their long and established history, these engineering standards are not infallible, having led to the channelization of waterways, hardening of urban edges, and beach stabilization with rigid structures, that has cause broad environmental impact and amplified risk.

Alternative technologies are developed outside the narrow conventions of traditional coastal engineering – veering from the history and suggesting something slightly new. Traditionally engineered coastal structures function within known parameters and their engineering standards have been developed over centuries – an obvious prerequisite for ensuring the proper function of vital infrastructure. Yet the small margins for error have also limited options by narrowing material options and structural alternatives. According to Martin Reuss, a leading authority on hydraulic engineering history for the United States Army Corps of Engineers, the technologies of water control "have not changed fundamentally for ages. They include dams, levees and floodwalls, bank revetment, jetties, channel stabilization, and dredging. The emphasis is on the effective application of existing technologies; the innovation usually is in the details."[119] From this historical perspective the space for innovation is limited to incremental improvements to established conventions developed within a narrow disciplinary scope. The distinction between traditional and non-traditional, innovative, and alternative technologies therefore highlights how novel approaches to coastal stabilization are suppressed and establishes a frame through which to comprehend insider/outsider relationships operating among entrenched networks and power structures.

Alternative devices are those designed, conceived, or promoted outside a relatively narrow disciplinary scope. In essence, the conventions of coastal engineering are entrenched and resistant to change not only in coastal systems but also to innovation through alternative pathways. This dialectic spans decades, emerging from an overreliance on rigids seawalls and

[119] Martin Reuss, "The Art of Scientific Precision: River Research in the United States Army Corps of Engineers to 1945," *Technology and Culture* 40, no. 2 (1999): 292–323.

other structures to control water and edify watersheds.[120] Historians often situate the evolution of the militarized coastal "defense" strategy as a remnant of a militarized past in which fortification and immovability became hallmarks of military fortifications and eventually navigable waterways. In the United States this history is explicit, as most coastal and riverine infrastructure are constructed by the United States Army Corps of Engineers (USACE) which originated as a distinct branch of the military in 1775-1799, contributing engineering works to wartime efforts and thus training engineers at the preeminent military academy, West Point.[121]

The impact of military engineering on coastal systems is widespread and ongoing, however recent inclusion of other performance criteria, such as environmental processes, indicates a shift towards more 'alternative' forms of coastal infrastructure. Orin Pilkey, Professor Emeritus of Earth and Ocean Sciences, at Duke University, and founder and director emeritus of the Program for the Study of Developed Shorelines, states of this militarized approach that; "Prior to World War II the most common choice of "shoreline protection" was hard stabilization, usually in the form of seawalls and groins... At that time, the sole consideration was the protection of buildings threatened by shoreline recession, and the environmental aspects of coastal engineering were not considered particularly important."[122] Today this approach to coastal stabilization is widely criticized as dynamic coastal systems thrash established coastal defense and flood structures causing harm and devastation. The overreliance on stability and permanence has also exacerbated threat, leading to what Gilbert Gaul calls a "geography of risk" in which engineered coastlines exacerbate threats instead of offering protection.[123] Criticisms of coastal "defense" have paralleled greater appreciation of coastal processes and ecology, leading to the realization that armoring the coastline is often fraught by long term negative environmental impacts. Thus, the search for alternatives emerges from the ongoing need to stabilize and control coastal systems and a shift away from conventional techniques.

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[120] "Seawall Built to Cut Raritan Bay Erosion," *The New York Times*, May 4, 1975, sec. Archives, https://www.nytimes.com/1975/05/04/archives/seawall-built-to-cut-raritan-bay-erosion.html; P.W. French, *Coastal Defences: Processes, Problems and Solutions* (Taylor & Francis, 2002),

[121] Todd Shallat, *Structures in the Stream: Water, Science, and the Rise of the US Army Corps of Engineers* (University of Texas Press, 2010).

[122] Orrin H Pilkey and Howard L Wright III, "Seawalls versus Beaches," Journal of Coastal Research, 1988, 41–64.

[123] G.M. Gaul, *The Geography of Risk: Epic Storms, Rising Seas, and the Cost of America's Coasts* (Farrar, Straus and Giroux, 2019)

Pushback against rigid structures also cut a clear transect through policy and law at the state and local level. Governmental responses in policy and funding provide important insights into the scale and scope of the problem facing coastal regions as well as the ongoing search for alternatives. For example, the State of Florida passed a law in 1989 to encourage and incentivize invention and testing for new methods of shoreline stabilization, and similarly the State of North Carolina developed rules in 1985 limiting rigid structures and passed legislation to this effect in 2000. These early law in effect created space for innovative, or alternative, technologies, and the today this trend continues as local, regional, state, and federal governments, attempt to address rapid coastal change in the context of climate change and sea level rise. More Recently, new pathways have opened for the testing and development of alternative technologies through design competitions such as the Resilience By Design competition in New York (see chapter 1) that has led to the creation of 'Living Breakwater' pilot projects, and ongoing evaluation of experimental technologies by the United States Army Corps of Engineers through the "Engineering With Nature" initiative that advances nature based solutions, such as artificial reefs, for coastal engineering.[124]

Regardless of the tension, alternative and innovative coastal stabilization technologies continue to be invented, prototyped, and tested by a range of individual inventors, companies, universities, and designers engaged in coastal stabilization works. Knowledge of these alternatives is patchy as they exist outside the canons and real-world pilot projects are geographically disparate. To date, the most comprehensive dossier chronicling the breadth of alternative stabilization technology exists within global patent archives where descriptions of thousands of such devices currently exists. A 2012 survey of these alternative devices and methods states that; "most are derivations of or modifications of the traditional shoreline engineering approaches. The structures are categorized by placement location (in the water or on the beach) and functional similarity to well-recognized engineering structures such as seawalls, breakwaters, and groins. There is some overlap, as some of the alternative devices do not necessarily conform to the criteria for any particular category. They are subdivided into devices placed in the water (breakwaters and artificial seaweed) and devices placed on the

[124] "Engineering With Nature," accessed November 15, 2022, https://ewn.erdc.dren.mil/.

beach (groins, seawalls, dewatering systems, dune stabilizing systems and other devices)."[125] Of course, the existence of these alternatives does not mean that they have been tested or work as claimed. Given the scale, duration, and complexity of environmental works it is unlikely that even a small fraction will be evaluated in practice evaluated, however policy mechanisms and regulations in the United States, and elsewhere, have been implemented to create opportunities for experimental alternative technologies.

In the state of Florida coastal conservation laws date back decades and include permitting and funding to test novel technologies along its shores. Coastal stabilization is an important subject in the state, as the beach is a major tourist and real estate asset in addition to the broader environmental and ecosystem values. A survey article surveying the state's legal approaches to the issue states that The Florida Legislature recognizes through laws on the book that coastal areas are "dynamic geologic systems with topography that is subject to alteration by waves, storm surges, flooding, or littoral currents," and that "coastal areas are among Florida's most valuable resources and have extremely high recreational and aesthetic value which should be preserved and enhanced."[126] Provisions within coastal protection laws limit the construction of a variety of structures landward of the mean-high water line but also provide space for experimental technologies. The specific law (Sec. 29, 89–175 – Rule 62B-41.0075) establishes a mechanism for research and development related to the widespread erosion problems in Florida. The law defines a process through which to assess the performance of proposed devices and evaluate alternative to costly coastal engineering works while minimizing environmental risk and adverse ecosystem impact.[127] Under the scope of this law, a range of experimental technologies were tested, including Artificial Seaweed, Net Groins, Beach Scraping, Beach Dewatering, Physical Structures (Geotextile Groins), Proprietary Reef Structures, and Thin Line Submerged Breakwaters.[128]

In North Carolina similar coastal erosion problems exist. The sand dominated coastal processes in the state inherently limit the efficacy of rigid structures in coastal stabilization

[125] Orrin H Pilkey and J Andrew G Cooper, "'Alternative' Shoreline Erosion Control Devices: A Review," in Pitfalls of Shoreline Stabilization (Springer, 2012), 187–214.
[126] Joy R Brockman, "Coastal Ecosystem Protection in Florida," *Nova L. Rev*. 20 (1995): 859.
[127] Brockman.
[128] Pilkey and Cooper, "'Alternative' Shoreline Erosion Control Devices: A Review."

projects. Negative environmental impacts of rigid structures ultimately led to creation of rules banning the use of engineered structures such as seawall, breakwaters, and groins. The North Carolina Coastal Resources Commission was founded in 1974 to establish policies for the state's coastal management program.[129] One of the commissions first initiatives was evaluation of the impacts of seawalls on the sandy coastline, leading to directives approved in 1985 to ban all rigid structures, seawalls, groins, and breakwaters, along beaches and waterways. Although not technically a law passed by legislature, the 1985 rule banning the construction of rigid structures was in practice for decades, with revision in 1992 to allow for protection of significant historic sites and navigation channels. These rules, or guidelines, were eventually written into law in 2003 after legal challenges which led to the legal ban on hard structures that remain in effect. Today, under this law "No person shall construct a permanent erosion control structure in an ocean shoreline. The Commission shall not permit the construction of a temporary erosion control structure that consists of anything other than sandbags in an ocean shoreline. (NC G.S. §113A-115.1)" Although the state has recently allowed for the construction of terminal groins, the ban is essentially still in effect.[130] In the context of an ongoing search for alternatives, these rules are important as they led to pilot projects using non-rigid structures and a series of experiments for alternative technologies that were developed and evaluated along the North Carolina Coast.

The situations observed in Florida and North Carolina are not unique as coastal stabilization efforts proliferate globally. The extent of global coastal armoring is difficult to accurately assess, but specific urban areas provide insights about generalized conditions around the world. The marine environment of Sydney Harbor, for example, is estimated to be 96% urbanized by walls, piers, wharves, jetties, docks, and other structures, with more than 50% of the shoreline composed of seawalls.[131] Of course, the sandstone geology of cities such as Sydney varies from urbanized coasts Florida or North Carolina, however the extent of marine armoring is important to comprehend the scale and scope of the problem. In California, America's most

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[129] David W Owens, "Coastal Management in North Carolina Building a Regional Consensus," *Journal of the American Planning Association* 51, no. 3 (1985): 322–29.
[130] Whitney Knapp, "Impacts of Terminal Groins on North Carolina's Coast," 2012.
[131] M G Chapman et al., "Effect of Urban Structures on Diversity of Marine Species," *Ecology of Cities and Towns: A Comparative Approach*. Cambridge University Press, Cambridge, 2009.

populated state, an "astonishing" 110 miles of the entire 1,100-mile coastline is armored. In highly urbanized areas, such as the four southern counties of California (Ventura, Los Angeles, Orange, and San Diego), the issue is exacerbated, with more than 33% of the 224-mile coastline armored with riprap (i.e. engineered stone slopes and structures) and ubiquitous concrete walls.[132] This urban condition is of course not unique to Sydney or Southern California. Most major harbors and urban waterfronts are heavily armored with variable configurations of steel sheet piles, cut stone, rip-rap, concrete, and timber, leading to extensive "ocean sprawl" that negatively impacts ecological connectively and distribution of species, in addition to the issue of coastal sediment transport.[133] Given the extent of coastal armoring, the search for alternatives is set to expand exponentially yet mechanism through which alternatives succeed in enacting change remain opaque as the majority of coastal engineering works have historically been undertaken by large government entities and contractors.

Coastal Stabilization - an Actor Network Theory Perspective

The search for alternative stabilization technology is imperative and will require coastal communities, governments, industry, and policy makers, to engage new inventors and forge new networks that operate outside the conventions of establishment. The scale and complexity of this coastal stabilization means that no singular entity (i.e. government organization, corporation, etc.) is capable of addressing the problem, requiring a reconceptualization of the problem space to identify ways to effectively operate within it. Actor Network theory (ANT) offers frameworks through which to comprehending the new networks, their agents, artifacts, and affect, within the problems space. It brings into relation geographically diverse and chronologically disparate assemblages flattening the scale and highlighting the sociotechnical aspects of policy in relation to environment.

ANT has been utilized widely to help comprehend complex systems and assemblages, including information systems, urbanization, policy, technological innovation, and other complex

[132] Gary B Griggs, "The Effects of Armoring Shorelines—the California Experience," in *Puget Sound Shorelines and the Impacts of Armoring—Proceedings of a State of the Science Workshop*, 2009, 77–84.
[133] Melanie J Bishop et al., "Effects of Ocean Sprawl on Ecological Connectivity: Impacts and Solutions," *Journal of Experimental Marine Biology and Ecology* 492 (2017): 7–30.

social systems. Although originally conceptualized in the context of science and technology studies in the early 1980's by Bruno Latour and others, ANT has provided a robust and resilient framework through which to analyze the associations and interactions of actors in networked space, and how these actors and networks engaging in systems of policy, innovation, and environment, to form novel assemblages. As ANT progressed from social science it impacted other domains and fields, including environmental studies, where it has offered distinct insights regarding this human-environment interaction, suggesting a more horizontal assemblage of human and non-human actors associated with an environmental problem space.

The framework provided by Actor Network Theory helps to recast environment as a complex assemblage of technologies, policy, geographical scales, actors, and process, operating in an environmental network space. This has proved especially insightful in the context of climate change. Researchers in this area claim that "an Actor Network Theory (ANT) perspective of 'climate' change facilitates an examination of the complex socio-technical/political/economic systems that comprise the problem space and expands our 'world view' of 'climate' change beyond the physical climate to include the 'social' climate, 'political' climate, 'security' climate and 'economic' climate with particular emphasis on the socio-technical domain and its cross domain influences."[134] Reformulating questions of environment as a more horizontal assemblage of interconnected domains, highlights the actions of engaged networks operating within the problem space to enact change. With regards to the specific case of coastal stabilization, the technologies, policies, inventors, and coastal processes may be understood through their interconnected domains and networks, simultaneously expanding the scope of the problem space, and revealing its connectivity across geographical scales.

For Latour, and others, scale is a question of network size, making it particularly useful in the domains of geography and environment in which scales of territory and geography have prevailed. Addressing questions of scale in his 1996 essay, Latour states, "Small scale/large scale: the notion of network distinction that has plagued social theory from its inception. The whole metaphor of scales going from the individual to the nation state through family, extended

[134] Anthony J Masys, "'World Views' on Impacts and Responses to Climate Change: An Actor Network Theory Perspective," vol. 6 (IOP Conference Series. Earth and Environmental Science, IOP Publishing, 2009).

kin, groups, institutions etc. is replaced by a metaphor of connections. A network is never bigger than another one, it is simply longer or more intensely connected."[135] Conceiving of the environment as a networked space facilitates the conception of places, spaces, and systems, through terms of interconnectivity as opposed to measured distance, making it particularly valuable when considering the global problems of climate change and sea level rise. Geographers working at the time of Latour's essay state of this transformation that ANT "has shown how networks 'draw things together' by gathering diverse places and times within common frames of reference and calculation. This 'gathering' process results in very distant points finding themselves connected to one another while others, that were once neighbours, come to be disconnected. Thus within ANT, space becomes 'a question of the network elements and the way they hang together. Places with a similar set of elements and similar relations between them are close to one another, and those with different elements or relations are far apart."[136]

Flattening of network space and compression of scale offered by ANT is particularly useful when considering the sociotechnical and policy aspects of climate change and thus the issue of coastal stabilization. For example, environmental changes, such as sea level rise, are trans-scalar wicked problems that engage many actors and instigate new networks to develop strategies and responses to environmental risk. Theoreticians researching in this area state; "This perspective highlights how existing networks help to tackle sea-level rise and, how climate change adaptation and sea level rise "recruit" new sets of actors into response networks. The ANT perspective also points to non-human entities (e.g. sewage systems or power plants), thus providing an innovative element to mapping vulnerable networks facing climate impacts." [137] The implications of this perspective are radical as technological and social change reformulates coastal Anthromes, instigating new networks and bring about systemic change.

As a framework for climate change planning and policy ANT also provides insights regarding networks and actors emerging in response to these global environmental challenges.

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[135] Bruno Latour, "On Actor-Network Theory: A Few Clarifications," Soziale Welt, 1996, 369–81.
[136] Jonathan Murdoch, "The Spaces of Actor-Network Theory," *Geoforum* 29, no. 4 (1998): 357–74.
[137] Kaisa Schmidt-Thomé and Lasse Peltonen, "Actors, Networks and Actor-Networks in Coping with Sea-Level Rise," *Special Paper-Geological Survey of Finland* 41 (2006): 51.

Theoreticians working in the area climate change and sea-level rise planning recognize the operational capacities of emergent technologies, inventors, agencies, and policies (i.e. actors) networked in a response to these global challenges. Researcher in this area documents that planning frameworks for sea-level-rise can be advanced through ANT, stating; '"From a planning perspective, power to coordinate actions and collaborate emerges from network connections," going on to say that "Network power is a shared ability of linked agents to alter their environment in ways advantageous to these agents individually and collectively. Network power emerges from communication and collaboration among individuals, public and private agencies, and businesses in a society." [138] From a policy perspective, responses to sea-level-rise can be similarly interpreted through an ANT lens. Theoretical writing in this domain states that policy can be understood as an "assemblage" or a shared understanding of a "collective script" that engages those concerned with the issues of climate action.[139] Emerging from this literature is the sense that broad networks, assemblages, and human/non-human actors (i.e. technology) are engaged in the process of environmental change and the challenges resulting from a warming planet and shifting policy landscape.

Case Study: USACE and the Search

The search for alternative coastal stabilization technologies necessitates the involvement of diverse actors, policies, agencies, and technologies engaged in solving a wicked environmental problem. The mechanisms through which this innovation happens has varied pathways depending on geographical and social context. Importantly, the designation of a technology as "alternative" inherently means it confronts entrenched layers of economics and politics commonly associated with coastal engineering works. This is clearly illustrated by the struggle between inventors /actors and the United States Army Corps (USACE) of Engineers who control the processes and methods of flood control, navigation, and coastal stabilization in the United States. An analysis of distinct cases and technologies reveals individual actors, businesses, agencies, and institutions participate in the process of invention using patented technology in

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[138] David E Booher and Judith E Innes, "Network Power in Collaborative Planning," *Journal of Planning Education and Research* 21, no. 3 (2002): 221–36.
[139] Marfuga Iskandarova, "From the Idea of Scale to the Idea of Agency: An Actor-Network Theory Perspective on Policy Development for Renewable Energy," *Science and Public Policy* 44, no. 4 (2017): 476–85.

response to a changing coastline and when incentivized by policy initiatives, economic incentives, awards, and recognition within broader networks – confronting the entrenched power of the USACE. From ANT perspective we can observe the actor-network struggling to produce a standardized process by which they enact change, and an entrenched power system struggling to innovate. Within this system patents play a unique role as intermediary between actors, network, and environment.

The central role of the USACE in flood control, coastal stabilization, and navigation originates with court rulings made during Ogden v. Gibbons in 1824, which granted the federal government the power to regulate interstate commerce and therefore the control of navigable waterways. Ultimately, Ogden v. Gibbons paved the way for the Rivers and Harbors Acts of 1899 which prohibits the obstruction or alteration of navigable waters of the United States without a permit from the Corps of Engineers, this included construction of wharves, jetties, weirs, bulkheads, and other structures. A consecutive series of Flood Control Acts further expanded the scope of the USACE, leading to innumerable projects along US coastlines and rivers designed, permitted, and built by the Army Corps of Engineers.[140] The rise of the USACE monopoly on waterways was not without conflict as it threatened the power of private engineers, inventors, and entrepreneurs and called into question the role of the federal government in the development of internal improvements.

Some early American engineers challenged the rising power of the USACE with a range of tactics, including petitions to other branches of government to approve novel works, innovative patents for new technologies, and creation of new funding schemes to advance new forms of infrastructure. One of the most famous examples of this ongoing struggle occurred at the Mississippi River's South Pass in the Gulf of Mexico, where the self-taught engineer James Buchannan Eads proposed to build jetties using and innovative construction technique believed to be more efficient than those proposed by government engineers. In 1874, Eads petitioned the US Congress with a plan, and patented technology, to construct parallel jetties at South Pass using a novel construction technique to maintain navigable channels, confronting an established

[140] "U.S. Army Corps of Engineers Headquarters > About > History > Brief History of the Corps > Improving Transportation," accessed May 23, 2023, https://www.usace.army.mil/About/History/Brief-History-of-the-Corps/Improving-Transportation/.

army engineers plan already in development.[141] The patented system involved the fabrication of a floating jetty that would be positioned, anchored, and eventually encased in sediment to define channel geometry.[142] While Eads' jetty system was entirely untested in North America at the time, it promised to be cheaper and more efficient than competing plans from the Army Corps of Engineers. The government agreed to a fee structure based on the annual performance of his prototypes, with the initial cost of construction covered by Eads and his partners.[143]

The process of prototyping Eads' patented jetties began in 1875 and lasted until 1879. It proved that his jetties could maintain navigable depths and earned Eads' millions of dollars and worldwide recognition for saving the port of New Orleans.[144] The competition between Eads and the USACE also led to the creation of the Mississippi River Commission in 1879, which intended to balance power between private and federal engineers. Importantly, the 1879 law that established the Mississippi River Commission is still in effect. It calls for its membership to consist of three U.S. Army Corps of Engineers officers, one member of the National Oceanic and Atmospheric Administration (formerly the Coast and Geodetic Survey), and three civilians, two of whom must be civil engineers, therefore balancing perspectives on the future of the river's delta.

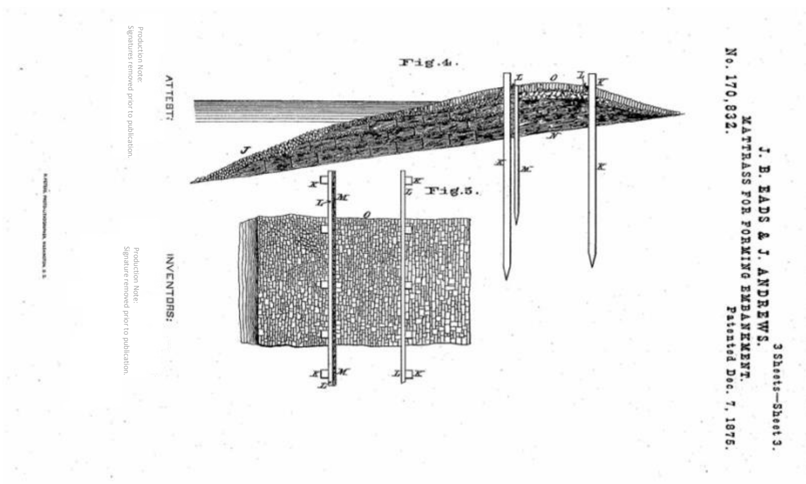

Figure 8: Patent By James B. Eads. Used to petition congress as part of his plan to "improve" the mouth of the Mississippi River US170832. 1875. (Source: European Patent Office, https://www.epo.org/en)

Among the private engineering community, Eads' victories also established a short-lived precedent for challenging the monopoly of government engineers and agencies under the

[141] James Buchanan Eads, Joseph Meredith Toner Collection (Library of Congress), and YA Pamphlet Collection (Library of Congress), *Mouth of the Mississippi. Jetty System Explained*. (St. Louis: Times Print, 1874).

[142] James Buchanan Eads, Mattrass for forming Embankments, US170832, issued December 7, 1875

[143] James Buchanan Eads and Estill McHenry, Addresses and Papers of James B. Eads, Together with a Biographical Sketch. (St. Louis: Slawson & Co., printers, 1884).

[144] Brett Hansen, "Removing The Mississippi's Mud Lump: The Eads South Pass Navigation Works," *Civil Engineering Magazine Archive* 78, no. 10 (2008): 36–39.

principle "No Cure, No Pay," which declared that new technologies should be tested and evaluated with limited risk to the government.[145] Heralded, at the time, as way to break the "monopoly in the hands Army Engineer Corps."[146] Eads' patent was integral to development of his plan for the Mississippi, essentially leveraging intellectual property to validate the novelty of his plan and fight against the monopoly of the USACE.

USACE and The Ongoing Search

The search for alternative coastal technologies, such as those proposed by Eads, continues. Although lacking in the narrative gravitas, we can observe the role of new actors and networks engaged in the process of coastal stabilization and attempts to develop alternatives. The five specific cases below illustrate the networks and actors that coalesce around patent technologies and explore how they come into being through unique geographical contingencies and assemblages – confronting the entrenched power of the USACE. Specific cases included the advent of the "Wave Robber" by Webster Pierce, the" Reaction Breakwater" by Lewis M. Haupt, the "Holmberg System" by Dick Holmberg, Beach Cones System, and Seascape Artificial Seaweeds. Each of which reveal the trappings and promises of the search for alternative coastal stabilization systems and the networks, actors, and implication for stabilization of the coast.

Today the USACE has manages these relationships with inventors and collaborators through a series of structured partnership mechanisms that allow for the innovative technologies to be shared between partners – including Patent License Agreement (PLA) that provides a legal agreement that grants a license to use or practice an invention. The Engineering Research and Development Center (ERDC) Office facilitates opportunities to share and collaborate on research and technology commercialization. The ERDC technology transfer office assesses the commercial potential technologies developed by the USACE, pursues patent, trademarks, or other intellectual protection for technologies deemed commercially viable. Through this mechanism novel technologies are evaluated, tested, permitted, and sometimes integrated into USACE practices.

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[145] James J Scott, "A Passion for the Remarkable," *Constr. Law*. 21 (2001): 46; William Clemens Hueckel, "Methods of Improving the Mississippi River," 1908; Walter M Lowrey, "The Engineers and the Mississippi," Louisiana History, 1964, 233–55.
[146] George Wisner, "American Harbor Engineering," *Scientific American Supplement*, no. 815 (1891).

Reaction Breakwater

The "reaction breakwater" was invented by Lewis M. Haupt in 1901 as a novel method for coastal stabilization and maintenance of navigable channels through the utilization of natural currents, scouring, and sedimentation. Haupt patented his invention and disseminated news of his discovery in lectures to institutes and universities, popular media, and through peer reviewed publication. He initially intended to follow the "no cure no pay" method pioneered by James Buchannan Eads in the late 19th century in which private inventors/companies would conduct massive environmental works and be paid based on project success. The USACE ultimately awarded the contract for construction of the prototype to another corporate entity, thus thwarting the plan.

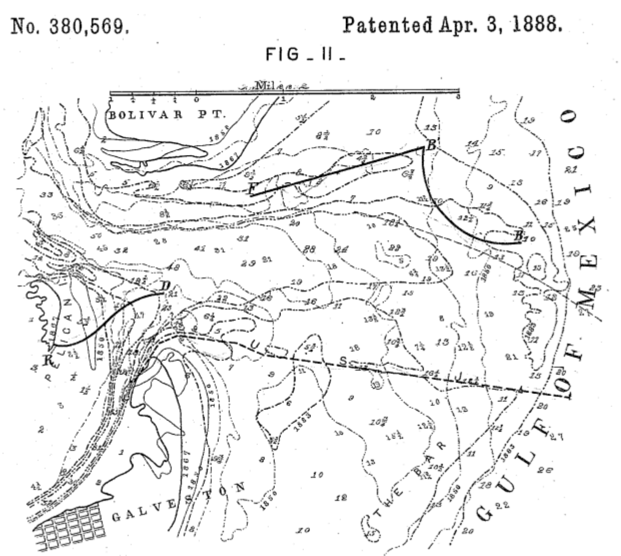

Figure 9: US 380569 "Dike or Breakwater" sited in Galveston Texas, 1888. (Source: European Patent Office, https://www.epo.org/en)

Lewis M. Haupt was considered, by some, to be the natural successor to the legacy of James Buchanan Eads, as the eminent American hydrologic engineer.[147] During his lifetime he worked as a topographical engineer for Fairmont Park, a patent examiner at the USPTO, a Professor of Civil Engineering at the University of Pennsylvania, and consultant to the Nicaraguan canal.[148] Professor Haupt's theories of hydrologic engineering earned him a Magellanic Premium Award from the American Philosophical Society in 1887 for the 'Reaction Breakwater', a self-dredging breakwater system, and legal rights being granted for a "Dike or Breakwater" (US

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[147] L M Williamson, *Prominent and Progressive Pennsylvanians of the Nineteenth Century: A Review of Their Careers, Prominent and Progressive Pennsylvanians of the Nineteenth Century* (Record Publishing Company, 1898).

[148] Leland M Williamson et al., Prominent and Progressive Pennsylvanians of the Nineteenth Century. (Philadelphia: Record Pub. Co., 1898).

380,569) which applied principles described in his research.[149]

News of the reaction breakwater reached a wide audience through a multipage article in *Scientific American*, which aimed to garner popular support for the system.[150] Pursuant to the patent and plan, a functional prototype was to be constructed and tested at Aransas Pass, Texas, by the Reaction Breakwater Company in collaboration with the USACE, although contracts were ultimately awarded to local contractors. Haupt's creative invention seemingly bothered the US Government's War Department and USACE, who's official reports claim that the patent and research was "' purely theoretical, are unconfirmed by experience, and contain nothing not already well known, and which has a useful application in the improvement of our harbors." [151] Whether the intention of the War Departments statement was to stifle innovation, avoid paying patent royalties, or simply to award a contract to other parties may never be known. But, after a series of failed plans and contracts for a breakwater at the Aransas Pass, Lewis Haupt's curved reaction breakwater was partially constructed, proving its efficacy in maintaining a navigable channel depth within 15 months.[152] The government later paid Haupt, and the success of the partially constructed 'Reaction Breakwater' vindicated Haupt's theoretical claims and prescience of the American Philosophical Societies' Award.

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[149] Lewis M Haupt, Dike or breakwater, US380569, issued April 3, 1888.

[150] Lewis M Haupt, "The Reaction Breakwater as Proposed for the Opening of the Southwest Pass of the Mississipi River," Scientific American: Supplement, August 18, 1900, 20604–6.

[151] Lewis M Haupt, "History of the Reaction Breakwater at Aransas Pass, Texas," Journal of the Franklin Institute 165, no. 2 (1908): 81–97.

[152] *Factory and Industrial Management* (McGraw-Hill publishing Company, Incorporated, 1900).

FIG_III_

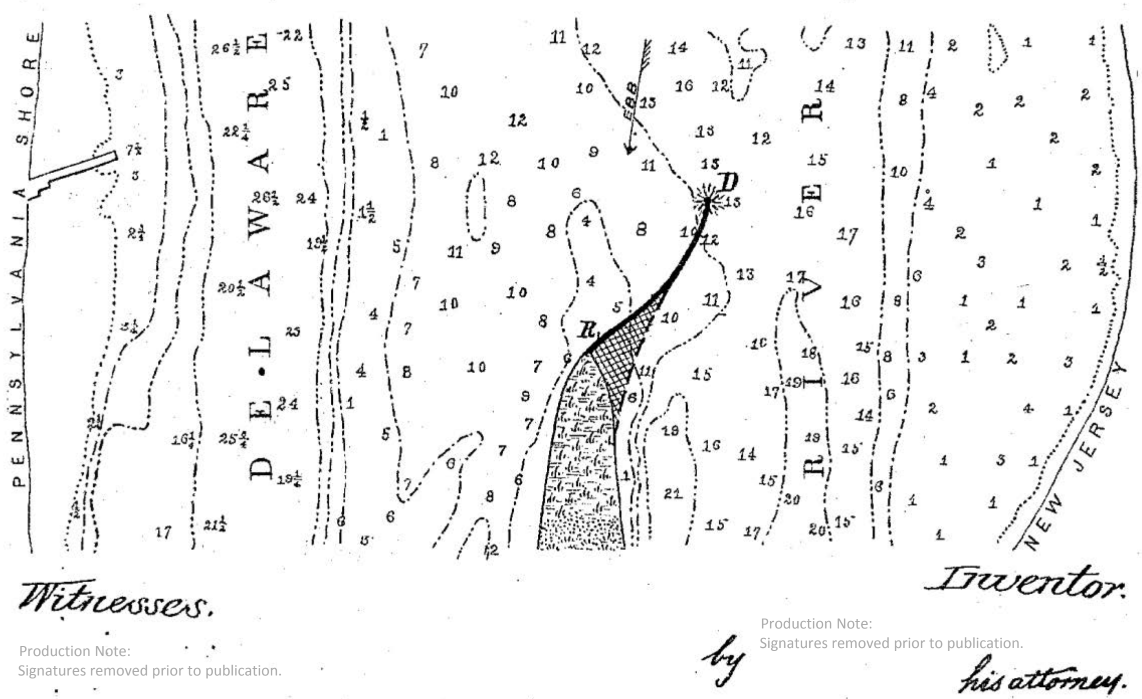

Figure 10: US 380569 "Dike or Breakwater" sited in Delaware within the patent drawings.1888. (Source: European Patent Office, https://www.epo.org/en)

The debacle called into question the War Department's stance on innovation and intellectual property in engineering works. A lawsuit HAUPT v UNITED STATES in 1920 reveals the details of the arrangement and also the process by which the war department attempted to undermine the process by not following the design plan and patent specification. According to the lawsuit, congress made three appropriations for such improvement expressly requiring the work to done in accordance with the plans, and patent, however further appropriations were not made even though the reaction breakwater was successful.[153] The reaction breakwater prototype at Aransas pass was intended, by Haupt, to validate the performance of the system so it could be scaled up and implemented at the Southwest pass of the Mississippi river.

News of plans for jetties at the Southwest Pass of the Mississippi spread, and by 1901 Lewis M. Haupt had adapted his reaction breakwater design to the specific hydrologic and fluvial

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[153] United States. Supreme Court and W P Company, Supreme Court Reporter: U.S. Reports. Cases Argued and Determined in the Supreme Court of the United States (West publishing Company, 1922).

conditions at the Southwest Pass. Haupt's patent (US 687,307) for a "Jetty or Breakwater" was granted November 26th, 1901, and intended to revise and update claims made in his previous patents and improve upon Eads Jetties proposed for use at the Southwest Pass of the Mississippi and in other deltas of sediment laden rivers. Haupt summarizes his invention as such, "In this improvement the purpose is more particularly to apply the energy of the fluvial waters, charged with their own sediment, in such manner as to create, erosion, produced by the concentration and reaction of a permanent opposing medium placed in or near their path and resulting in the deposition of sediment upon the opposite flank of the channel from that upon which the artificial structure is erected." [154] In its simplest form, Haupt's "Jetty or Breakwater" maintains navigable channels through the force of river water and the littoral drift amplified by the curvature of the jetty. These two interacting forces are mediated by geometry of the jetty, and ultimately put to work scouring a channel adjacent to the structure and allowing for the accretion of river sediment on the opposing bank to the constructed jetty.

Haupt's patent is site specific and includes specific details about the conditions of the Southwest Pass. He claims the invention: "is designed to make the jetty the tool through which the potential energy of the natural forces is applied to secure and maintain commercial channels, and the results are inseparably connected not only with the form of the tool, but with the manner of its application. Under these

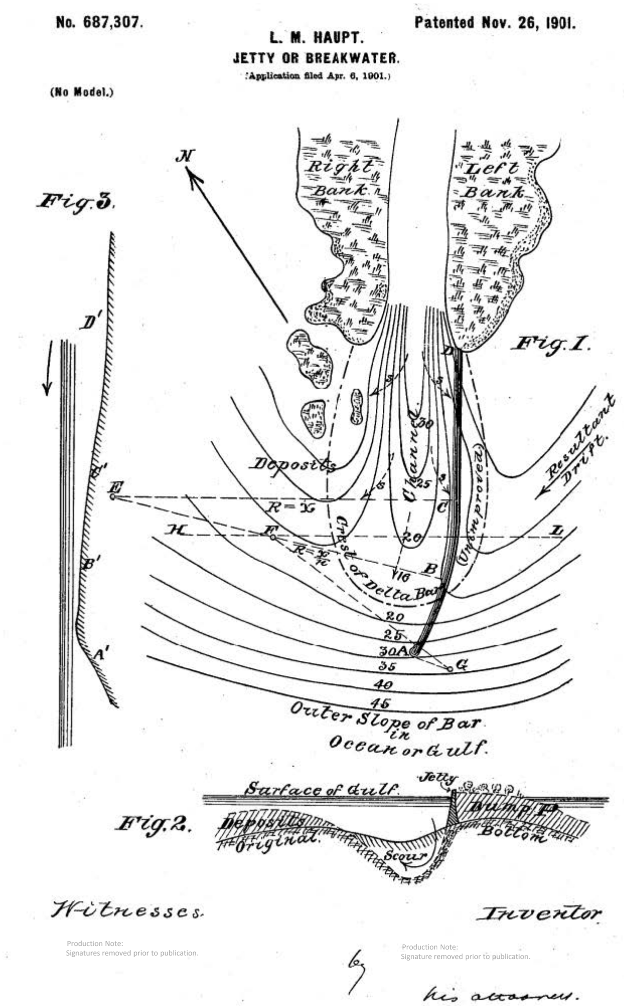

Figure 11: US 687,307) for a "Jetty or Breakwater" sited at the southwest pass of the Mississippi River. 1901. (Source: European Patent Office, https://www.epo.org/en)

154 Lewis Haupt, Jetty or breakwater.,US687307 issued November 26, 1901.

circumstances a drawing would seem to be unnecessary; but to aid in the interpretation of my invention a diagram is submitted based upon the physical conditions existing at the Southwest Pass of the Mississippi River, taken as a type. A study of the regimen of the pass itself, made from the thorough survey and report known as Document No. 142, House of Representatives, Fifty-fifth Congress." Though it remains unclear if the MRC or Army Corps were aware of the patent, a draft act of Congress within Lewis Haupt's archives at the American Philosophical Society indicates that it was considered at the highest levels of government. [155]

WaveRobber

The "WaveRobber" is a patented technology developed by a Cajun inventor, Webster Pierce, with approved plans by the USACE for evaluation. Pierce has been observing subsidence and land loss in southern Louisiana his whole life as a fisherman, providing the inspiration for the invention. Pierce was born and raised in Cut Off, a coastal community in Lafourche Parish, southern Louisiana. His invention, the Waverobber, captures sediment and dissipates wave energy using a slopped surface with ridges and tubular passages that allow suspended sediments to pass through the device. He got the idea from observing accretion of sediments around a discarded Christmas tree, however once the Christmas tree decomposed the sediments washed away – leading Webster to invent a system that would mimic this process. Mr. Pierce set out to develop a more permanent and localized solution, building sediment capture prototypes from parts of washing machines and other scrap material.[156] Although a relative outsider without formal training, Pierce

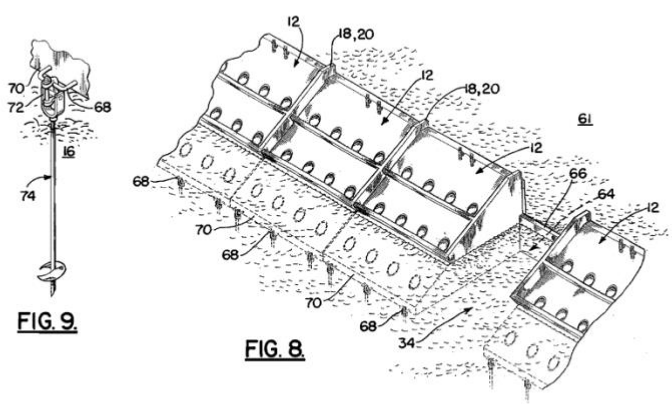

Figure 12: US8226325B1 for "Wave suppressor and sediment collection system" 2009. (Source: European Patent Office, https://www.epo.org/en)

[155] Lewis M Haupt, "Scientific American: Supplement" (Munn and Company, 1900).
[156] "This 72-Year-Old Used A Washing Machine Motor To Build 'Wave Robber,'" accessed June 7, 2023, https://www.fastcompany.com/3013539/this-72-year-old-used-a-washing-machine-motor-to-build-wave-robber-save-the-s.

advanced his idea through prototyping, patents, awards, design competitions, university research, and statewide initiatives in supporting novel approaches. The coast of Louisiana changed drastically during his lifetime, having lost thousands of acres to subsidence.

In 2009 Pierce submitted a patent US8226325B1 for “Wave suppressor and sediment collection system” and since its invention it has been through university trials, received innovation awards, passed field trials, and reached evaluation stage by the USACE.[157] In 2013, at the age of 71 he won the Greater New Orleans Foundation Water Challenge on Monday for his Wave Robber, a device he designed, prototyped, and tested, to help reverse land loss in southern Louisiana. The invention of the waverobber reveals the intimate relationship between geography, prototyping, and local knowledge in the search for alternative technologies. It also displays the important pathways for innovation that support and validate “outsider” knowledge.

The waverobber has taken a unique path through institutions, competitions, and the legal system. Pierce initiated a collaborative research project with Dr. Daniel Gang, and a University of Louisiana at Lafayette research team. Evaluation of the device was conducted using testing it in the laboratory and in the field. The collaboration was facilitated by Scott LeBlanc, a graduate student in civil engineering, who was responsible for maintaining the testing sites and collecting and analyzing data. Hydrodynamic modeling involved the creation of the three scale models in a 1,000-gallon tank. A paddle, driven by a pulley and motor, creates waves, pushing water and sand toward the test units. Weirs, placed between the devices, allow the water to flow back toward the wave generator. The Wave Robber Wave Suppressor Sediment Collection System meets project evaluation requirements, and a plan is being developed with a budget of $967,113 through the USACE to "Evaluate the effectiveness of the Wave Robber system as an alternative method of shoreline protection equivalent to traditional methods, while trapping ambient sediment"[158] During this process the intellectual property was also further revised with additional patents granted for similar technical systems based the initial invention.

[157] Jr Webster Pierce, Wave suppressor and sediment collection system, US8226325B1, filed October 9, 2009, and issued July 24, 2012.
[158] https://www.mvn.usace.army.mil/Portals/56/docs/environmental/cwppra/PPL/PPL%2031/PPL%2031%20Demo&CW.pdf

Seascape Artificial Seaweed

The early development of artificial seaweed for erosion control purposes has been reported to have started around 1962, either in Denmark or England, with the first field installation on the Danish shoreline near the North Sea in 1963. Across the Atlantic the idea of soft, seaweed-like structures, to capture sediment and mitigate erosion gained relevancy in the 1980's as alternatives to seawalls were being considered in North Carolina at the at Cape Hatteras lighthouse through a pilot project between the Seascape Manufacturer and the USACE. The lighthouse was threatened by beach erosion and heritage site and proposal were submitted for economical "soft" solutions not requiring the use of rigid coastal defense structures. Rules banning the use of hard structures in the state (see above) necessitated the search for alternatives and bids for the project were submitted to the State of North Carolina and the USACE for evaluation. During this process William Garrett advanced a proposal for "seascape" artificial seaweed and the project gained traction.

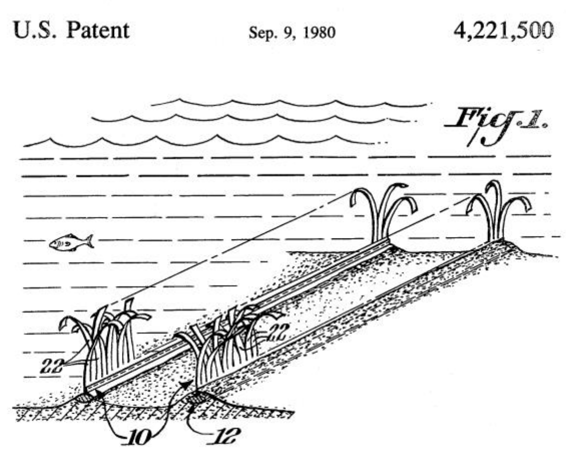

Figure 13: Figure 13: Patent US4221500 "Synthetic seaweed" (1980) for use in inhibiting coastal erosion. (Source: European Patent Office, https://www.epo.org/en)

Seascape Artificial seaweeds were invented and patented in the in the United States in 1980's with the aim of using flexible materials to mimic the role of benthic seaweeds in accretion of sediments and beach stabilization. Innovation in material technologies played a central role in the invention of artificial seaweeds. The specific seascape units were made of Dupont's Typar spun-bound filter fabric, a nonwoven polypropylene fabric, felt-like in appearance, intended for use primarily as a gravel underlayer in road construction and as carpet backing. [159] Each of the units include a fabric anchor that is filled with 50 to 100 pounds of sand or gravel. The anchor holds the Polypropylene fiber which is then

[159] Spencer M Rogers, "Artificial Seaweed for Shoreline Erosion Control," 1986.

attached to a foam pad for added flotation. This structural configuration is consistent with synthetic seaweed patents granted to William Garrett in 1980 (US4221500) and 1984 (US4478533) respectively (figure 13).[160]

Seascape manufacturer reports that it acts as an underwater sand fence trapping suspended sand to form an offshore sand bar or reef. News of the invention was included in the New York times section on "patents", which was included in the newspaper at the time. The advertisement states the invention aims to "inhibit coastal erosion by reducing ocean currents and promoting the collection of sand and other sedimentation…. In a telephone interview, Mr. Garrett said he had made 15 Seascape installations around the country, all but one on shores of the Atlantic."[161] Evaluation of the seascape system was conducted for the Cape Hatteras Seashore National Park Service by the US Army Engineer District, Wilmington (SAW). Field data collection activities were performed by the US Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center (CERC) Field Research Facility (FRF) in Duck, North Carolina.

A comprehensive report evaluating the system was published by the USACE in 1986. [162] The trials began in 1982 with design and installation phases, and monitoring from 1982-1984, though results were not satisfactory to continue installation into the future as the system showed evidence of mitigating erosion but eventually ripped to pieces, scattering fragments along the shoreline. The report also seemed to indicate that accretion was possibly due to other forces, stating; "Although considerable accretion occurred during the monitoring period, the accumulation was the result of a general buildup of the beach which averaged 25 ft over the 6 .1-mile study area. There was no conclusive evidence to link the buildup to the 5,000 ft of SEASCAPE® which was deployed in October and November 1982. Moreover it was not possible to attribute burial of the SEASCAPE® to the action of the artificial seaweed versus burial by normal wave-driven migration of sand." Given the ultimate demise of the Seascape modules the final USACE report was unlikely to come back with a favorable evaluation. Although mired by

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160 William L. Garrett, Synthetic seaweed, US4221500A, filed January 26, 1979, and issued September 9, 1980.
161 Stacy V. Jones, "PATENTS; Synthetic Seaweed' Inhibits Coastal Erosion," The New York Times, October 27, 1984, sec. Business, https://www.nytimes.com/1984/10/27/business/patents-synthetic-seaweed-inhibits-coastal-erosion.html.
162 James William Forman, "Generalized Monitoring of'SEASCAPE'Installation at Cape Hatteras Lighthouse, North Carolina," 1986.

failure we can learn from the Seascape Artificial Seaweed process as it reveals the layered networks and actors involved in testing novel environmental material systems and the role of corporate innovation in advancing coastal works.

The Holmberg System

The Holmberg System for shoreline stabilization was invented and patented in the 1980's as a novel system for capturing sediment and building beaches using local sediment to fill geotextile structures. The systems US4889446A "Erosion control foundation mat and method" was granted in 1986, covering a novel erosion control structure made of a large permeable mat with peripheral weighted pockets that anchor the mats on the bottom of the body of water. In essence the system uses geotextiles to build Goins and jetty's with locally available materials, thus reducing construction costs.[163] (figure 14) The inventor, Dick Holmberg, has a contentious history with the USACE as he has worked with private landowners to reverse erosion coastal erosion on private properties – operating as a sort of evangelical and entrepreneurial erosion consultant. The Holmberg System was often scrutinized by state and federal engineers even though private landowners often believed the track record and future promises of the novel system based on claims of the inventor.

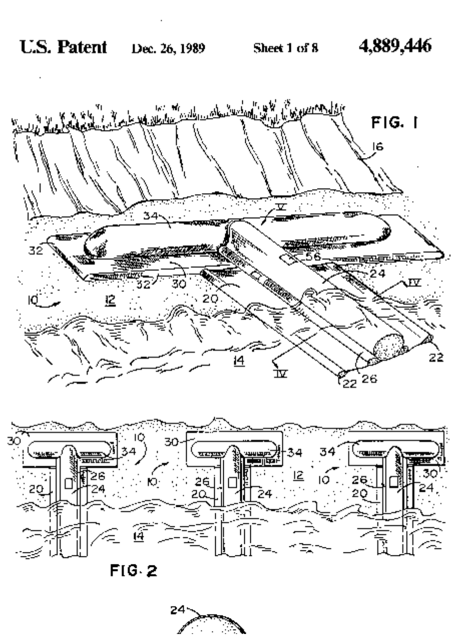

Figure 14: US4889446A "Erosion control foundation mat and method" (1989) known as the Holmberg System. (Source: European Patent Office, https://www.epo.org/en)

Coastal erosion naturally cross jurisdictional boundaries, impacting private, state, and federal lands alike, therefore making private interests are important to consider. Mr. Holmberg positioned himself, and his novel erosion control system at this juncture, providing solutions for private landowners while confronting coastal

[163] Dick L. Holmberg, Erosion control foundation mat and method, US4889446A, filed December 22, 1986, and issued December 26, 1989.

policies and the USACE who maintains oversight of navigable waterways - even on private property. As Mr. Holmberg states of the problem;

"All countries with shoreline erosion need to review their present policies and make administrative changes to encourage such innovation via large-scale planning and objectively monitored demonstration projects. Those who dictate policies of retreating from our coasts and express such views as letting nature take its course are wrong. Nature is not the enemy and abandoning the seashore should never be considered as an option. In the United States and some other countries, streamlining permit procedures and a review of jurisdictional overlap is advocated to ensure a timely response to solving the current crisis."[164]

Working to address these concerns the Holmberg's system was invented to mitigate scour and block beach migration, and the business model was designed to facilitate private landowners' dreams of stopping or reversing coastal erosion – positing environmental policy versus landowners' rights. A local newspaper in Flagler beach, where Holmberg Was proposing to work, analyzed the situation, citing 58 instances where Dick was in the news for attempts to pursue contracts. With regards to his relationship with the USACE the newspaper concludes that "Holmberg does not have a good track record with the federal agency, his recurrent bête noire over the years. Holmberg has long claimed that the corps has a vested interest in dredging, which is why it opposes Holmberg's own, allegedly simpler, less expensive, and more effective alternative."[165]

Through a series of pilot projects Holmberg developed loosely corroborated evidence of his systems efficacy, which in conjunction with the patent and corporate marketing encouraging private landowners to commission Holmberg's system and advance the projects through permitting stage. Mr. Holmberg's focus on private property and issues of coastal retreat makes his activities and technology contentious, raising concerns among some community members while also challenging permitting and review processes of the US Army corps of Engineers. A Los Angeles times article offers this perspective. "To some waterfront property owners on the Great Lakes, Dick Holmberg is a savior of shorelines. To some government officials, he is a nuisance

[164] Dick Holmberg, "Alternative to Traditional Ways of Treating Shoreline Erosion," ed. Constantine Goudas et al., *Soft Shore Protection: An Environmental Innovation in Coastal Engineering* (Dordrecht: Springer Netherlands, 2003), https://doi.org/10.1007/978-94-010-0135-9_15.
[165] FlaglerLive, "Flagler County's Holmberg Problem: Beach Erosion Guru Dredges Up Skepticism," FlaglerLive (blog), July 31, 2012, https://flaglerlive.com/42032/dick-holmberg-technologies/.

making a lot of money at the expense of desperate homeowners willing to try his method of preventing beach erosion."[166] Irrespective of the controversy, a series of videos on the Dick Holmberg Youtube.com channel document a legacy of successful projects the United States and Saudi Arabia, with in depth explanations of the theory behind the invention and the controversies resulting from his challenges to the USACE and dredging industry.[167]

Beach Cone

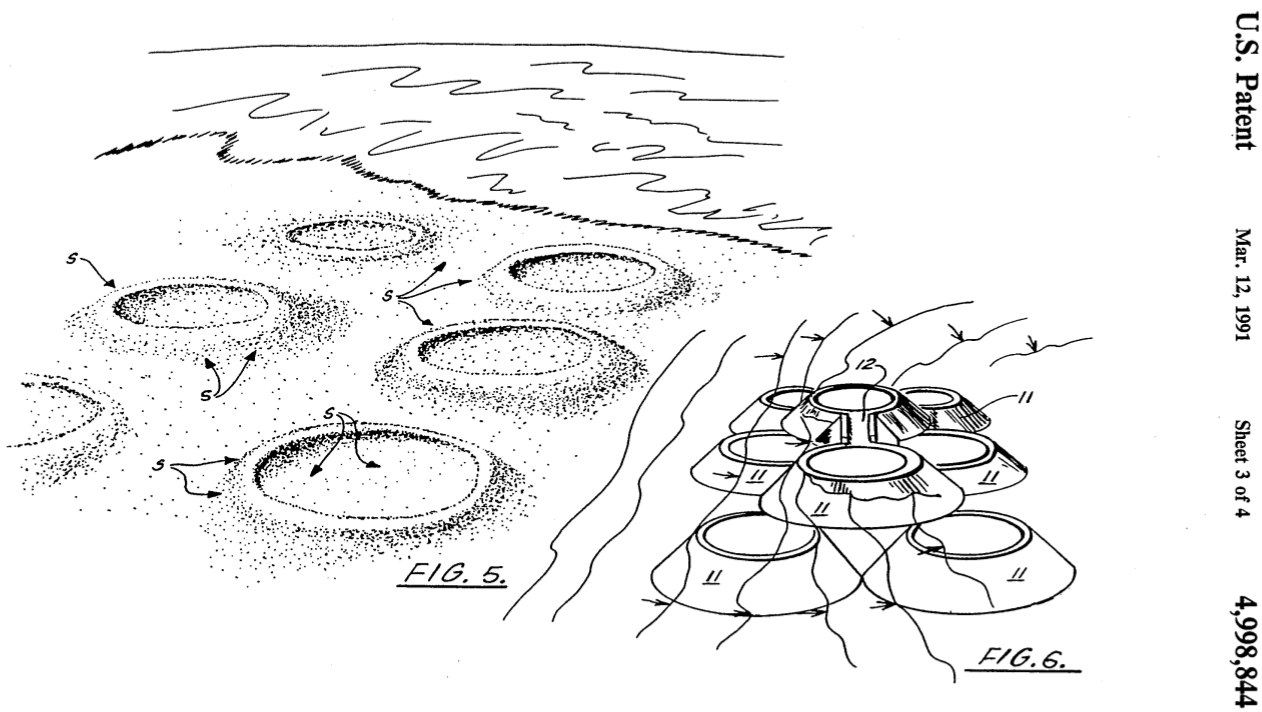

Figure 15: Patent US4998844 "Wave actuated coastal erosion reversal system for shorelines" (1990) utilized in coastal stabilization in southern Lousiana. (Source: European Patent Office, https://www.epo.org/en)

The Beach cone was invented in the 1990's as a structural technique for increasing sedimentation in deltaic and coastal landscapes. Field studies of beach cones were initiated in collaboration with the USACE in areas of significant oil and gas activities to evaluate if the system could ameliorate harmful impact to coastal systems. The goal of the project was to test and evaluate the effectiveness of the "beach cone" with regard to arresting erosion and possibly reversing the process by accreting sediments on areas of oil drilling. Beach cones were invented

[166] Facebook et al., "Beach Erosion Engineer Called a Godsend, Fake," Los Angeles Times, September 10, 1989, https://www.latimes.com/archives/la-xpm-1989-09-10-mn-2578-story.html.
[167] Saving Beaches and Dunes - Holmberg, 2010, https://www.youtube.com/watch?v=wA7D8UERl6A; Beach Erosion, Saudi Arabia Holmberg, 2010, https://www.youtube.com/watch?v=2ZDujtRH9cI.

by William J. Mouton, Robert Grush, and Dolores B. Alton as indicated in U.S. Patent Number 4,998,844 March 12, 1991. The patented system, and technical specifications are featured in a USACE report on the project.[168]

Among the inventors, William Mouton (1931-2001) has the most biographical information available. Mourton was internationally recognized as a pioneer in the design of long-span steel space-frame structures and tubular systems for high-rises, as well as modular prestressed concrete buildings and domes - working for his career as a professor at Tulane University. His biography by the New York Times lists among his accomplishments, work with the USACE on flood control and development of foundation systems for building in New Orleans. The Structural engineering summit website states "He held more than 20 patents, including erosion control concepts for Louisiana's wetlands, regeneration systems for rebuilding sand beaches, a unique mono-track system for high-speed mass transit, and a counter-rotating combustion engine."[169] In the specific case of Beach Cones, it appears Mouton learned from Eads, self-publishing a book "Beach cones : the wave-actuated coastal erosion reversal system" outlining the proposed method, patenting the system, and entering into a licensing agreement with the USACE after the system was trialed.

The evaluation process was initiated in 1992 under specifications of the patent. A subcontract to Xavier University to assess the ecological quality of the experimental sites involved the study of the biogeochemical cycle of trace metals. A subcontract to Louisiana State University concentrated on historical sedimentation rates at the experimental sites and the accretion rates after beach cone placement. The pilot project assessed the impact of 600 beach cones and associated wave blocks in areas where coastal erosion has been a serious problem and to assess the utility of these devices in combating the problem of coastal erosion. Seven potential sites were selected, and cones were installed at six of these sites. This included sites with varied typologies, including eroded marsh area between two bays, the shoreline of a bayou, the shoreline of a bay, the entrance to a pipeline canal, a second eroded marsh between two

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[168] William J. Mouton, Robert Grush, and Dolores B. Alton, Wave actuated coastal erosion reversal system for shorelines, US4998844A, filed January 30, 1990, and issued March 12, 1991.

[169] "William J. Mouton, 70, Engineer and Professor - The New York Times," accessed June 7, 2023, https://www.nytimes.com/2001/07/08/us/william-j-mouton-70-engineer-and-professor.html.

bays, and an eroded shoreline of a barrier island. While accretion at some sites was substantial it was not sufficient to support new marsh biota, which was an established benchmark of success established prior to the project. Of particular interest was the sediment transport in polluted areas, as the system could have potentially mitigated transport of contaminated material near pipelines and extraction wells.

Discussion: Patent intermediaries and the search for alternatives

The heterogenous networks engaged in coastal stabilization works often confront entrenched, or more established networks and actors, and may be considered integral to engagement of innovative technologies, inventors, and agencies in complex environmental works. Patents are central to this process as they provide a legal mechanism for the transfer of technology and serve as an intermediary through which to communicate the nature of an invention operating between actor, network, artifact, and action. Theorists of ANT state that "intermediaries play a fundamental role and intermediary is anything that circulates between actors and helps define the relation between them."[170] This includes materials such as drawings, texts, reports, scientific articles, laws and regulations, software, contracts, etc. "standing for" and "acting on behalf of" the actor and serve to build network communicate. As is observed in other sectors of technology the patent serves to protects the intellectual property of inventors. Within the specific cases of alternative coastal stabilization technology, the patent appears to contribute to the coalescing of new networks focused on specific environmental works and enabling them to address more entrenched power structures – even in situations where the patented technology was developed by relative outsiders to engineering communities.

Current research on ANT and climate change suggests that a recasting of environment as 'network', or complex policy initiatives as 'assemblage' enables new climate actors, and leaders, to emerge.[171] These new approaches to issues of a changing climate have the potential to collapse boundaries between human and non-human actors (i.e. technology), flatten hierarchies within and between networks, and address issues of scale and complexity inherent in planetary

[170] Silvia Gherardi and Davide Nicolini, "Actor-Networks: Ecology and Entrepreneurs," n.d.
[171] Michele Acuto, "The New Climate Leaders?," *Review of International Studies* 39, no. 4 (2013): 835–57.

management. In the context of technological innovation for coastal stabilization it is particularly salient as innovation networks, approach problems of a changing coastline at global scales and form new assemblages with policy and environment. Within these emerging networks patent documents and/or other forms of intellectual property have the potential to operate as intermediary, building networks and engaging diverse actors in environmental change. These networks link individual inventors, corporate research entities, environmental regulations, testing and evaluation of new technologies and materials, government engineers, environmental managers, and coastal communities, etc., to the advent of an innovative environmental technology.

In the specific case of coastal stabilization, and the search for alternatives, we can observe the unique contribution of patents to attempts at network change. A diverse ground of inventors and their technological alternatives (i.e. actors) confront the conventional techniques for shoreline stabilization such as rigid seawalls, massive breakwaters, and other structures, along with the power structure of entities such as the United States Army Corps of Engineers USACE. Catalyst for this change is observations that the environmental impacts of rigid and fixed inherently impact processes such as long-shore drift, exacerbate scouring, alter groundwater exchange, and otherwise contradict important coastal processes. In the attempt to enact change a range of new technologies have been invented including, artificial seaweeds, flexible breakwaters, bionic dunes, sediment capture devices, etc. These “alternative” techniques expand the repertoire of coastal stabilization. Irrespective of the patchy record, alternative technologies continue to be invented, piloted, and implemented through collaborative ventures with universities, grant support by agencies, stabilization projects on private lands, and government programs, leading to a patchwork of alternative solutions and big promises. There are also important geographical contingencies in the search for alternative bridged by an ANT perspective, thus flattening hierarchies and reducing issues of scale implicit in coastal works.

3. Corporate Ecologies: the pitfalls and promises of industrialized artificial reef technology

Corporate research and development play an important role in the realization of artificial reefs, linking industry to large-scale environmental processes and the ecological engineering of marine systems. Countries around the world, including the United States, Japan, Australia, and others throughout Europe, South America, and Asia have coordinated artificial reef programs to improve marine fisheries – with thousands of hectares and millions of individual reef units currently in operation. The legal, scientific, and economic dimensions of artificial reefs are well documented in scholarly literature, chronicling how countries such as Japan, the United States, and China, have invested billions to research, develop, and implement innovative reef technology in support of fishing industries. One of the lesser-known aspects of the global artificial reef phenomenon is the relationship of artificial reef programs to technological innovation and the patent system. This is surprising, as artificial reefs are a unique sector of environmental technology represented by a dedicated patent class of the Cooperative Patent Classification (CPC) scheme and the newly established Y02A. Technologies covered by these classifications are integral to an ever-growing list of real-world projects, impacting large-scale ecological and biological systems. In the evolution of these social-ecological-technical systems we can observe the role of the patent system in establishing new environmental sectors and managing sequential innovation in marine and biological systems.

Collectively artificial reefs have altered marine ecology, catalyzed investment, and incentivized technological innovation revealing how policy directives and technical specifications can lead to the creation of artificial ecological systems on a global scale. The relationship between policy, industry partners, and innovation is important to consider as history reveals potential benefits, and risks, of corporate involvement in large scale environmental planning. Three individual case studies are analyzed here, including the ENSEI program in Japan, an American program to utilize waste automobile tires, and a recent global effort to build artificial reefs using iron slag concretes. In the case of Japanese ENSEI we observe the founding of a wholistic system for marine innovation, replete with social programs for fisherman and engaged industry partners to build and deploy reefs. The U.S. case varies, having its origins complicated by corporate interest of the automobile industry, and efforts to transfer of Japanese technology to fill a knowledge gap due to lags in research and shortage of industrial partners. The final, most recent case explores the recent development of "green" reefs using iron slag which exhibit similar patterns of corporate interest but under the guise of global sustainability. In each we see the role of corporate interests, and patented technologies, in defining new sectors of innovation with large-scale environmental impacts.

An Overview of Artificial Reef Programs – an industrial ecological complex

Artificial reefs have been created in oceans, seas, lakes, and rivers around the world for centuries with the ambition of increasing fish yields, altering species distribution, and altering the ecology of the ocean at grand scales. In general, artificial reefs refer to human-made structures installed in aquatic habitats that serve as a substrate and/or shelter for organisms. In many cases these structures aim to improve the productivity of fishing grounds for commercial fishing, but many examples exist of artificial reefs installed for recreational fishing and diving. [172] Artificial reef structures vary in origin. Some are installed as 'primary reefs' that are purpose built for marine fisheries enhancement, others are referred to as 'secondary reefs' that have been created by repurposing structures such as oil platforms and shipwrecks that are adapted to serves as reefs – this relates primarily to the origin of the reef structure and method of installation. Collectively these structures and material interventions in the marine environment represent a global effort to alter the productivity of fishing grounds with enormous ecological, social, and environmental impacts.

Historically, the use of artificial reefs can be traced back to the Mediterranean Sea more than 3000 years ago where Sicilian fisherman cast ballast stones, known as 'tonnare', from ships to create artificial reefs. Over time the 'tonnare' accumulated into artificial rocky habitats that attracted benthic fish and seaweeds – therefore increasing fish catches in those areas. Reportedly this practice was so productive that the material needed for rubble reefs contributed,

[172] Craig Blount et al., "Using Ecological Evidence to Refine Approaches to Deploying Offshore Artificial Reefs for Recreational Fisheries," *Bulletin of Marine Science* 97, no. 4 (2021): 665–98.

in part, to the submergence of the ruins of ancient Greek temples. [173] This type of unplanned, or ad hoc, practice of augmenting fishing grounds was not discrete to Europe. Japanese fisherman observed for centuries that artificial structures increased yield, and as far back as 1640's fisherman created reefs of old ships, rocks, and bamboo structures to increase fish yields in artificial fishing grounds.[174] Stories of these early artificial reefs are now woven into lore, with historians describing accounts "a warrior who had made a fishing ground at sea using stones from a mountain in Kochi Prefecture" in the mid 17th century.[175]

Today is widely accepted that the art and science of 'modern' artificial reef technology emerged and advanced most rapidly in Japan. Reportedly, the first documented purpose-built and primary artificial reefs were deployed in Japan in 1952 as part of 5-year government sponsored plan to improve commercial fishing. Although development of purpose-built reef technology is relatively new, Japanese investment in the reef sector dates to the 1930's when the government provided financial subsidies to augment fishing grounds. Since the 1930's government investment continued, expanded considerably over the decades through consecutive planning projects and coordinated investments in artificial reefs (see an extended discussion later in the Chapter). The impact of these investments on Japanese fishing and society cannot be understated. By 1989 an estimated 9% of the potential area to the coastal shelf had been developed into new fishing grounds through artificial reefs construction. And, by the early 2000's Japanese purpose-built reefs had been installed at roughly 20,000 sites within territorial waters.[176] In hindsight, the Japanese modernization of marine policy, innovation, and investment essentially created a new sector, eventually resulting in the transfer of intellectual property to the United States to support the establishment of similar programs.

In the United States an analogous history is also reported. The first artificial reefs built in the US occur in the 1880s, when anglers on the Atlantic Coast used "long huts sunken off the coast of South Carolina as a fishing reefs." [177] Contemporary reports also cite sunken vessels

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[173] Silvano Riggio, Fabio Badalamenti, and Giovanni D'Anna, "Artificial Reefs in Sicily: An Overview," *Artificial Reefs in European Seas*, 2000, 65–73.
[174] Yasushi Ito, "Artificial Reef Function in Fishing Grounds off Japan," *Artificial Reefs in Fisheries Management*, 2011, 239–64.
[175] Y Ogawa, "Artificial Reef and Fish," Propagation of Fisheries, Special, no. 7 (1968).in
[176] Lachlan AW Ramm et al., "Artificial Reefs in the Anthropocene: A Review of Geographical and Historical Trends in Their Design, Purpose, and Monitoring," *Bulletin of Marine Science* 97, no. 4 (2021): 699–728.
[177] RB Stone, RS Grove, and CJ Sonu, "Artificia] Habitat Technology in the United States. Today and Tomorrow," 1991, 11–13.

being used for recreational fishing in the 1930's off the coast of New Jersey, and purpose built Artificial Reefs being constructed of scrap car bodies in the Gulf of Mexico off the coast of Alabama in 1953.[178] The pacific coast also piloted artificial reefs in the 1950's. In 1958, the California Department of Fish and Game started a preliminary study monitoring artificial reefs made of car bodies dumped off the coast of Southern California. This pilot project is well documented in subsequent monitoring report, published in 1963, confirming the positive increase in fish and fauna diversity and quantities.[179]

Figure 16: Biologist-divers Charles H. Turner (left) and John G. Carlisle, Jr. take photos and record data on newly installed artificial reef. Photograph by Gene Daniels, 1958 (Copyright University of California)

As artificial reefs gained popularity through an influx of knowledge from Japan a comprehensive National Artificial Reef plan was published in 1985 and a distinct patent class of the United States Patent Classification was created circa 1983 (see an extended discussion later in the Chapter). Attempts to modernize artificial reef technology in the United States took a very different path than those in Japan. The earliest modern reefs in the US utilizing automobile tires led to catastrophic failures, and as the National Artificial Reef plan launched, a lag in technological capacity necessitated the transfer of technologies from Japan to fill gaps in primary research and manufacturing.

Of course, the development of modern manufactured artificial reefs is not limited to Japan and the United States. Countries and regions around the world have a long history of

[178] R Fikes, "Artificial Reefs of the Gulf of Mexico: A Review of Gulf State Programs & Key Considerations," National Wildlife Federation, 2013, 22.
[179] John G Carlisle Jr, Charles H Turner, and Earl E Ebert, "Fish Bulletin 124. Artificial Habitat in the Marine Environment," 1963.

artificial reefs as documented in wealth of publications spanning decades and geographies.[180] Although artificial reefs are a global phenomenon, tracking the global status of artificial reefs in scale, scope, and ecological impact is exceedingly difficult. To date no global database exists to track the evolution of artificial reef technology, their location, or productivity – making it hard to assess global impacts comprehensively. As a result, many research articles focus on localized impacts of reefs on species distribution and fish quantities but overlook the big picture of global artificial reef programs. As a 2002 article laments "A global database, which could include attributes such as location, purpose, materials, and monitoring activities, is lacking," - accordingly the author built a dataset to highlight trends using recent conference publications to establish a list of countries with ongoing artificial reef programs. [181] According to this study, surveying conference proceedings in 1991 & 1999 active artificial reef programs existed in Australia, Brazil, Canada, Chile, China, Cote d'Ivoire, Cuba, England, France, Germany, Greece, India, Israel, Italy, Japan, Korea, Malaysia, Maldives, Mexico, Monaco, Nigeria, Norway, Philippines, Poland, Portugal, Russia, Scotland, Spain, Sri Lanka, Taiwan, Thailand, Turkey, USA, Virgin Islands.[182] A more recent article from 2021 uses a similar methodology to track reef international development in artificial reefs, relying on an analysis of 1074 published papers and then extracting reef location and size. The authors conclude that artificial reefs have been built in 71 countries, with even distribution in western/eastern hemispheres and a greater distribution in the northern hemisphere. Across the earth reefs are distributed at depths from 1-1074meters, with most existing from 5-40meters, being composed of concrete, steel, rock, rubber, plastic, wood, shell, fiberglass, metal, ceramic, coral, and brick. [183] Among the conclusions reached in the paper are recommendations for globally coordinated and standardized data sets and a broader research scope, including construction details, to help

[180] A. Jensen, K. Collins, and A.P. Lockwood, *Artificial Reefs in European Seas* (Springer Netherlands, 2012), J.H.P. Ramos, Impact of Artificial Reefs on the Environment and Communities, Practice, Progress, and Proficiency in Sustainability (IGI Global, 2022), W. Seaman, *Artificial Habitats for Marine and Freshwater Fisheries* (Elsevier Science, 2013)

[181] William Seaman Jr, "Unifying Trends and Opportunities in Global Artificial Reef Research, Including Evaluation," ICES Journal of Marine Science 59, no. suppl (2002): S14–16.

[182] Seaman Jr.

[183] Ramm et al., "Artificial Reefs in the Anthropocene: A Review of Geographical and Historical Trends in Their Design, Purpose, and Monitoring."

understand the role of artificial reefs in the context of ecology, society, and Anthropocene futures.

Reports from individual countries provide a snapshot of global artificial reef activities. For example, China's sea ranching efforts using artificial reefs are enormous, with 67 million cubic meters of fabricated artificial reefs and 8,500 hectares of macrophyte (algae) beds constructed to date. Impacts of this 40-year effort showed higher abundance, biomass, and/or species richness of marine organisms in artificial reef areas than adjacent sites.[184] Artificial reefs are also abundant in Europe. A survey article published in 2011 list 252 artificial reef sites installed by 19 countries across the Mediterranean, Atlantic, North Sea, Baltic Sea, and other European waterways, with a range of systems and scales under development in the region. France, for example, is among the earliest adopters of modern artificial reef technology with 20 sites and 90,000 cubic meters of structure as of 2011.[185] Databases for specific regions also provide insight for specific locations globally, such as the State of Texas Parks and wildlife website, which shows the location and material type of the states 20 artificial reef sites but fails to provided monitoring data.[186] Given the global development of artificial reefs scientist are in the process of suggesting and developing universal standards to facilitate research and reporting. It appears that most confusion in the research arises from a lack of universal standards for measuring, reporting, and documenting artificial reefs.

The composite image of artificial reef scattered across academic literature, governmental reports, and conference proceedings point to the massive scale, material use, and impacts on the environment - making them interesting to consider from an ecological engineering and sociotechnical perspective. Frontiers in artificial reef research include a broader consideration of their ecological and societal impacts. For example, current research in the fish farming and artificial reefs seem to recognize more comprehensively these interrelationships. As one

184 Shurong Liu et al., "Characterizing the Development of Sea Ranching in China," *Reviews in Fish Biology and Fisheries*, 2022, 1–21.
185 Gianna Fabi et al., "Overview on Artificial Reefs in Europe," *Brazilian Journal of Oceanography* 59 (2011): 155–66.
186 "TPWD Artificial Reefs Interactive Mapping," accessed February 28, 2023, https://tpwd.texas.gov/gis/ris/artificialreefs/.

researcher states, “A viable future for marine ecosystems will require incorporation of ecological perspectives into polices that integrate fishing, aquaculture, and conservation.” [187]

Many researchers also now recognize the potential of artificial reefs to positively impact marine systems and even their potential in ecological restorations and conservation. A recent article on the role of artificial reefs on rehabilitation of marine habitats states that “from an ecological perspective artificial reefs exhibit significant potential as a tool in the rehabilitation of coastal ecosystems. However, their utilization in practice may have less to do with their technical merits than with the institutional frameworks and political processes which govern them,” thus highlighting the need for comprehensive policy cognizant of ecological and social factors.[188] Other researchers echo these sentiments, stating “Artificial reef research is an applied field and process-oriented study has often been given low priority. Despite the fact that the construction of an artificial reef, by definition, constitutes a field manipulation (i.e., experiment) that could be used to elucidate ecological process and function, the literature on this topic contains largely observational studies.”[189] These efforts are timely as artificial reefs impact the ecology of marine systems, provide food and resources for communities and are integrated into global economics, with other studies proclaiming the shifting the paradigm of artificial reefs from simply tools of marine productivity towards tools of marine enhancement through technology and material intervention in functioning ecosystems.[190] This includes integration with environmental planning practices, social programs, in addition to habitat restoration and fisheries metrics.[191] Collectively these research efforts help to situate reefs within a more complex set of contingencies and planning processes.[192]

[187] Rebecca Goldburg and Rosamond Naylor, “Future Seascapes, Fishing, and Fish Farming,” *Frontiers in Ecology and the Environment* 3, no. 1 (2005): 21–28.
[188] Helen Pickering, David Whitmarsh, and Antony Jensen, “Artificial Reefs as a Tool to Aid Rehabilitation of Coastal Ecosystems: Investigating the Potential,” *Marine Pollution Bulletin* 37, no. 8–12 (1999): 505–14.
[189] Margaret W Miller, “Using Ecological Processes to Advance Artificial Reef Goals,” ICES Journal of Marine Science 59, no. suppl (2002): S27–31.
[190] Avery B Paxton et al., “Meta-Analysis Reveals Artificial Reefs Can Be Effective Tools for Fish Community Enhancement but Are Not One-Size-Fits-All,” *Frontiers in Marine Science* 7 (2020): 282.
[191] Heath R Folpp et al., “Artificial Reefs Increase Fish Abundance in Habitat-limited Estuaries,” *Journal of Applied Ecology* 57, no. 9 (2020): 1752–61.
[192] Avery B Paxton et al., “Fitting Ecological Principles of Artificial Reefs into the Ocean Planning Puzzle,” *Ecosphere* 13, no. 2 (2022): e3924.

Among the emergent themes in artificial reef and fisheries research is the recognition of their interrelations with material, economic, and environmental systems. The Industrial ecology of artificial reefs recognizes the complex interdependence of industrial production, materials, and natural systems. In this vein, research activity suggests a more comprehensive approach to the production and effect of artificial reefs. For example, a recent article on artificial reefs in Galician estuaries explores the material flows of reef modules in the context of the Circular Economy, finding that integration of material waste and eucalyptus fibers proved advantageous in meeting the MIVES (Spanish acronym of Integrated Value Model for Sustainability Assessment) methods for quantifying sustainability.[193] Other researchers point towards the public perception of the industrial ecologies created by artificial reefs in the Gulf Of Mexico, and how narratives regarding technology and ecology in the regions discourse and policy. [194] This is to say that the material, social, economic, and ecological impacts of artificial reefs are now more comprehensively considered – including the sociotechnical aspects of how artificial reefs are developed and implemented. In this contemporary context artificial reef systems and materials continue to be invented and patented, including “green” artificial reefs developed to address issues of sustainability. Some of these systems rely on industrial byproducts, such as steel slag, calling into question the role of industry.

Overview of the Global Patent System and Artificial Reef technology with Emphasis on Japan, United States, and international patent classifications

The first U.S. patent to use the technical designation term “artificial reef” for the specific use of enhancing fisheries was submitted early late 1960’s and granted in 1971. It was submitted by Japanese inventors Shinichi Ishida, Takatsugu Kawano, and Chiaki Sato and was assigned to Asahi Kasei Kogyo Kabushiki Kaisha corporation - one of Japan’s largest chemical manufacturers. The patent, US3561402A “Artificial refuge reef for fish” originates from a Japanese Patent JP9866367A, granted in Japan in 1967. This small detail is significant as it establishes precedent

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193 Luis Carral et al., “Assessment of the Materials Employed in Green Artificial Reefs for the Galician Estuaries in Terms of Circular Economy,” *International Journal of Environmental Research and Public Health* 17, no. 23 (2020): 8850.
194 Dolly J∅ rgensen, “An Oasis in a Watery Desert? Discourses on an Industrial Ecosystem in the Gulf of Mexico Rigs-to-Reefs Program,” *History and Technology* 25, no. 4 (2009): 343–64.

for the transfer of Japanese artificial reef technology to the United States and also predates the existence of a specific category of technology to categorize artificial reefs.[195]

Asahi corp. describes a reef made of a synthetic resinous substance, but also outlies the scope of artificial reef technology, stating "As it is well known, the development and multiplication of fish resources are indispensable for the promotion of coastal fisheries, and as a part of the measures for such requirements, the settling of artificial reefs for fish have hitherto been executed. Although a number of artificial reefs for fish have been produced to date, they still cover only a very slight portion of the extensive coasts to be effectively utilized, and the major portion thereof is still unutilized, and it is required that a large number of artificial reefs for fish be continuously supplied therefor in the future."[196] The patent is emblematic of the Japanese investment in the ENSEI program, which leveraged corporate partnerships to advance fisheries and ecological technology. Evolution of the ENSEI program led to the transfer of artificial reef technology to the United States and establishment of specific patent classifications to coordinate innovation.

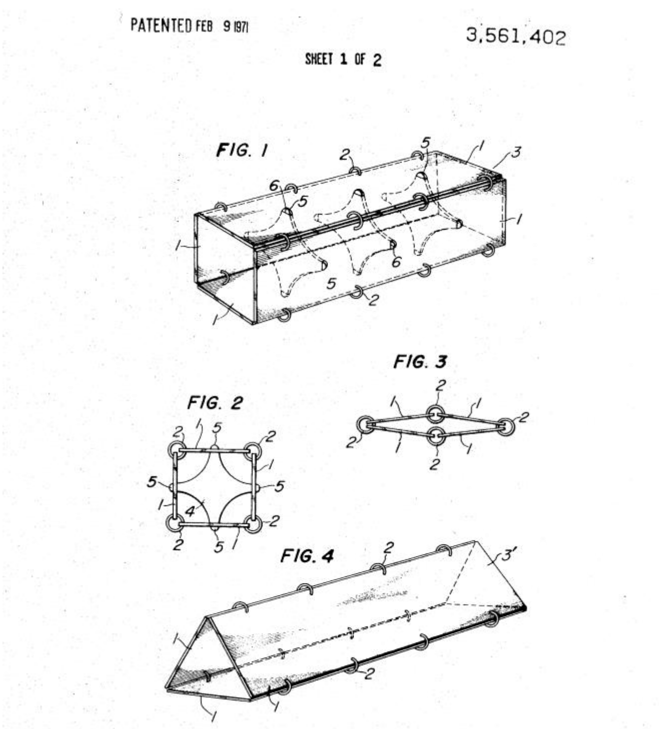

Figure 17: US3561402A "Artificial refuge reef for fish" (1971). Among the first Japanese reef systems patented in the united states. (Source: European Patent Office, https://www.epo.org/en)

Artificial Reefs now represent a distinct sector of environmental technology with a dedicated patent classification. In the most recent YO2A Classification scheme, 'Technologies for Adaptation to Climate Change', a specific sub-class exists for riverine and coastal innovation such

[195] Shinichi Ishida, Takatsugu Kawano, and Chiaki Sato, Artificial Refuge Reef for Fish, US3561402A, filed November 20, 1968, and issued February 9, 1971.
[196] Shinichi Ishida, Takatsugu Kawano, and Chiaki Sato, Artificial refuge reef for fish, United States US3561402A, filed November 20, 1968, and issued February 9, 1971,

as Artificial reefs, seaweeds, and Restoration or protection of coral reefs. The Y02A10/26 subclass for Artificial reefs or seaweed; Restoration or protection of coral reefs currently has 265 patents with the majority originating in China (109), the United States (69), Japan (46). Korea (39), Australia (34). France (23). As the Y02A classification scheme essentially reorganizes patents from the existing Cooperative Patent Classification (CPC), omitting some and including others, it is important to note that the patents organized by the scheme are also classified elsewhere and have a long history that intersects with environmental policy and patent law.

A distinct class of patented technology was established in the United States circa 1983 as part of the United States Patent Classification (USPC) for artificial reefs – helping to usher in technological innovations associated with the then in process National Artificial Reef Plan. The USPC established the artificial reef classification under the title heading "Animal Husbandry."[197] Although several Artificial reef patents existed prior to the creation of the USPC class, the creation of the dedicated class essentially organizes the area of innovation. It is noteworthy that this history coincides with a concerted effort by the United States government to transfer artificial reef technology from Japan through patent licensing and scientific exchange through scientific conferences and partnerships. Other parallel genealogies are also important, the USPC classification make provisions for reefs made with tires, originating from partnerships with the automotive tire industry to develop new products from scrap. All these factors contribute to the creation of the USPC codes for Artificial Reefs with the enactment of National Fishing Enhancement Act (1984) and publication of the Artificial Reef Plan (1985).

Evidence of this concerted planning effort is scattered through archives and research memos of the era. For example, transcripts from the "Subcommittee on Fisheries and Wildlife Conservation and the Environment" presented to congress in 1983 explores ways to promote development of artificial reefs in the United States. It reveals a distinct technical paradigm in the development of artificial reefs in which the United States aimed to build technical capacity in artificial reefs to enact the National Fisheries Enhancement Act (1984). According to the congressional transcript between Senator John Breaux and Mr. Daniel Sheehy, at the time of

[197] United States. Patent and Trademark Office et al., Manual of Classification, Manual of Classification (U.S. Department of Commerce, Patent and Trademark Office, Search and Information Resources, 1983),

implementing the act no firms in the United States had the technological capacity to design or produce artificial reefs. Sheehy, in his role as consultant for federal agencies evaluating the potential of reefs in the united states, suggests that it would be most expedient to use Japanese technology as the United States lags in intellectual property and would benefit from technology transfer, noting "I believe negotiations are now underway for licenses to produce some of the Japanese designs in the United States."[198] Sheehy's role in the technology transfer process is interesting to consider. At the time, Sheehy worked as a private consultant for the firm Aquabio, who was hired by the National Oceanic and Atmospheric Administration (NOAA) and the State of Florida Department of Natural Resources to introduce Japanese artificial reefs to the United states in the 1980's. Specifically they were involved in the translation of Japanese research and technical documents, and transfer of technology (through patent licenses) to the united states.[199] This occurred through joint academic conferences, research publications, and transfer of Japanese intellectual property resulting from decades of artificial reef research in the country.

Context for the creation of a specific class of artificial reef technology in early 1980's points towards a national need to build industrial capacity in this sector in association with a National Fisheries Enhancement act (1983). To facilitate in this process specific codes were created to coordinate innovation. The USPC has consecutively been updated since 1790 to keep track pace with technological progress. Initially the USPC included 16 classes of technology and by 2014 it included more than 430.[200] Two patent classes were created to define the scope of this sector. The first, 11/221 Artificial reef class covers "Subject matter including a device usually positioned on the sea bottom or in man-made bodies of water to facilitate fish-gathering and culturing thereon." The second, 119/222 class for "Artificial Reef with tire components" which covers an array of related configurations "wherein at least a portion of the habitat is constructed from one or more discarded rubberlike vehicle supporting members." The dedicated class for artificial reefs made of automobile tires is particularly curious as it emerges through cooperative

[198] United States. Congress. House. Committee on Merchant Marine and Fisheries. Subcommittee on Fisheries and Wildlife Conservation and the Environment, Artificial Reefs--Fisheries Development: Hearings Before the Subcommittee on Fisheries and Wildlife Conservation and the Environment of the Committee on Merchant Marine and Fisheries, House of Representatives, Ninety-Eighth Congress, First Session, on Artificial Reefs--H.R. 3474, July 18, 1983, Fisheries Development Corporation--H.R. 3806, September 20, November 10, 1983 (U.S. Government Printing Office, 1984)

[199] "Japanese Artificial Reefs," accessed March 1, 2023, http://www.aquabio.com/japanese-artificial-reefs.html.

[200] Simmons, "Categorizing the Useful Arts: Part, Present, and Future Development of Patent Classification in the United States."

ventures with the EPA and tire manufacturing industry. In 2015 the USPC system was replaced by the Cooperative Patent Classification (CPC) at which time the dedicated class for artificial reefs composed of tires was translated to the now defunct A01K61/72 - Artificial fishing banks or reefs made of tyres.

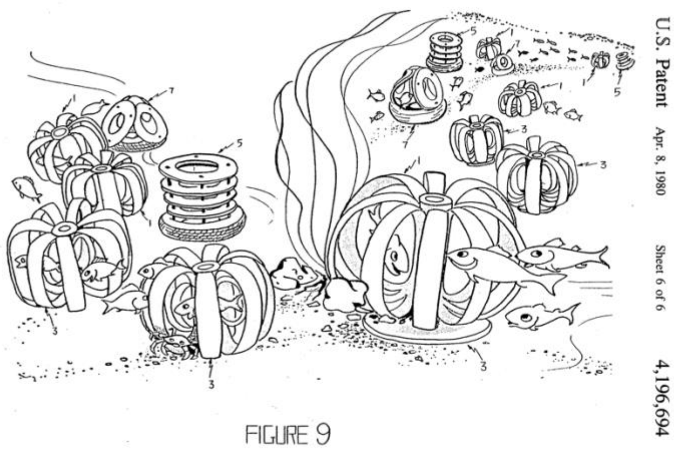

Figure 18: US419669 'Artificial Reef Elements And Method Of Deploying Same' (1980). A tire reef patent prior to the existence of a specific classification system for used tire reefs (Source: European Patent Office, https://www.epo.org/en)'

The first patent law in Japan was established by the "Patent Monopoly Act" *(Senbai tokkyo jōrei*) on April 18, 1885. For decades Japanese patents existed in relative isolation until consecutive revisions of patent law, most notably in 1959, make provisions for inventor's rights that adopted international standards. In 1977 Japan joined other nations in acceding the international patent classification as part of Strasbourg Convention, working towards international standards for patents and increased reciprocity including language translation.[201] This in effect opened Japanese innovations to the world – facilitating licensing and other forms of technology transfer. This loosely coincides with global efforts to digitize patent documents in the mid 1970's, however many gaps remain as less that 50% of Japanese patents have yet to be digitized and remain in obscurity.[202] These factors are significant as it further obfuscates the early classification system used, and patents granted, in Japan, making it necessary for special envoys and coordinated research efforts to facilitate the technology transfer of artificial reefs to the United States.

Today Japan adheres to the International Patent Classification (IPC), while maintaining its own Japanese Patent Classification system (JPC). The JPC comprised of search terms, known as f-terms which corelate to and expand upon the IPC classification. The Japanese f-terms are not a

[201] Bernd Hansen and Dirk Schüssler-Langeheine, *Patent Practice in Japan and Europe: Liber Amicorum for Guntram Rahn* (Kluwer Law International BV, 2011).
[202] Willem Geert Lagemaat, "Patent Archives—the Silent Threat," *World Patent Information* 27, no. 1 (2005): 27–29.

replacement for the International Patent Classification (IPC) but an augmentation of the system that provides a means for searching documents through different criteria and data points. For example, The Artificial reef f-code 2B003 includes subcategories for ease of identification, including installation configuration, structures, characteristics other than structure, materials, and target organism – thus expanding the metadata associated with each patent. Technically, "every F-term consists of a five-digit theme code and a four-digit term code, for example 2B003AA01. In our example, 2B003 is the theme code (`artificial fish reefs')" making it possible for non-Japanese searchers to efficiently find the subject area are relevant patents.[203] This unique f-term system is beneficial to the Japanese patent review process which is outsourced and evaluated by subject area experts with specific knowledge of technical fields, greatly improving the quality of patents granted within specific technical fields.[204]

Today artificial reefs are neatly organized with the Y02A, making them easy to find and also refocusing the scope of artificial reefs on the coastal adaptation. The occurrence of an artificial reef classification in the Y02A patent classification scheme was not happenstance, as many of the patents included in the classification scheme existed as part of preexisting classifications. This reorganization typically relies on source patents from the CPC categories; E02B3/00: Engineering works in connection with control or use of streams, rivers, coasts, or other marine sites, including E02B3/046 specifically for artificial reefs, and A01K61/00 Culture of aquatic animals, including A01K61/70 for artificial fishing banks or reefs.[205] Importantly, we can trace the evolution of artificial reef patent classification from the Y02A, through the CPC, and other patent classification systems, to private industry's innovations and concerted efforts at technology transfer between nations dating back at least to the 1970's – revealing a complex skein between environmental policy, technology, and industry. As appoint of reference, the most recent patent granted under the Y02A10/26 subclass for "Artificial reefs or seaweed; Restoration or protection of coral reefs" is GB2610697A for "Artificial reef for coastal protection" granted in

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[203] Irene Schellner, "Japanese File Index Classification and F-Terms," *World Patent Information* 24, no. 3 (2002): 197–201.
[204] OP Neretin, NV Lopatina, and Yu S Zubov, "Digitization of the Intellectual Property Field: From Scientific Justification to Practical Implementation," Scientific and Technical Information Processing 46 (2019): 67–72.
[205] "CPC Scheme - A01K ANIMAL HUSBANDRY; CARE OF BIRDS, FISHES, INSECTS; FISHING; REARING OR BREEDING ANIMALS, NOT OTHERWISE PROVIDED FOR; NEW BREEDS OF ANIMALS," accessed February 26, 2023, https://www.uspto.gov/web/patents/classification/cpc/html/cpc-A01K.html#A01K.

2023 – a coastal stabilization reef designed to catalyze coral growth through electrical cathode action that accumulates calcium on conductive members.[206] (figure 19)

Individual Cases

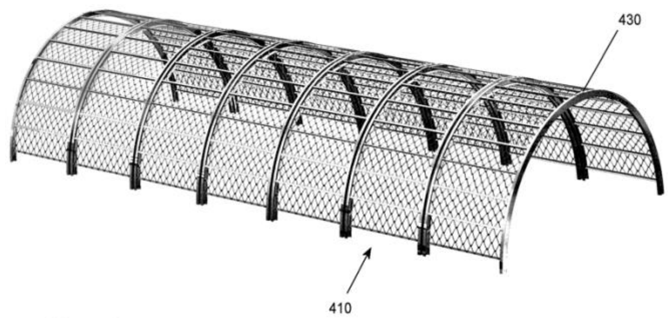

Figure 17

Figure 19: GB2610697A for "Artificial reef for coastal protection" An electrical current running through the frame serves as a cathode for mineral accretion and coral growth. (Source: European Patent Office, https://www.epo.org/en)

Individual case studies below examine private sector involvement in artificial reef technology to highlight the role of patents in catalyzing innovation and investment in this environmental sector. The three cases span more than 50 years of artificial reef innovation across geographies and patent systems, revealing the promises and pitfalls of corporate research, development, and investment. Emphasis in this section is on the use of tires in US artificial reefs and their relationship to the patent system. Two other cases are also discussed for context and to widen the discussion. This includes distinct initiatives include the ENSEI program in Japan, and a recent global effort to build green artificial reefs using iron slag concretes. In each we see the role of patents in defining new sectors of innovation and the response of private companies to the initiative through patent submissions, pilot projects, and research.

Ensei Program And The Birth Of A Japanese Artificial Reef Industry

The first purpose-built artificial reefs were constructure of concrete in Japan 1952 with support from the Japanese Government, initiating a decades long effort to modernize fishing grounds.[207] At this time series of prototype reefs were developed testing effective designs in Hokkaido. In 1958 larger scale project were initiated, yet the reefs failed to attract enough fish to

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[206] John Douglas Bateman William, Gonzalez Olias Dolores, and Bernardo Udelman Leon Samuel, Artificial reef for coastal protection, GB2610697A, filed July 15, 2022, and issued March 15, 2023.
[207] Moon Ock Lee, Shinya Otake, and Jong Kyu Kim, "Transition of Artificial Reefs (ARs) Research and Its Prospects," *Ocean & Coastal Management* 154 (2018): 55–65.

support a complementary fleet of fishing boats – leading to the development of massive structures which are estimated to have reached 1,213,390 m2 by 1966.[208] Attempts to modernized Japanese fishing were initiated through a series of fisheries development plans from 1952-1987 (table 3). Among these the Daiichiji Engan Gyogyo Seibi Kaihatsu Jigyo, (First plan for creation and development of coastal fishing grounds) initiated in 1976 is notable as it integrated government resources and industry partnerships to build advanced fisheries in Japanese territorial waters. The modernization projects resulting from the Daiichiji Engan Gyogyo Seibi Kaihatsu Jigyo, referred to in select English language publications as "Ensei", radically transformed marine ecosystems and the Japanese economy, leading to the establishment of an ecological technology industry to build and augment fisheries through innovation – a legacy that continues today.

1952-1958	Senkai Gyogyo Kaihatsu Jigyo Shallow water fishing grounds development works
1953-1957	Juyo Kairui Zoshoku Jigyo Important seashell species extensive aquaculture
1956-1961	Shin Nosangyoson Kensetsu jigyo New fishermen & farmers village construction
1959-1961	Engan Gyogyo shinko Promotion of coastal fisheries
1962-1970	Daiichiji Engan Gyogyo Kozo Kaizen Jigyo First amelioration plan for coastal fisheries
1971-1982	Dainiji Engan Gyogyo Kozo Kaizen Jigyo Second amelioration plan for coastal fisheries
1979-1985	Shin Engan Gyogyo Kozo Kaizen Jigyo New amelioration plan for coastal fisheries
1976-1981	Daiichiji Engan Gyogyo Seibi Kaihatsu Jigyo First plan for creation and development of coastal fishing grounds
1982-1987	Dainiji Engan Gyogyo Seibi Kaihatsu Jigyo Second plan for creation and development of coastal fishing grounds

Table 3: Artificial Reef Programs Backed by the Japanese Government (source: Jean-Marie Thierry, Artificial reefs in Japan — A general outline, Aquacultural Engineering, Volume 7, Issue 5, 1988, Pages 321-348)

The Ensei program was a complex social, environmental, and technical program based on "marinovation" (marine innovation) which aimed to modernization of fishing grounds and address declines in the fishing industry.[209] The ENSEI program aimed to rebuild a fishing industry through investment in fishing ports, cultural programs, and marine technology under four main

[208] Jean-Marie Thierry, "Artificial Reefs in Japan—a General Outline," *Aquacultural Engineering* 7, no. 5 (1988): 321–48.
[209] F Simard, "Un Nouveau Plan de Développement Pour Les Pêches Au Japon: Le Marinovation," *Pêche Maritime* (La) 65, no. 1297 (1986): 260–70.

subject headings proposed by the national fishing agency. This included plans that with provisions for the following 1) a 'Marin Combinant' referring to industrial development project centered on fisheries, 2) 'Marin Tech' focused on high technology development and innovations for advanced techniques in fisheries, 3) proposals for 'Maritime Village' based on redevelopment schemes for fishermen’s' villages centering on socioeconomical modernization 4) establishment of 'Marine Culture' through the creation of a broader marine civilization supported by leisure and educational facilities such as marine parks or museums.[210]

News of the ENSEI project reached broader academic audiences in 1991 through a “technology transfer” initiated as part of the Japan-US symposium on Artificial Habitats for Fisheries (Tokyo June 1991) and the Fifth International Conference on Aquatic Habitat Enhancement (Long Beach CA 1991) which address the key research finding of the ENSEI program. A summary article, published in 1994, effectively describes the scale, scope, and results of the ENSEI programs. At the time of publication ENSEI was in its 3rd 6-year funding phase with nearly 6-Billion US Dollars spent. The impact of the program is far reaching, having led to the development of 55 regional masterplans with 26 designated marinovation centers, expansion of fishing grounds, and creation of novel technologies for cultivation of marine species.

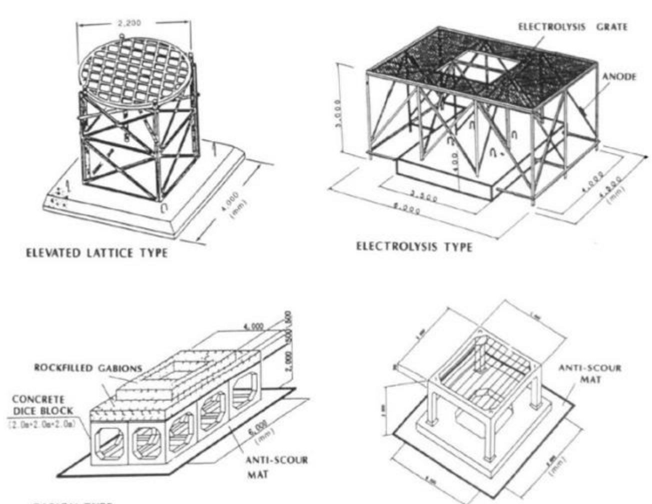

Figure 20:Artificial kelps Reef types developed by MF-21 (source: Robert S Grove et al., “Aquatic Habitat Technology Innovation in Japan,” Bulletin of Marine Science 55, no. 2–3 (1994): 276–94.)

Implementation of the plan was accomplished through a semi-governmental authority founded in 1985 known as "Marino-Forum 21" (MF-2I) to provide a nucleus of a joint research effort among government, academia, and industry. A snapshot of the organization in March 1991 reveals the following: “MF-21 membership totaled 229 organizations, including 138 private firms, 41 prefectures and municipalities, 39 non-profit organizations, two

[210] Thierry, “Artificial Reefs in Japan—a General Outline.”

universities, and nine government laboratories. Its industry members included many of Japan's leading firms in specialties such as the steel and shipbuilding industries (13 firms), general, heavy and marine construction industries (37 firms), electrical, electronics, and machine industries (21 firms), chemical and textile industries (33 firms), the survey and marine instrumentation industry (15 firms), and fishery and related industries (19 firms)." [211] The MF-21 worked collaboratively, combining ecological considerations with a broad spectrum of engineering disciplines. This included experts in coastal and oceanographic engineering, electronics, naval architecture, and material sciences, giving rise to a new discipline called "eco-technology" is emerging in Japan. [212]

Few English language accounts document the impact of Mf-21 on industry partners. However, one notable example comes from Ishikawajima Construction Materials Co. Ltd, who was involved in building product manufacturing, and ventured into the artificial reef industry. According to the account, the "artificial underwater fish reef" created by the company became a best-selling product as the Ishikawajima Construction Materials Co. Ltd was the first to create manufacture the system as Japan modernized national fisheries. Although the company had extensive construction for infrastructure and buildings, the cement artificial underwater fish reef essentially created a new market, and the technology became exclusive domain of Ishikawajima Construction Materials. Later, according to accounts, an artificial underwater fish reef cooperative was created to develop new technology and the President of Ishikawajima Construction Materials Co was appointed as the first chairman."[213] Reflecting on the role of industry, it is now clear that the MF-21 was integral to the establishment of the sector.

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[211] Robert S Grove et al., "Aquatic Habitat Technology Innovation in Japan," *Bulletin of Marine Science* 55, no. 2–3 (1994): 276–94.
[212] Grove et al.
[213] Hansen and Schüssler-Langeheine, Patent Practice in Japan and Europe: Liber Amicorum for Guntram Rahn.

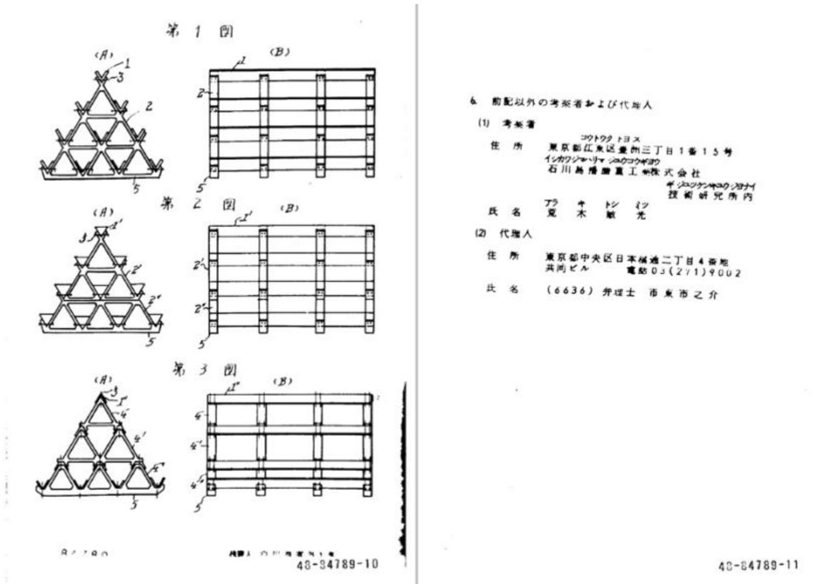

Figure 21: JPS4884789U Early Japanese Artificial Reef Patent granted in 1973 prior to coordinated international standards for patents that opened Japanese innovation to the world. (Source: European Patent Office, https://www.epo.org/en)

Japanese expertise in artificial reefs, and therefore their patent portfolio, evolved from extensive government investment, private industry research, and cooperation with local fisherman and organizations. A publication from 1981 survey the state-of-the-art describes the situation as follows "In Japan, where artificial reefs are most highly developed, large scale fish shelters are now commercially manufactured by more than 15 Japanese companies. These are fabricated from reinforced concrete, steel, iron, PVC, and FRP. The designs, many of which are patented, are based on extensive engineering efforts undertaken by corporations, national laboratories, and universities. Biological investigations are conducted by both regional and prefectural laboratories in cooperation with fishermen's groups" [214] A subsequent survey article from 2000 states "Japanese fisheries prefectures have their own builders for reef construction, with barges and installation experience. Patents have been taken out for 130 models of reefs with different functions." [215] Unfortunately, the Idiosyncrasies of patent language translation and document digitization in Japan limit search capacities for these early patents, though this fact is changing as translation software improves and is integrated with patent databases. (figure 21)

[214] Daniel J Sheehy, "Artificial Reef Programs in Japan and Taiwan," vol. 41, 1981, 184–98.
[215] J Watson, Gilbert Barnabe, and Regine Barnabe-Quet, *Ecology and Management of Coastal Waters: The Aquatic Environment* (Springer Science & Business Media, 2000).

U.S. Auto Industry Waste & The Push for Tire Reefs

Construction of artificial reefs I the United States was based partially on the Japanese experience but took a very different path to national planning policy. In the late 1960 an experimental program in the state of Florida was initiated by government agencies and local fisherman to use scrap automobile tires to construct artificial reefs, with an estimated 1,000,000– 2,000,000 tires placed offshore.[216] Today, even after environmental clean-up, these unballasted tires continue to wash onshore today and tires are now considered poor reef materials. The experiment initiated a layered process policy development, scientific research, patent innovation, and tire reef construction under state, and federal, supervision that culminated in the establishment of National Fishing Enhancement Act (1984) and publication of Artificial Reef Plan (1985). Development of the plan built upon the successes of the coordinated Japanese ENSEI program and the failures of America tire reefs.

Scrap automotive tires are an enormous source of pollution, filling landfills and contributing to plastics in the ecosystem. By the 1970's the problem had become acute and government agencies began to seek alternatives – including the utilization, or arguably disposal, of tires in artificial reefs. The positive initial outcomes of experiments in the 1960's eventually reached the United States senate, helping to inform early initiatives and shape research. In 1972 a Senate Committee on Public Works - Subcommittee on Flood Control: Rivers and Harbors, heard reports on Artificial reefs using tires as part of an Omnibus Water Resources Authorization. Officials in that session were presented "facts" suggesting that tires were viable materials for reef construction. The report to congress states that "Tires Prove Successful" offering a description of tire reef assembly methods and claiming "Tires are one material that was found readily available inexpensive to assemble into units and easy to handle. There are many ways to utilize tires in constructing reefs."[217]

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[216] Robin L Sherman and Richard E Spieler, "Tires: Unstable Materials for Artificial Reef Construction," *Transactions on Ecology and the Environment* 88 (2006): 215–23.

[217] United States. Congress. Senate. Committee on Public Works. Subcommittee on Flood Control: Rivers and Harbors, Omnibus Water Resources Authorizations--1972: Hearings Before the Subcommittee on Flood Control--RIvers and Harbors of the Committee on Public Works, United States Senate, Ninety-Second Congress, Second Session., Omnibus Water Resources

Following these initial reports to congress, a detailed publication (SW 119) titles "Scrap Tires as Artificial Reefs" was written for the Environmental Protection Agency (EPA) Federal solid waste management programs in 1974. The authors of the report, Richard B Stone, Chester C Buchanan, and Frank W Steimle Jr., developed the report under an Interagency agreement between the National Marine Fisheries Service and the US Department of Commerce.

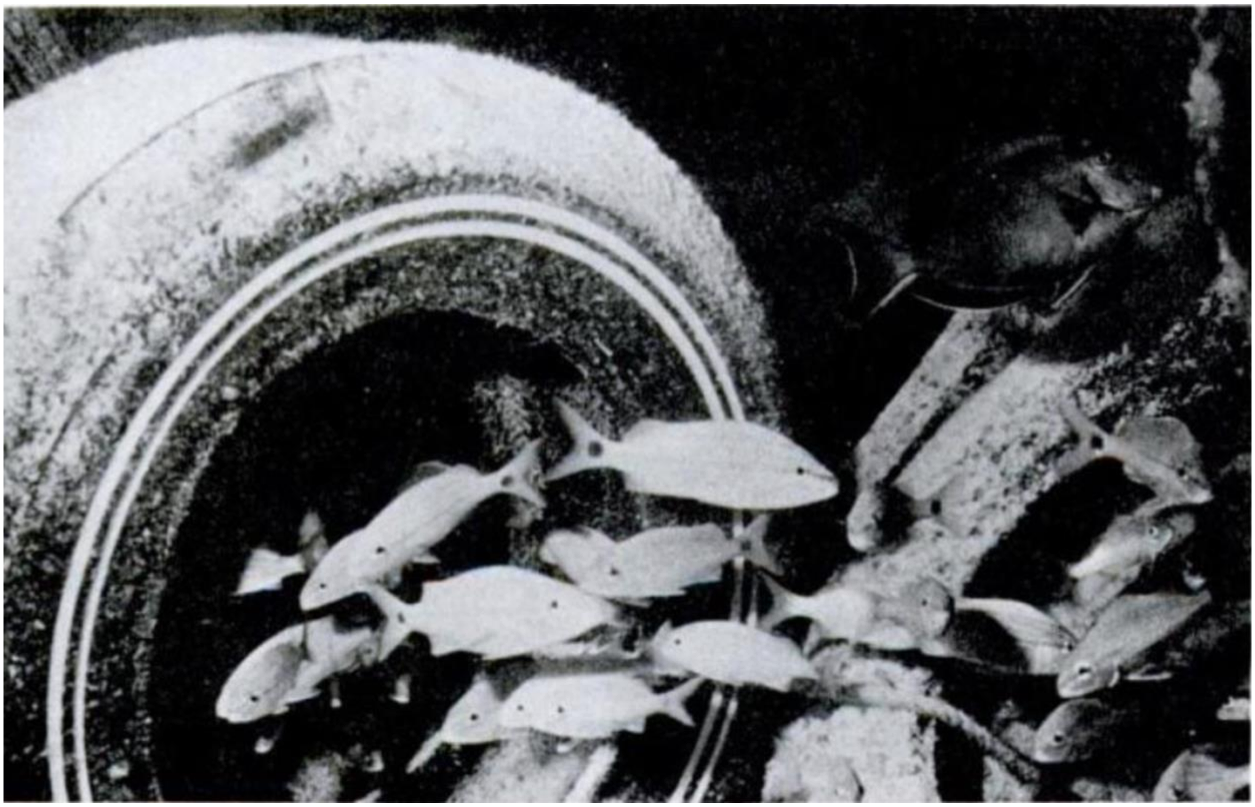

Figure 22: Tires providing shelter for fish (source: scrap tires as artificial reefs 1974)

The short 33-page publication can be understood as promotional material indicating areas of potential synergy between the disposal of tires and the construction of reefs – including the economic and environmental benefits and possibility for innovation. The publication states that "The disposal of scrap tires is a problem national in scope. New and more efficient techniques are needed to handle this disposal problem Scrap tires pose a menace to public health and add to the degradation of our landscape" - a problem that authors believed may be mitigated by tire recycling and for utilization in alternate programs such as artificial reef construction. Revealingly, the publication, and program it describes, came into being through a cooperative agreement

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Authorizations--1972: Hearings Before the Subcommittee on Flood Control--RIvers and Harbors of the Committee on Public Works, United States Senate, Ninety-Second Congress, Second Session (U.S. Government Printing Office, 1972) with the Solid Waste Management Program of the US Environmental Protection Agency and the National Tire Dealers and Retreaders Association.[218]

The publication artfully weaves together specifics related to tire recycling and the demand for materials to meet artificial reef projections. For example, the authors state that all currently proposed (as of 1974) artificial reefs would require 400,000,000 tires, an amount that they estimate is woefully insufficient. Conveniently they note that more tires are always available, suggesting the enlargement of all sites to accommodate 600,000,000 tires in order to meet fishing reef needs. The abundance of tires, gaps in recycling programs, and detriment to the terrestrial landscape at the time seemed to suggest that automobile tires were the best option to create artificial reefs through a coordinated effort from local waste management programs up through the federal government.

In 1974 at the time of publication of ""Scrap Tires as Artificial Reefs", and for the subsequent decade, artificial reefs were developed in the United States through cooperation between the federal, state, and local government, often in collaboration with local recreational fishing groups. This disjointed process was sustained by interest in the construction of artificial reefs and ongoing pilot project testing reef construction and location. In 1983 the federal government initiated a far-reaching plan to advance fisheries science and increase yields. As such the National Fishing Enhancement Act of 1983 "Sets forth standards for the design, construction, and location of artificial reefs. Directs the Secretary of Commerce to develop guidelines for a national artificial reef plan. Sets forth terms and conditions for permits for the construction of such reefs.[219]

The US National Artificial Reef Plan was developed pursuant to the National Fishing Enhancement Act of 1984. In the Act, the US Congress outlines the role of artificial reefs in fishery enhancement, declaring " properly designed , constructed , and located artificial reefs can enhance the habitat and diversity of fishery resources ; enhance United States recreational and commercial fishing opportunities ; increase the production of fishery products in the United States; increase the energy efficiency of recreational and commercial fisheries ; and contribute

[218] Richard B Stone, Chester C Buchanan, and Frank W Steimle, Scrap Tires as Artificial Reefs... (US Environmental Protection Agency, 1974).

[219] "National Fishing Enhancement Act of 1984," Public Law 98-623 § (n.d.).

to the United States and coastal economies." [220] In the act, the US Congress directs the Secretary of Commerce to develop and publish a comprehensive plan within one year to advance reef technology and construction of artificial reefs.

The plan, popularly referred to as the "National Artificial Reef Plan" addressed the following aspects of artificial reef creation in the United States; 1) geographic , hydrographic , geologic , biological , ecological , social , economic , and other criteria for siting artificial reefs ; 2) design , material , and other criteria for constructing artificial reefs ; 3) mechanisms and methodologies for monitoring the compliance of artificial reefs with the requirements of permits 4) mechanisms and methodologies for managing the use of artificial reefs ; 5) a synopsis of existing information on artificial reefs and needs for further research on artificial reef technology and management strategies, 6) an evaluation of alternatives for facilitating the transfer of artificial reef construction materials. The Secretary of Commerce formulated the resulting national artificial reef plan in consultation with a range of Federal agencies that would later be involved in reviewing and approving Federal permits for artificial reef construction. Consulting agencies included National Marine Fisheries Service, U.S. Fish and Wildlife Service, Environmental Protection Agency, Minerals Management Service, U.S. Coast Guard, and U.S. Amy Corps of Engineers. As components of the federal a federal plan emerged it was also reviewed and revised by individual States, local governments, Regional Fishery Management Councils and Marine Fisheries Commissions, industry, artificial reef authorities, and the public.

The plan comprehensively outlines the scope and planning of artificial reefs, including the materials to be used. This includes a discussion of positive attributes of tire materials and a slight mention of concerns raised by tire structures. The positive description offered as part of the plan states of discarded tires that "Uncompressed scrap tires, a plentiful source of artificial reef construction material, are adaptable to many designs, they can be bound into units, modules, or other habitat structures that provide extensive surface area and interstitial spaces for invertebrates and fishes (most notably demersal and cryptic species). Tires are exceptionally durable, without demonstrated toxic effects attributable to leaching or decomposition processes." Structural concerns associated with u tires are also mentioned briefly, though do

[220] National Fishing Enhancement Act of 1984.

not seen to outweigh the positive uses. The National Reef Plan claims that tires are highly unstable on the bottom as they tend to become dislodged when placed in the ocean if not ballasted of integrated with structure. The report states that "tires can move out of the reef site to nearby natural reefs, trawling grounds, and beaches. This movement negates construction objectives and can result in significant damages and costs. Tire reefs have been restricted or banned in some States (e.g., California and Washington)." [221] Irrespective of the concerns, novel structural configurations were developed to anchor tires and build multidimensional reefs around the United States, with innovations in tire reefs mostly resulting in novel systems for anchoring, post processing, and structural integration.

Over the decades further testing and evaluation continually proved the inappropriateness of tire reefs, however they continued to be built and trialed. States like Hawaii tested tire reef configuration through permitted experiments, concluding in 1989 that concrete was a superior material for recruitment of marine organisms when compared with tires and metal.[222] Further real-world experiments continued to corroborate the instability of tires. In Broward County, Florida, where an estimated 2,000,000 tires were scuttled to create a reef in the late 1960's as part of an environmental cleanup, and recycling, continues at enormous environmental and financial cost. [223] Similar clean-up efforts are in process around the world, including Guam where an experimental tire reef was constructed in 1973, and has caused decades of damage.[224] Research in the 1990's also suggests that surface leachates do enter the marine environment, however results were inconclusive regarding "persistence, fate, transport, or possible bioaccumulative effects," of the compounds in marine environments.[225] Recently, the debate around the environmental impacts of tire rubber in marine environments has been

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[221] U.S. Department of Commerce., "1985. National Artificial Reef Plan". Compiled by Richard B. Stone, National Marine Fisheries Service, Washington, D.C. 39 Pp," NOAA Technical Memorandum NMFS OF-6 § (n.d.).
[222] R C Fitzhardinge and J H Bailey-Brock, "Colonization of Artificial Reef Materials by Corals and Other Sessile Organisms," *Bulletin of Marine Science* 44, no. 2 (1989): 567–79.
[223] Sherman and Spieler, "Tires: Unstable Materials for Artificial Reef Construction."
[224] https://www.hawaiipublicradio.org/people/associated-press, "Underwater Tire Reef Experiment In Guam To Be Cleaned Up," Hawai'i Public Radio, January 19, 2020, https://www.hawaiipublicradio.org/local-news/2020-01-19/underwater-tire-reef-experiment-in-guam-to-be-cleaned-up.
[225] SI Hartwell et al., "Toxicity of Scrap Tire Leachates in Estuarine Salinities: Are Tires Acceptable for Artificial Reefs?," *Transactions of the American Fisheries Society* 127, no. 5 (1998): 796–806.

renewed by the ubiquitous use of the material in recycled building materials and its occurrence as microplastic particles in ocean waters.[226]

Any caution regarding the use of tires in reef construction was post-rationalized in hindsight – as the policy directive and innovation infrastructure was established before extensive environmental impacts were evacuated. At the time of the National Fisheries Enhancement act, two patent classes were created to define the scope of this sector – including a specific subclass to cover reefs made of tires. The first, mentioned previously, 11/221 Artificial reef class covers "Subject matter including a device usually positioned on the sea bottom or in man-made bodies of water to facilitate fish-gathering and culturing thereon." The second, 119/222 class for "Artificial Reef with tire components "covering "Subject matter wherein at least a portion of the habitat is constructed from one or more discarded rubberlike vehicle supporting members." The existence of the tire reef classification led to the establishment of a similar class in 2015 as part of the Cooperative Patent Classification (CPC) at which time the dedicated class for artificial reefs composed of tires was translated to the now defunct A01K61/72 - Artificial fishing banks or reefs made of tyres – within which the last patent was indexed in 2019 (see KR102042054B1 'artificial fishing banks').[227]

Patents covered by these classifications span the spectrum of structural possibilities of repurposed tires that attempted to address requirements for stability and habitat parameters. In it we see the relationship between technical specifications, policy, and technological ingenuity in the tire reef sector. In the 1990's the National Marine Fisheries and The U.S. Army Corps of Engineers established structural guidelines for artificial fishing reefs in the United States. According to the technical specifications tire reefs systems using tires must be embedded or captured in concrete two times the weight of the tire plus 10% and novel structure systems were invented to meet these criteria. For example, US6042300A Concrete and tire artificial reef, submitted in 1998 b David M Walter, describes a reef system composed of an "equilateral tetrahedral frame, comprising six concrete beams inserted through the center of a number of

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[226] Roy R Gu, "Beneficial Reuses of Scrap Tires in Hydraulic Engineering," *Water Pollution: Environmental Impact Assessment of Recycled Wastes on Surface and Ground Waters*, 2005, 183–215; Louise L Halle et al., "Ecotoxicology of Micronized Tire Rubber: Past, Present and Future Considerations," *Science of the Total Environment* 706 (2020): 135694.
[227] Ji Ho Han, artificial fishing banks, KR102042054B1, filed March 22, 2019, and issued November 7, 2019.

automotive tires. The ends of the concrete beams are fastened together at four points" with a weight ratio that meets this requirement.[228]

Others show similar structural ingenuities in post processing and anchoring of tires that address the tendencies of tires to dislodge and thus meet standards for artificial reef planning.

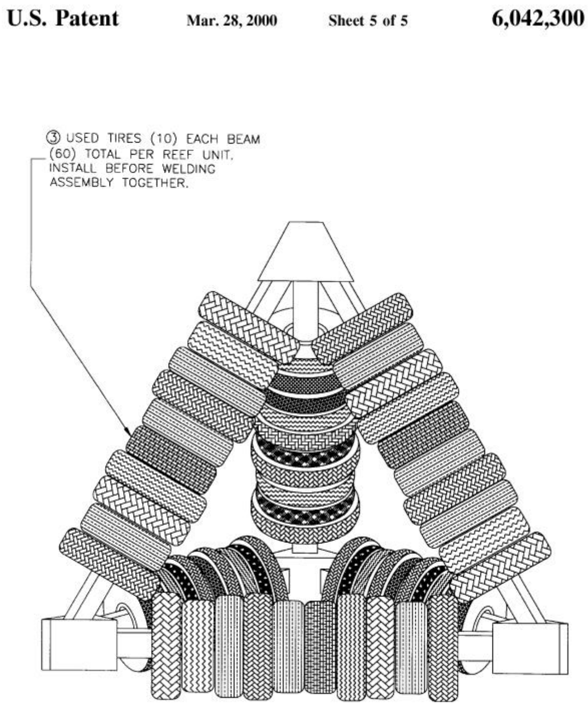

Figure 23: US6042300A "Concrete and tire artificial reef" designed to meet the weight/tire ratio. (Source: European Patent Office, https://www.epo.org/en)

Of particular interest are the cluster of Korean patents submitted 2000-2019 for tire reef, and now siloed in the defunct A01K61/72 (circa 2018) patent classification (see KR20160076101A 'Artificial fishing banks using scrap tires'), and the Japanese patents for tire reefs that have been pending for more than two decades (see JP2006180799A 'Waste Tire Fishing Bank').[229] Both seeming emblematic of a strategic phasing out of tire reefs globally based on environmental policy and the reorganization of the technology sector within the CPC.[230]

Steel Industry, Slag, And Reefs

Today industry continues to play a role in the development of novel artificial reef technology, however coastal sustainability, globalization, and ecology provide a very different context. Innovation in the coastal sustainability space has led to the creation of "green" artificial reefs that are now deployed around the world. Given the links to industrial byproducts, such as

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[228] David M. Walter, Concrete and tire artificial reef, US6042300A, filed December 29, 1998, and issued March 28, 2000.
[229] in Ki Jung, Artificial Fishing Banks Using Scrap Tires, KR20160076101A, filed December 22, 2014, and issued June 30, 2016; Kiyoshi Higa, Waste Tire Fishing Bank, JP2006180799A, filed December 28, 2004, and issued July 13, 2006.
[230] European Patent Office, "CPC NOTICE OF CHANGES 457," February 1, 2018, https://www.uspto.gov/web/patents/classification/cpc/pdf/CPCNOC457DP0187A01K.pdf.

iron slag, it is reasonable to question whether they are evidence of greenwashing of examples of productive partnerships between marine science and corporate interests.

Artificial reefs made of iron slag are a hot topic for marine researchers and the steel industry. A wealth of recent literature supports its use is slag from iron production in artificial reefs as it supports the growth of marine organisms and may facilitate carbon sequestration. In its simplest terms, Slag is a by-product of smelting metal ores and reclaimed used metals to create metal products. Ferrous (i.e., iron) slags are produced in different stages of the iron and steelmaking processes resulting in slags of with various physical and chemical properties. Some of these slag byproducts can be used in concrete and other secondary products, including artificial reefs. As ferrous slags are created through heavy industry and have massive environmental impacts, the recent uptick in research activity, patents, and pilot projects can be viewed as a shift towards more sustainable practices or potentially a future environmental calamity.

The recent interest in iron slag as an artificial reef material emerges parallel to the need for more sustainable materials in artificial reef construction. This included a concerted effort by heavy industries, such as steel manufacturing, to advance sustainability goals and resource efficient building materials and has led to the development of green artificial reefs. Green Artificial reefs (GARs) are reefs constructed of renewable, waste, and recyclable materials that improve the lifecycle analysis of reefs and those that contribute to carbon sequestration efforts. In the specific case of GARs made from steel slag the advantages are claimed to include the ability to recycle of steelmaking slag, absorption and solidification of atmospheric CO_2, and contribution to the sustainability of coastal environments.[231]

In general GARs look at the economy and life cycle of materials to evaluate the sustainability of artificial reef modules. To date, this has included the evaluation of material modification ranging from shell of marine bivalves as concrete aggregates to addition of plant-based fibers, and even waste from heavy industry with potentially beneficial environmental impacts. In this context research on steel slag indicates some very promising potential uses. For

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[231] Kumi Oyamada et al., "A Field Test of Porous Carbonated Blocks Used as Artificial Reef in Seaweed Beds of Ecklonia Cava" *Nineteenth International Seaweed Symposium: Proceedings of the 19th International Seaweed Symposium, held in Kobe, Japan*, 26-31 March, 2007., Springer, 2009, 413–18.

example, the carbonization process in which layers of carbon materials develop on raw slag during weathering shows positive contribution to the establishment of corals.[232] Other studies show the increased growth of marine seaweeds and microalgae through introduction of steel chelates into marine environments.[233] This of course impacts larger biogeochemical processes, with pilot studies from 2014 suggest that slag may also have potential for carbon sequestration through the Mineral carbonization of the industrial waste material by converting it into carbonates – a process analogous to natural weathering. The study indicates that as the minerally carbonized slag ages it becomes a substrate for marine organisms through colonization of the material which may be integrated with marine structures.[234] The list of potential benefits of steel slag in artificial reefs is interesting to steel manufacturers, especially those closely located to coastline, as well as fishery industry partners and others concerned with the health of marine ecosystems.[235]

These studies have caught the attention of researchers, industry partners, and marine ecosystem managers who are keen to test the novel cement mixtures with existing reef technologies. One such study used "Reef Cubes" with modified concrete mixtures. The study deployed the "reef cubes" in the subtidal zone of Torbay, Devon, UK, for a comparative study. The material types included "an alkali activated slag concrete (Type: AAM), a cement-limestone blend (CEM-II) concrete (Type: C) and a cement-limestone blend (CEM-II) concrete with an additional micro silica pozzolan and an exposed aggregate texture (Type: CP)." Results of the study [236] Although these pilot projects are promising, questions remain regarding the long-term environmental impact of heavy metals from artificial reefs, initial research indicates that test sites of steel, slag, and other reefs did not impact the environment.[237]

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[232] Tarek Aa Mohammed et al., "Coral Rehabilitation Using Steel Slag as a Substrate," *International Journal of Environmental Protection* 2, no. 5 (2012): 1–5.

[233] Chun-Yen Chen et al., "Basic Oxygen Furnace Slag as a Support Material for the Cultivation of Indigenous Marine Microalgae," Bioresource Technology 342 (2021): 125968.Chun-Yen Chen et al., "Basic Oxygen Furnace Slag as a Support Material for the Cultivation of Indigenous Marine Microalgae," *Bioresource Technology* 342 (2021): 125968.

[234] N Thulasi Prasad et al., "Carbon-Dioxide Fixation by Artificial Reef Development in Marine Environment Using Carbonated Slag Material from Steel Plant" (OCEANS 2014-TAIPEI, IEEE, 2014), 1–5.

[235] Ping Chen, Chao-Kai Kang, and Jin-Li Yu, "Marine Life and Coastal Restoration by Utilizing Steel Slag to Create Sea Forest on Sandy Coast of Southwest Taiwan" (OCEANS 2019-Marseille, IEEE, 2019), 1–4.

[236] Samuel Hickling, Jamie Matthews, and James Murphy, "The Suitability of Alkali Activated Slag as a Substrate for Sessile Epibenthos in Reef Cubes®," *Ecological Engineering* 174 (2022): 106471.

[237] Seongsik Park et al., "Assessment of Heavy Metals Eluted from Materials Utilized in Artificial Reefs Implemented in South Korea," *Journal of Marine Science and Engineering* 10, no. 11 (2022): 1720.

Context for the recent emergence of slag artificial reefs is important to consider. Although it may be impossible to timestamp the origins of the use of iron slag in artificial reefs, we can point towards patent sources and scientific literature to contextualize the field. In a 2002 article on the "new" applications of cites steel slag experiments by NKK steel (Japan) as among the earliest examples describing an experiment initiated In November 1997 in which "25-cm-cube slag blocks were placed on the bottom of the Inland Sea off the coast of Setoda Town in Hiroshima Prefecture, and their surfaces were monitored. It was confirmed as early as by the end of January 1998 that marine plants were growing on the surface of the slag blocks and shellfish adhered on the slag blocks surface. In the summer of 1998, green marine plants were proliferating on the slag blocks."[238] These novel experiments show the relative newness of slag in artificial reef applications and call to attentions the sources of this research which is often funded by industry partners. As recent survey article similarly suggests that interest in alternative uses of steel slag begins to increase in the early 2000's when publications and patent submissions increased rapidly. The authors note that "more recently the researchers are publishing their work in patent and not publishing them in non-patent publications. Therefore, review of utilization of steel slag without consideration of patent publication is incomplete." [239] From this perspective we can see how industry research and development activities are shaping the contours of the field.

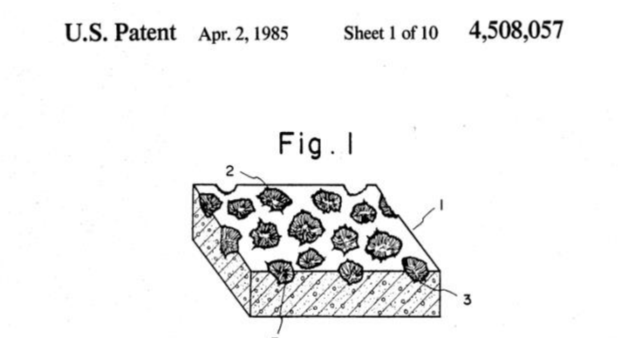

Figure 24: US4508057A for "Algal culturing reef unit, artificial reef unit and artificial culturing and fishing field unit" (1985). showing the surface texture created by the introduction of iron slag in concrete mixture. (Source: European Patent Office, https://www.epo.org/en)

Although it is impossible to determine how steel slag green artificial reefs reached global prominence, it is interesting to note that artificial reef guidelines published in the United States in 1997 & 2004 do not list slag as a material. The comprehensive, and widely distributed, "Guidelines For Marine Artificial Reef

[238] Tatsuhito Takahashi and Kazuya Yabuta, "New Application of Iron and Steelmaking Slag," *NKK Technical Report-Japanese Edition-*, 2002, 43–48.
[239] Yogesh Nathuji Dhoble and Sirajuddin Ahmed, "Review on the Innovative Uses of Steel Slag for Waste Minimization," *Journal of Material Cycles and Waste Management* 20 (2018): 1373–82.

Materials", was Compiled by the Artificial Reef Subcommittees of the Atlantic and Gulf States Marine Fisheries Commissions initially in 1997 and revised in 2004. The guide includes descriptions of reefs composed of numerous materials, including Concrete, Wood, Shell, Rock, Electrodeposition, Fiberglass, Ferro-cement, Ash Byproducts, Solid Municipal Incineration Ash Byproduct, Coal Combustion Ash Byproduct, Oil Combustion Byproduct Ash, Vehicles, Vehicle Tires, White Goods, and others, while not mentioning metal slags. Independent evolution of the technology appears to originate I Japan through steel industry partnerships.

Analysis of patents documents traces the use of iron sulfates in concrete mixtures for artificial reefs to a 1983 patent by Tetsuo Suzuki of Tokyo Mushasi Manufacturing Co LTD, Tokyo Japan. The Invention US4508057A for "Algal culturing reef unit, artificial reef unit and artificial culturing and fishing field unit" proposes and artificial reef artificial reef unit where iron sulfate, or iron (II) sulfate, or an acid and iron oxide powders, are formed on the surface of concrete to attract seaweeds, algae, fishes, and shellfishes.[240] More recent patents such as JP4433831B2 granted to JFP Steel Corporation for "Ecosystem-constructed underwater structures", and JP2010104362A for "Hardened material for creating seaweed bed" (figure 25) utilize steel slag

[240] Tetsuo Suzuki, Algal culturing reef unit, artificial reef unit and artificial culturing and fishing field unit, US4508057A, filed September 16, 1983, and issued April 2, 1985.

materials explicitly in a stacked and bed forming structural configurations to help rebuild ecosystems.[241]

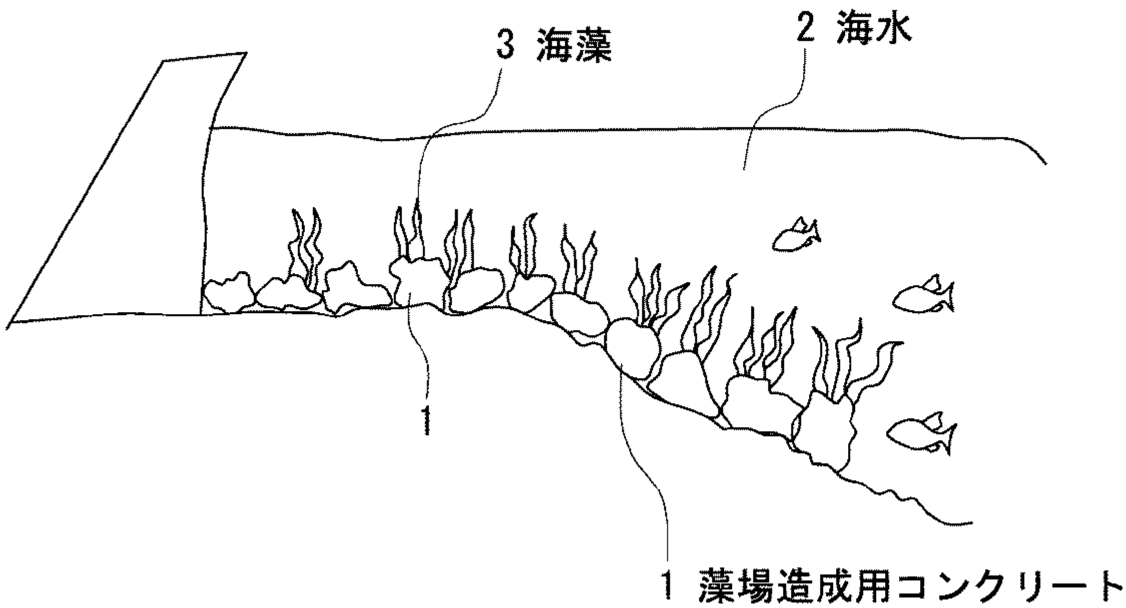

Figure 25: JP2010104362A for "Hardened material for creating seaweed bed" showing a possible configuration of steel slag units for seaweed cultivation" (Source: European Patent Office, https://www.epo.org/en)

Discussion

Technological innovation through public/private partnership played an important role in establishing the artificial reef sector. As such, artificial reefs have a distinct patent class in the Cooperative Patent Classification (CPC) and the recently implemented Y02A classification scheme. Establishment of patent classifications for innovation in artificial reef technologies reveals a complex relationship between private business, technological innovation, and environmental transformation – with both negative and positive outcomes. The policies, funding, and patents that initiate these partnerships are important to consider as we approach environmental and ecological engineering challenges in the context of coastal adaptation and resilience efforts as they serve as analogous cases for the advent and implementation of future infrastructure. In the case of automotive tire reefs in the United States we can observe the how

[241] Kazuhiro Komiya, Hardened Material for Creating Seaweed Bed, JP2010104362A, filed September 9, 2009, and issued May 13, 2010.

lobbying, economics, and industry waste concerns, impact policy through fraught innovations and dubious science. Conversely, the Japanese Ensei program show how coordinated planning, industry partnerships, university research, and social programs, can lead to the establishment of entirely new sectors of ecological technology and creation of productive fishing grounds. The most recent case of iron slag use in green artificial reefs exhibits the tendencies of both cases, with industry pressure to use waste material counterbalanced with an emerging body of scientific literature and pilot projects validating safe use.

Unifying the cases is the theme of corporate interest, research, policy, innovation, and patents in the establishment of new environmental technologies and sectors. The existence of a distinct patent class for artificial reefs in the USPC, CPC, JPC and Y02A results from years of policy development, innovation, and public/private investment in artificial reef programs. It also represents concerted efforts by government for technology transfer between nations and attempts to catalyze innovation in an environmental problem space. Patents, and the patent system, are known to incentivize private investment in new sectors of the economy and catalyze investment, innovation, and development of more established industries. As a general rule, it is assumed that the rate of patenting in a specific sector parallels innovation, research, development, and investment. Of course, anomalies do exist, such as the exponential rate of patenting in "high tech" sectors in the 1990's without a rise in commonly observed research inputs.[242] But in the case of artificial reefs the links between policy, funding, investment, and patents, present a clear pattern of sector developing from establishment of a patent classification with both negative and positive environmental implications.

Artificial reefs, and other environmental technologies, require significant investment to develop and protracted timeframes for testing and evaluation. As is observed in the artificial reef sector, the promise of patents creates "prospect" in a new area. According to originators of prospect theory, including Edmund Kitch and others, a prospect means "a particular opportunity to develop a known technological possibility", essentially rewarding firms for investment and

[242] Jinyoung Kim and Gerald Marschke, "Accounting for the Recent Surge in US Patenting: Changes in R&D Expenditures, Patent Yields, and the High-Tech Sector," E*conomics of Innovation and New Technology* 13, no. 6 (2004): 543–58.

development in new areas of technology.[243] Catalyzing investment in new areas of technology in one function of the patent systems. Through establishment of guidelines and national policy, governments can use the lever of the patent system to guide investment, research, and innovation in sectors of national importance.[244] As is observed in the case of automobile tire reefs in the United States this type of environmental "prospecting" can lead to ocean dumping, pollution, and decades of environmental cleanup. On the flip side, collaborative ventures such as the Ensei program can lead to breakthroughs in ecological technology and establish new sectors that transform coastal systems – showcasing the scale and agency of coordinated innovation in coastal systems.

[243] Edmund W Kitch, "The Nature and Function of the Patent System," *The Journal of Law and Economics* 20, no. 2 (1977): 265–290.

[244] Mark A Lemley and Dan L Burk, "Policy Levers in Patent Law," *Virginia Law Review* 89 (2003): 1575.

Section Interlude: From "Observations and Natural Case Studies" to "Opportunities and Emerging Frameworks"

The first three chapters offer a critical reflections and insights on the latent, yet persistent, role of patented technology in coastal systems. Since these cases occurred prior to the implementation of the Y02A patent classification scheme, they can be understood as natural case studies in how intellectual property operates within coastal anthromes. They document a coastal innovation space that is latent, sometimes messy, incongruent, and largely undocumented. Even high-profile coastal planning and design initiatives such as the New York region's "Resilience by Design" competition, and promoters of oyster-tecture and Living-breakwaters technologies invented during the process, operated within an innovation space in which these domains remained siloed. This is unsurprising, as patents have long been associated with corporate interest and not a deterministic force in environmental planning efforts. However establishment of the Y02A and the creation of explicit technology classes for green infrastructure, coastal systems, mapping, and sensing, instigate a very different future in which adaptation and resilience works in coastal systems and the built environment syncopates with innovation.

Linking innovation to coastal adaptation through the Y02A is a provocation, or call to action, with few precedents. Given this reality, the natural case studies presented here point towards potential issues and opportunities. For example, the relatively well-known case of artificial reef planning in the United States and Japan shows that concerted efforts to alter marine ecosystems and increase biological yields can be accomplished through innovative social, policy, and economic programs in combination innovative industry partners and innovation infrastructure of the patent system. Although interesting in and of itself, the case of artificial reef planning provides a template for future coastal adaptation and resilience works that aim to massively rehabilitate depleted ecosystems or establish novel ecologies in newly formed seas resulting from sea level rise. This will require layers of government, industry, and society to collaborate on coastal issues and necessitating innovation, research, and development. Of course, concerns about the true interests of heavy industry and big-business are well founded, yet skepticism does not negate the accomplishments made in Japanese government and its ‘marinovation’ partners through the Ensei program – a scheme that helped seed similar programs and technology in the United States. An argument could be made that programs such as Ensei and the United States National Artificial Reef Plan, further consolidating power in large corporate interests or within government, overlooking key socio-technical aspects of innovation. Conversely, optimists will see the potentiality in government sponsored programs and partnerships to build ecological systems at oceanic scales and look towards the lessons learned as the nest wave of coastal development plans are unfurled.

A counter view to the possibility of centralized corporate power, offered in chapters 2 & 3, explores how networks of outsiders, individuals, experts, and institutions can instigate change within corporate and government monopolies through intellectual property rights, challenging entrenched power structures and catalyzing change in coastal systems – with outcomes that range from transformational works proposed in the Mississippi Delta by Haupt and Eads, to the messy and unsuccessful installation of seascape artificial seaweeds at Cape Hatteras. These historical accounts not only show how innovation, politics, and policy transform large-scale environmental systems, the serve as a template for the struggles of the future in which novel coastal adaptation resilience technologies of the future are tested and implemented. Since coastal systems exist within a contested problem space, any new technology must confront the entrenched powers of entities such as the USACE, with patent rights operating as an intermediary and “stick” through which to instigate new networks and catalyze change.

In the following chapters (4-6) the opportunities and potentiality of integrating the patent system (i.e. Y02A, data, forecasting, infrastructure, law) and innovative patented technologies into environmental design and planning praxis are explored. Integration of the Y02A scheme with praxis presents distinct challenges, however the opportunity builds knowledge infrastructure, project new technological futures, and translate theory into action, are great and warrant deep consideration from professions steeped in traditions of “best practices” and precedent, which are sometimes contradictory to open systems of innovation and technological exchange. Hybrid vigor resulting from the union of global sociotechnical processes and localized sites and design/planning practices challenges convention and points towards the emergence of an innovation model. Ultimately, the proceeding chapters argue that the potentiality of the Y02A classification scheme will be unlocked through future technological pathways for coastal adaptation and resilience in enables, and the operationalization of these pathways through professional practices of the allied professions of environmental design and planning. Since no instruction manual exist for the adaptation of coastal systems in the face of climate change, the living repository of technology coordinated by the Y02A has the capacity to link the adaptive capacity of technology to site and urban systems through the allied disciplines of environmental design and planning.

4. Knowledge Infrastructure for Coastal Infrastructure: utilization of patent innovation studies in the Bay Area Resilience by Design Challenge.

Patent documents have been archived for six centuries globally and provide a valuable dossier of technological knowledge in every sector of the known Technosphere, including environmental technologies that are used to engineer, map, and inhabit coastal regions. The enormity of the global patent archive, now estimated to exceed 140 million searchable documents, is astounding and is among the world's largest technological databases and a robust form of knowledge infrastructure. Obviously, the primary function of the patent system is bureaucratic management of sequential innovation and establishment of legal rights for inventors. However, the patent system's capacity for search, citation, image archiving, and language translation also serves as a repository of technical knowledge and providing deep insights about current innovation, past discoveries, and future trends.

Technical information in patent documents is communicated through visual representations, or projections, of technology that simultaneously reveal the functioning of an invention whilst creating distinct challenges with regards to applicability and performance of untried technology. Within this dialectic between representation and application, design and planning professions have the opportunity to translate and evaluate novel technology, foregrounding novel systems through their integration in planning processes and design proposals. As is observed in chapter 1 through the advent of oyster-tecture, the development and application of novel environmental technology presents challenges of prolonged project timelines, siloed inventor groups, and incongruencies in the exchange of technical information that may lead to an innovation chasm and other bottlenecks that inhibit the realization of new technology in the built environment. Engaging the global patent archive during coastal adaptation planning processes has the potential to address some of these concerns, linking real-world sites and coastal systems to innovative knowledge infrastructure.

During the 2017 Resilience By Design Bay Area Challenge in California, the Common Ground Team integrated patent data and technical specifications into the design process to help develop site planning strategies for deltaic restoration, ecological enhancement, and transportation infrastructure. The team was composed landscape architects, planners, architects, ecologists, and other consultants, including Richard Hindle (author) who contributed expertise regarding patents and helped build technical dossiers for use by the design team. Translations between technical dossiers, detailed designs, and overarching site planning strategies helped advance the project through heuristic problem solving and led to proposals for creative landscape systems for the degraded San Pablo Baylands; including a living benthic research lab and novel sediment capture systems to build ground. This chapter offers a critical reflection and detailed analysis of the year-long design process to better understand how patents, and their associated knowledge infrastructure, can contribute to coastal adaptation and resilience design and planning processes. As part of this analysis, special attention is given to the modes representation through which technical information is communicated and the systems of search, classification, and citation, that organize provide access to patent data. Since there is no "construction manual" or "best practices" for complex sites facing subsidence, liquefaction, sediment deficits, ecological degradation, ongoing development pressures, the repository to novel patented inventions facilitated rapid iterations and provided references for the design process. This contrasts with more conventional modes of praxis in which a series of expert consultants (i.e. ecological, soil, hydrology, geotechnical, transportation) provide feedback and review of design iterations and phased plans. Although these experts were also part of the Common Ground Team, the introduction of "other" knowledge, and technical concepts from broad networks of inventors, remixed the workflow and allowed for heterogenous ideas to be considered as part of the design phases.

During the yearlong competition process, the technical dossiers evolved, facilitating design iterations and the refinement of the site's final masterplan, however the process left many questions unanswered regarding testing, implementation, and viability of the speculative systems when reduced to practice and integrated into a site during construction phases. To address the questions of testing and evaluation in the site's long-term evolution, the team proposed a "living lab" to be built on the site to research, test, and evaluate, key technological systems operating on the site, allowing the team to bridge between the two distinct realms of global innovation and site-specific design strategies. Of course the proposal does not solve the real-world challenges of construction, testing, and viability of untried technology. In the dialectic between design proposals utilizing innovation technology, and the implementation these novel technologies in real-world sites, important issues are raised regarding the timescales of landscape design and construction and pathways through which to ensure innovative environmental technologies reach vulnerable sites and communities responsibly through planning and design praxis. A foundational step in this process is the exchange of technical information and the translation of this technical information into viable design proposals. The Y02A classification scheme has the potential to operate as knowledge infrastructure in support of these efforts, helping to inform planning and design process through the searching and archiving of prior-art and rapid diffusion of new advances in coastal technologies that address the adaptation and resilience challenges of the future.

Knowledge Infrastructures

Knowledge infrastructure is defined by Paul Edwards as "robust networks of people, artifacts, and institutions that generate, share, and maintain specific knowledge about the human and natural worlds."[245] In essence these infrastructural systems are complex networks of information/knowledge intertwined with social, technical, and environmental systems, with radical implications for the way society perceives and manages the world. As the word "infrastructure" implies the knowledge systems serve as substructures supporting other systems, and are enmeshed with society, economy, energy, material use, politics, and the management of complex environmental systems. Climate change data, for example, reveals the ongoing relationship between the technologies used to map and model the environment and our understanding of a changing planet. The interrelation of data, technology, science, and society through which we comprehend a changing planet represents as a form of 'climate knowledge infrastructure' that shape sour management of the environment. [246] Similarly, in agricultural

[245] Paul N. Edwards, *A Vast Machine : Computer Models, Climate Data, and the Politics of Global Warming* (Cambridge, Mass.: MIT Press, 2010). p. 17
[246] Edwards.

sectors knowledge infrastructure is essential to the dissemination of technical knowledge and data, leading to changes in industry and large-scale land management strategies.[247]

Most of what is known of knowledge infrastructure is derived from innovation rich sectors of technology and industry. However, as contemporary frameworks of the Anthropocene become more widely recognized it is now evident that knowledge infrastructures are linked to planetary processes through evolution of the Technosphere (i.e., the sum of technologies produced by humans and the systems that support it[248]). Theorists argue that knowledge infrastructures, through their enmeshed institutional and environmental linkages, have the capacity to contribute to "large-scale, long-term, anthropogenic environmental change" making them essential for future planetary management.[249] Other scholars make related claims, arguing that the dynamic interplay between knowledge infrastructure, institutions, and environmental systems operate at multiple scales, from the individual actor/organization to vast territorial networks.[250] Today we may look towards these systems of information and knowledge exchange as infrastructure to support both the advancement of human endeavors and agents of change in planetary systems.

Linkages between knowledge infrastructure and the earth's atmospheric, hydrologic, ad geologic systems are readily observable in fields of climate science and agriculture, but also within the allied fields of environmental design, planning, and engineering through the use and production of spatial data and science. Geographical knowledge infrastructure, such as Geographical Information Systems (GIS), are regularly utilized in practice and pedagogy to spatialize data and develop core technologies such as those integrated with smart cities. Collectively these geographical knowledge infrastructures have the capacity to alter the built environment through territorial intelligence.[251] This form of knowledge infrastructure spatializes geographical data to effectively plan, design, and analyze the built and natural environment,

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[247] Laurens Klerkx and Cees Leeuwis, "Balancing Multiple Interests: Embedding Innovation Intermediation in the Agricultural Knowledge Infrastructure," *Technovation* 28, no. 6 (2008): 364–78.
[248] "The Unbearable Burden of the Technosphere," UNESCO, March 27, 2018, https://en.unesco.org/courier/2018-2/unbearable-burden-technosphere.
[249] Edwards, "Knowledge Infrastructures for the Anthropocene."
[250] Moulaert and Hamdouch, "New Views of Innovation Systems: Agents, Rationales, Networks and Spatial Scales in the Knowledge Infrastructure."
[251] Robert Laurini, *Geographic Knowledge Infrastructure: Applications to Territorial Intelligence and Smart Cities* (Elsevier, 2017).

making the data sets, tools, and actors integral to planetary management. And although verging on the technocratic, access to this geographical data is important not only to professional praxis but to the creation of an informed public through knowledge 'discovery' interfaces that support interaction and engagement with large datasets that empower decision makers at local levels across a range of geographies and cultural contexts.[252]

Looking towards a future in which urbanized and managed coastal systems become more technologically advanced, networked, mapped, sensed, and ecologically integrated, a coordinated strategy is required ground innovation in the range of works undertaken in the coastal adaptation and resilience problem space. Addressing issues of technological capacity within emergent sectors, the Y02A patent classification scheme covering the "technologies for adaptation to climate change" aims to focus the core capacities of the patent systems on the global challenges of a changing planet – building the essential knowledge infrastructure for innovations in related climate adaption sectors including coastal adaptation and resilience. Details of the Y02A scheme are fully discussed in the following chapter (chapter 6), however it is important to note here that the scheme aims to coordinate patent data, facilitate dissemination of technical information, hasten technology transfer, and operationalize the knowledge infrastructure of the patent system in climate adaptation efforts. With regards to the core functions of search, citation, and classification, the Y02A consolidates and organizes the cross-sectoral technologies required to address climate change, making searches more accessible and creating new classifications of technology – including green infrastructure, water systems, and coastal technologies.[253] Obviously, the technical information communicated via patents is highly specific to the representational conventions and legalese of the patent system in which drawings and text are akin to invention, raising important questions about the viability of new technology whilst unlocking the possibility of projecting future imaginaries through visual representation.

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[252] Inya Nlenanya, "Building an Environmental GIS Knowledge Infrastructure," in *Data Mining Applications for Empowering Knowledge Societies* (IGI Global, 2009), 260–77; "Water Atlas," ArcGIS StoryMaps, April 14, 2020, https://storymaps.arcgis.com/stories/808093e2f9ce402db1a837027ca05a5e.

[253] "CPC Scheme - Y02A TECHNOLOGIES FOR ADAPTATION TO CLIMATE CHANGE," accessed May 9, 2023, https://www.uspto.gov/web/patents/classification/cpc/html/cpc-Y02A.html.

Representing Technology

Technical information is communicated in patent documents through text and image. This fact facilitates the projection of new technology and calls into question the nature of invention as often the representation of technology often precedes its "tangible" existence. This epistemological loophole in the inventive process is important to consider as it simultaneously hastens the rate of invention but may lead to issues, including misinterpretation and manipulation of the process. Representation of technology is central to modern patent rights, which is founded on the theory that drawings, and text, can be sufficient to describe the scope and functioning of an invention. Central to this issue is the term "reduction to practice" which is a step in the inventive process in beyond the initial conception when either an invention is shown to work or a patent application with sufficient disclosure is submitted. In essence this means that the drawings, models, and textual description are akin to invention as they should describe the proper functioning of the invention.

A patent is, in essence, a textualized and visualized representation of an invention, operating simultaneously as a legal document disclosing the nature of an invention and projection of a future potentiality. Modern representational standards for patents originated in the United States and later France in the latter part of the eighteenth century – requiring drawings and models of novel inventions.[254] The US Patent Act of 1790 states that grantees shall deliver to the Secretary of State, Secretary of War, and Attorney General "a specification in writing, containing a description, accompanied with drafts or models, and explanations and models (if the nature of the invention or discovery will admit of a model) of the thing or things, by him or them, invented or discovered."[255] Through this representational mechanism inventors coevolved the technological substrate of "the arts" towards unforeseen ends through future projections and representation of innovative technology.

Today drawings are now universally included in patent applications, when necessary, to effectively communicate the details of a specific invention. These drawings, along with textual claims, descriptions, and citations, are later published and searchable, facilitating the diffusion of

[254] Biagioli, "Patent Republic: Representing Inventions, Constructing Rights and Authors."
[255] US Government, "United States Patent Act" (1790).

innovation and the communication of technical information. The value of patent drawings is manifold, serving to effectively describe new inventions and simultaneously in the communication of technical knowledge and creation a visual repository to inform future inventions. As Eugene Furgeson argues in “Engineering and the Mind’s Eye,” representations of technology are fundamental to the development and dissemination of technical knowledge, reminding us that Edison’s inventions were first sketches before prototypes – operating like Edison’s automatic printing telegraph to directly communicate information between image and eye. This complex process of representing and communicating technical information involves not only the interpretation of data, text, and equations but also the visual communication of ideas from which new ideas and technologies can be developed.[256] In the context of the patent system, text and image are used to disclose the nature of invention, helping to describe a new technologies scope and application while contributing primary information to the larger knowledge infrastructure of the patent system as it build upon sequential innovations disclosed in drawings and text.

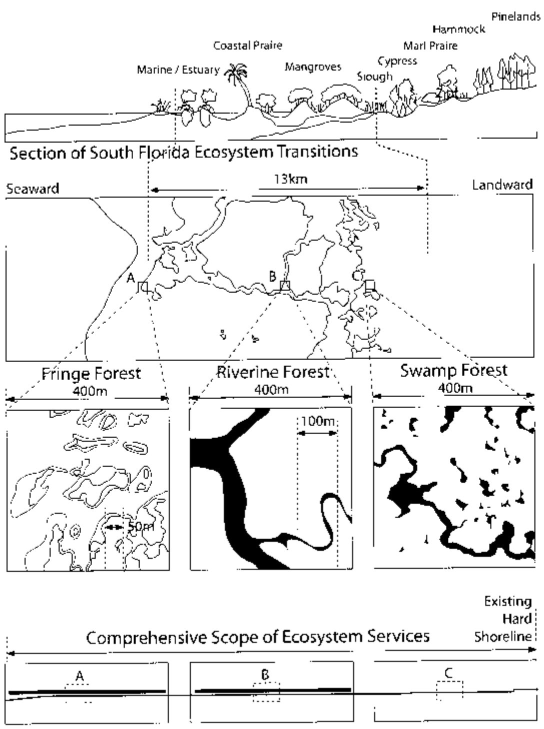

FIG. 4

Figure 26: US8511936B2 “Method and apparatus for coastline remediation, energy generation, and vegetation support” includes maps and ecological data to situate the technology in context (2013). (Source: European Patent Office, https://www.epo.org/en)

Conventional patent drawings, include plan, section, elevation, axonometric, and diagrams, drafted in black and white line and labelled to correspond to textual description in patent claims. Critics argue that drawings of patented technology using patent conventions of technical drawing (I.e. Plan, section, axonometric, diagram, etc.) are deterministic in the types of technology that can be invented, leading to a kind

[256] Eugene S. Ferguson, *Engineering and the Mind’s Eye* (Cambridge, Mass.: MIT Press, 1993).

of banal standardization biased towards mechanized inventions and industrial production.[257] Yet many inventions aim to operate in domains beyond the mechanical and industrial with innovative approaches to the contingencies of site and geography. Briefly consider a recent patent by Keith Van de Riet, Jason Vollen, and Anna Dyson known as a US8511936B2 "Method and apparatus for coastline remediation, energy generation, and vegetation support", also mentioned in chapter 4, which includes technical specifications and mappings that show the ecological extents of the invention.[258] (figure 26)

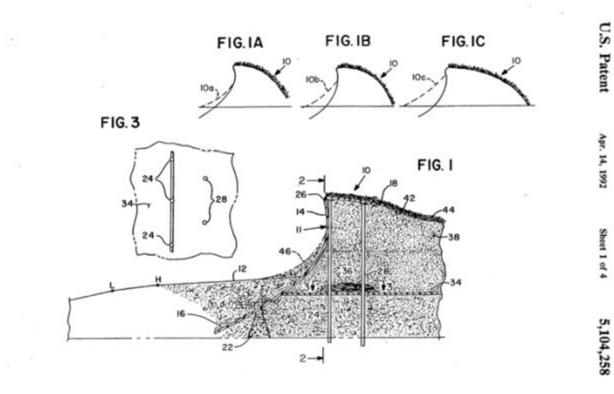

Figure 27: "Bionic dune" US 5104258 (1992) showing technical details of a self-building dune construction system. This invention is now in the public domain and can be freely used and manufactured. (Source: European Patent Office, https://www.epo.org/en).

Numerous technologies and forms of infrastructure converge in coastal zones, and as such coastal technologies have a long history of visual representation in patent documents. These drawings can be invaluable for the communication of technical and environmental knowledge, helping to build robust historiographies and to project future imaginaries. Within the context of coastal adaptation and resilience planning, a vast visual and technical repository exists within the patent archive for the technologies to structure, build, sense, and design adaptive and resilient coastal systems. Since no "construction manual" or "guidebook" exists for adapting coastal systems to climate change, this evolving knowledge infrastructure can serve both heuristically to help problem solve and as a technological database to develop frameworks for innovation. Practitioners and theoreticians can interpret, build upon, debate, or advance these, and early technologies as they build context for future discoveries or technical details. For example drawings of Allan W. Ianall's "Bionic dune" US 5,104,258 (1992) describes the structure and configuration of a dune system

[257] Rankin, William, "The 'Person Skilled in the Art' Is Really Quite Conventional: US Patent Drawings and the Persona of the Inventor, 1870-2005," in *Making and Unmaking Intellectual Property: Creative Production in Legal and Cultural Perspective*, eds., Mario Biagioli and Peter Jaszi (Chicago, IL: University of Chicago Press, 2015).
[258] Van de Riet, K, J Vollen, and A Dyson. 2013. "Method and Apparatus for Coastline Remediation, Energy Generation, and Vegetation Support," US8511936.

designed to turn back sands and waters – offering a novel strategy for self-actuating dune restoration.[259] (Figure 27) The patent includes useful construction details and technical specifications. Importantly, many technologies, such as the bionic dune, are now in the public domain and can be freely produced and replicated by anyone.

Translating Patent Knowledge Infrastructure into Coastal Infrastructure: A case study from the Resilience by Design Bay Area Challenge

In 2017 the Resilience By Design Bay Area Challenge was launched in California, with ten international and multidisciplinary teams selected to develop strategies for sea level rise and climate change adaptation in the region. The "Common Ground" Team, led By Tom Leader Landscape Architects, used patent data and innovation studies, coupled with a heuristic process, to develop innovative strategies for coastal and resilience. Translations between patent knowledge infrastructure and coastal planning processes leverage the vast repository of technical knowledge archived by the global patent system to help problem solve and invent contemporary solutions emerging in the coastal adaptation and resilience. This approach to utilizing patent knowledge infrastructure to conceptualize new forms of coastal infrastructure was tested as part of the Resilience By Design Bay Area Challenge, thus establishing a framework for integrating sociotechnical aspect of innovation into localized site-strategies.

Background and Structure of the Resilience By Design Bay Area Challenge

Resilient by Design "Bay Area Challenge" was modeled on New York "Rebuild by Design", bringing together residents, public officials, and local, national, and international experts to develop innovative community-based solutions to strengthen the Bay Area's resilience to sea level rise, severe storms, flooding, and earthquakes. The Challenge was funded by the Rockefeller Foundation in partnership with the U.S. Department of Housing and Urban Development and supported by a range of local institutions and community partners.

[259] Allan W. Ianell, Bionic dunes, US5104258A, filed June 21, 1991, and issued April 14, 1992.

Organizationally, the program dovetailed with the Rockefeller Foundation's 100 Resilient Cities network, which aims to build social and technical infrastructure for climate adaptation and resilience in cities around the world.

The year-long Resilient by Design Bay Area Challenge is a collaborative design challenge located in the Bay Area of California. It contributed to specific resilience planning in San Francisco, Oakland, and Berkeley, through their involvement with the 100 Resilient Cities program and built capacities for greater regional collaboration to address climate adaptation with sites around the bay area region, including the San Pablo Baylands and southern extents of the bay near Palo Alto and Silicon Valley. The vast geography of the Bay Area presents a distinct planning challenge, as the shoreline crosses hundreds of jurisdictions and countless communities sharing, making coordinated planning efforts a challenge to implement. In response to this dynamic context, sites were assessed and later distributed around the region, with teams composed of design leads, consultants, and community groups in collaboration with local stakeholders.

The Bay Area Challenge launched on May 31, 2017, with an open call for Design Teams to participate and an open request for site suggestions within the regions. Over 50 teams from around the world applied to enter and 10 teams were selected to advance to the research phase. The research phase involved site evaluation and initial focused research on subjects germane to site selection such as subsidence, social justice, and transportation, etc. This process helped to scale and scope project types and geographical regions of interest. The design teams included firms such as AECOM, BIG, Bionic, TLS, Field Operations, Mithun, Base Landscape, SCAPE, Gensler, who guided team selection, site selection, and all phases of stakeholder collaboration in dialogue with the program management team and design jury.

The Collaborative Design phase (i.e. final design phase) kicked off in January 2018, with community meetings and the formation of local advisory groups in each project area. Nine projects and teams advanced through the year-long process, including Elevate San Rafael (Bionic), Unlock Alameda Creek (Public Sediment), The Peoples Plan (P+SET), South Bay Sponge (Field Operations Team), Estuary Commons (ABC), The Grand Bayway (Common Ground), Connect and Collect (Hassell+), ouR-Home (Home Team), Islais Hyper-Creek

(BIG+ONE+Sherwood). In essence each design team develop innovative design proposals for their final sites, including frameworks for research, social engagement, and implementation, etc. The competition, now completed, is extensively documented on the Resilience By Design Bay Area Challenge website and as part of a limited circulation publication that offer a comprehensive overview of the process and outcomes.[260]

Site, Team, and Project Narrative

The Common Ground Team selected the San Pablo Baylands, and its adjacent infrastructure and urban fabric as a site. The Common Ground Team was comprised of landscape architects, urban designers, architects, scientists, artists, educators, economists, community organizers, academics, ecologists, and civil, hydrological, geotechnical, and structural engineers. The team was led by Tom Leader (TLS) landscape architecture, and team members included in the San Francisco Exploratorium, Guy Nordenson and associate, Michael Maltzan architecture, Sitelab urban studio, HR&A Advisors, Lotus Water, Rana Creek Design, Dr. john Oliver, Richard Hindle (author), Fehr & Peers.

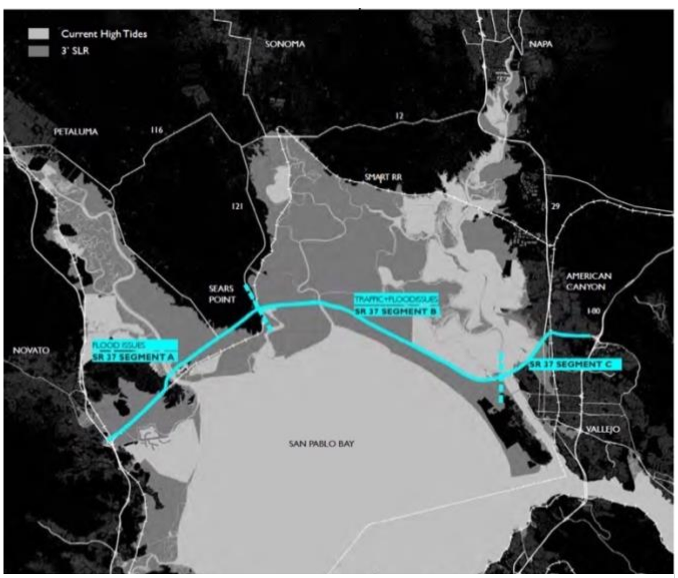

Figure 28: Site location and context - San Pablo Baylands, State Route 37, and Sea Level rise (Image credit: TLS & "Common Ground" Team, 2017-2018)

The site selected by the team was the San Pablo Baylands mash west of Vallejo, California, and State Route 37. A major component of the project was a restoration of the highly degraded, channelized, and subsided wetland now operating as agriculture, bound by levees, and traversed by California State Route 37 (figure 28). The heterogenous nature of the site presented distinct challenges, including how to reclaim the agricultural lands that are now below sea level due to subsidence. The mosaic of

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[260] "Bay Area: Resilient By Design Challenge," Bay Area: Resilient By Design Challenge, accessed June 21, 2021, http://www.resilientbayarea.org.

agricultural lands reveals acute problems with the site's topography, with some areas now transitioning to open water though levee breeches, and others remain actively cultivated.

State Route 37 was identified as a major issue, leading to the proposed Grand Bayway causeway. The road now exists as a low-lying commuter route that skirts the northern edge of San Pablo Bay, where it is simultaneously traffic-choked and increasingly flood prone due to sea level rise. The highway structure is situated on a precarious 'ballast' levee that confines an immense marsh complex at the interface of the Napa River, several creeks, and the San Pablo Bay situated between Carquinez Straight and the San Francisco Bay. The core of the site contains two large zones with distinct marsh ecosystems associate with the estuary of the Napa River and the San Pablo Bay – a complex coastal ecology known as the San Pablo Baylands. Historically, the western baylands were farmed and the eastern baylands that were used for salt ponds. Today cattle grazing and agriculture is still active, thought there is an effort towards restoration with limited success. The large portion of the site that was farmed for over 100 years lost much of the peat in the soil and had no input of sediment during that time, resulting in areas of land subsidence up to 7 feet. Restoring these areas by conventional means would consume a huge amount of resources so innovative strategies and novel approaches are essential to a future vision.

Figure 29: design vision for the "Grand Bayway", replacing state route 37. (Image credit: TLS & "Common Ground" Team, 2018)

The team developed a multifaceted approach to the site and a framework for the "Grand Bayway". The proposal aims to resolve the transportation problem of Highway 37 by designing a scenic elevated causeway that allows tidal flows and natural marsh migration to return to a natural condition. The causeway was designed with other iconic bay area crossings in mind, with expanded consideration for the natural environment and multimodal transit types. Principles of scenic byway design, curving to open views over the Bay and marshes and oriented to natural landmarks. The proposal established a new entryway to the San Francisco Bay Area. The team branded the project as an ecological "Central Park" for the region, as it aims to create value for the region, its identity, and its future. A grand mobility loop was proposed to encompass the open space involving pedestrian and bike routes collocated with an excursion train using an existing freight line. Importantly, the huge bay lands complex is inextricably linked to the resolution of the highway and the team invested considerable time developing strategies for this complex coastal landscape.

Building a Technical Dossier - The Patent System as Knowledge infrastructure for site design technologies

The core capacities of the patent system include a range of search, metadata, citation networks, language translation, image, and ever evolving classification systems serve as vital knowledge infrastructure for all sectors of innovation, including coastal adaptation and resilience. The importance of this innovation knowledge infrastructure is the subject of debate. However, it may be understood as serving not only the goals of industry, but also broader societal goals effective use of innovation and dissemination of knowledge. For example, the World Intellectual Property Organization (WIPO), a specialized agency of the United Nations located in Geneva, Switzerland, promotes "development of a balanced and effective international intellectual property system that enables innovation and creativity for the benefit of all."[261] In service of this mission, the WIPO utilizes the knowledge infrastructure of the patent system to advance strategic initiatives such as linking innovation to issues of global development and policy.[262] Of course, the innovation knowledge infrastructure not only has tangible implication for management of sequential innovation and global development issues, the systems also has the capacity to facilitate discovery, share knowledge, and providing

[261] "World Intellectual Property Organization," accessed June 14, 2023, https://www.uspto.gov/ip-policy/patent-policy/world-intellectual-property-organization.
[262] Yo Takagi, "WIPO's New Strategies on Global Intellectual Property Infrastructure," *World Patent Information* 32, no. 3 (2010): 221–28.

information that may be utilized and translated in legal, technical, and non-technical domains alike – including coastal adaptation and resilience sectors.

Patent documents, and their metadata, are widely used by inventors, companies, and scholars to construct innovation studies, define areas of innovation, and build upon technological trajectories in a range of technology sectors. For example, in the field of patent informatics patent data is used for predictive an analytical research forecasting trends in technological innovation, policy, economics, and society.[263] Individual corporations may also use patent data to help understand a business's capabilities, relationship to others in the industry, and to establish technological positions within a sector.[264] Patent data research relies on a wide range of research methods, including big-data 'scraping' to discover macrotrends to detailed analysis of specific patented technologies. Together the data and detailed information of specific patented technologies represent one the world's largest repositories of technical information that can be interpreted and translated in technical, and non-technical domains alike through the core functions of the global patent system is the capacity of search, citation, and classification of technology.

In the specific case of the 2017 Resilience By Design Bay Area Challenge, the Common Ground team utilized technical information from individual patents and analysis of their associated groupings, to develop a coastal adaptation and resilience strategy. Three types of publicly accessible searches were used during this process, including classification searches, citation searches, and keyword searches. This allowed the team to rapidly gain knowledge about the innovation landscapes related to the project and build upon established technologies, such as the site-integrated "sediment train" which advanced ideas disclosed in US1980634 "Method of Building Levees" (1932/34).[265] The system, now in the public domain, utilized railroad tracks and dragline excavators to coordinate levee construction and sediment management – serving

[263] Assad Abbas, Limin Zhang, and Samee U Khan, "A Literature Review on the State-of-the-Art in Patent Analysis," World Patent Information 37 (2014): 3–13; Ben Buchanan, "Unlocking the Value of Patent Data: Patent Informatics Services at the UK Intellectual Property Office (UK-IPO)," *World Patent Information* 30, no. 4 (2008): 335–37; Juite Wang and Yi-Jing Chen, "A Novelty Detection Patent Mining Approach for Analyzing Technological Opportunities," *Advanced Engineering Informatics* 42 (2019): 100941.
[264] Shann-Bin Chang, "Using Patent Analysis to Establish Technological Position: Two Different Strategic Approaches," Technological Forecasting and Social Change 79, no. 1 (2012): 3–15.
[265] William E. Philips, Method for building levees, US1980634A, filed November 14, 1932, and issued November 13, 1934.

as a precedent for a similar system as part of the site plan (figure 30).

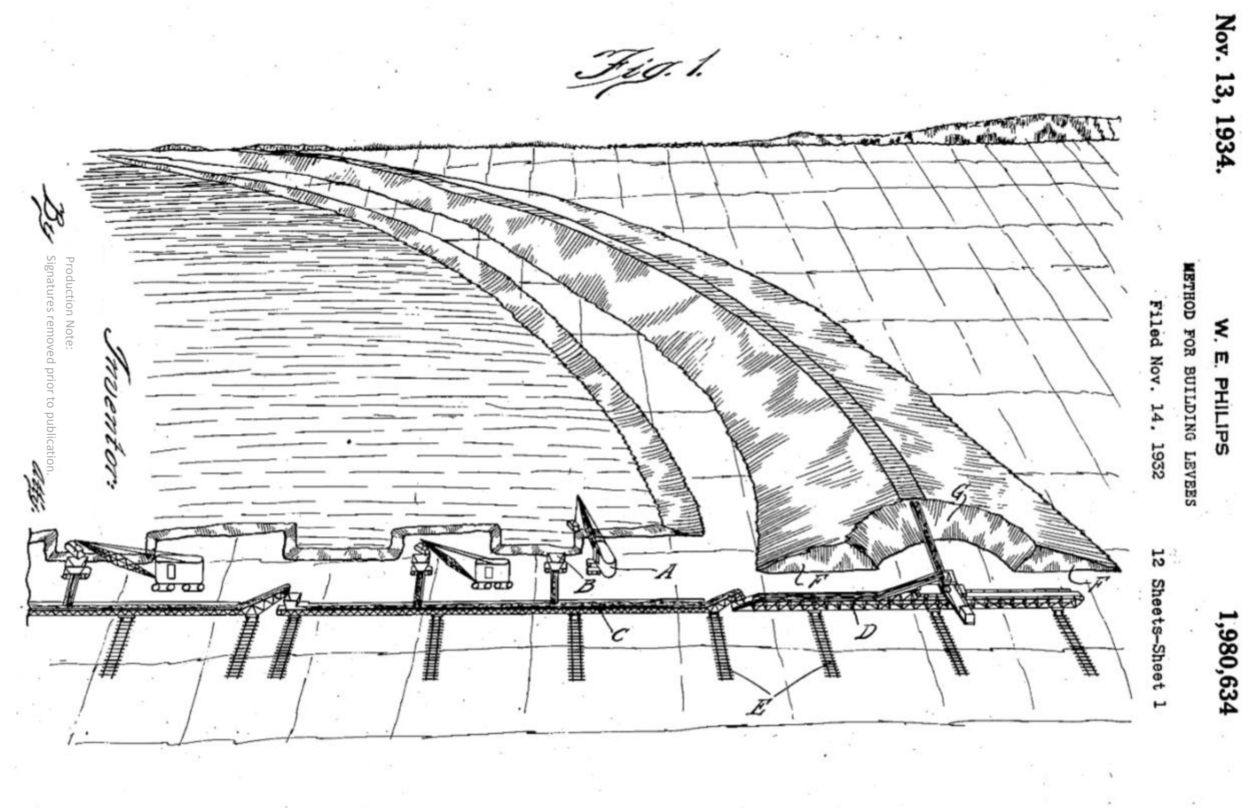

Figure 30: Drawing from US1980634 "Method for Building Levees" which provided technical information and conceptual precedent for the "sediment train" proposed by the Common Ground Team for use in deltaic restoration. (Source: European Patent Office, https://www.epo.org/en)

Citation networks essentially link prior art, and future inventions, using citations. Just as in scientific literature, patents include citations of prior art and non-patent citations to ensure the claims made by the patent are novel and constitute a substantively new contribution. Citation networks provide an important window into specific sectors of technology. Citation searches are among the simplest to conduct as bibliographic data is associated with each patent for citations and future reference to each patent. Accessing this information is simple through free online searches, and the data acquired in this manner can also be used to construct more robust network mappings or serve as the basis for advanced research in a specific sector. For example, recent publications on innovation in the building sector used patent citations as the primary method, concluding advances in computer, communication technology in the industry and recommend incentives for energy technology.[266] Google patents, the USPTO, and European Patent office, can all be used to construct citations networks that situate individual patents within a context or prior art and evaluate their relationship to future inventions. They can expand the notion of a singular invention and suggest areas for further research. Importantly they provide context for design interpretation through recognition of prior-art. Citations searches helped the Common Ground Team identify a suite of leading edge artificial reef technologies for inclusion in the San Pablo Baylands Scheme and also to the creation of a living "benthic lab" to test and evaluate new ecological technologies such as US6824327 for an "Artificial Barrier Reef" and the citation web of 33 past, and present, inventions included in its references (figure 31).[267]

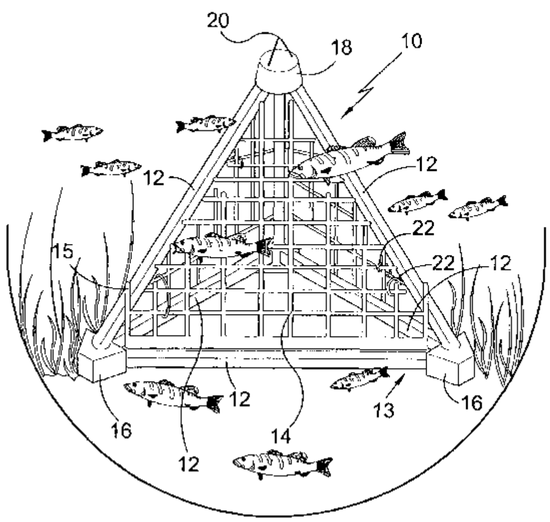

Figure 31: US 6824327 for an "Artificial Barrier Reef" (Source: European Patent Office, https://www.epo.org/en)

Linkages between inventions are made through citations, just as ideas are cited in scholarly literature. Citation of prior-art and patent classification are fundamental to the patent system, creating networks of related technologies to prove novelty and also situate a patented technology in context. These citations may be mapped to create citation networks and are valuable in innovation studies within and outside technological fields. For example, the metadata associated with a patent and its citation network may be used to not only to model innovation but to comprehend complex relations between urban planning and innovation.[268]

Keyword Searches provide another robust search tool within patent search databases. When coupled with customized date ranges, and issuing patent office criteria, assignee, and other meta-data keyword searches can provide a window into the innovation landscape associated with particular types of technology. In simple terms, keyword searches function like

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[266] Joy E Altwies and Gregory F Nemet, "Innovation in the US Building Sector: An Assessment of Patent Citations in Building Energy Control Technology," *Energy Policy* 52 (2013): 819–31.
[267] David M. Walter, Artifical barrier reef, United States US6824327B1, filed May 27, 2003, and issued November 30, 2004
[268] Jung Won Sonn and Michael Storper, "The Increasing Importance of Geographical Proximity in Knowledge Production: An Analysis of US Patent Citations, 1975-1997," *Environment and Planning* A 40 (2008): 1020–39.

other web searches allowing searchers to find specific documents, asses the relative frequency occurrence of a particular term, or gain knowledge about its relative scarcity within the assigned search criteria. This intuitive type of patent search is invaluable as a starting point for research, but also can be generative for more complex innovation studies. For example, researchers use keyword search networks to map sectors of technology and evaluate amount of patent innovation occurring in specific sectors. Importantly this approach can also be used to identify areas in which patent innovation is lacking, therefore suggesting areas of technology where new investment, research, and development may be warranted.[269] The mining of patent text also yields interesting insights about technology, with new tools available for analysis of massive textual data sets.[270] During the technical assessment phase of the of the Resilience By Design competition the Common Ground Team used keyword patent searches as a form of net casting, allowing them to build patent portfolios for initial concept for artificial island building and the creation of floating wetlands. This included initial evaluation of speculative technologies such as US4397587 "Method Of Constructing An Artificial Island And Island Constructed By The Same" which utilized a vast matrix of vegetation and sediment to build ground (figure 32).[271]

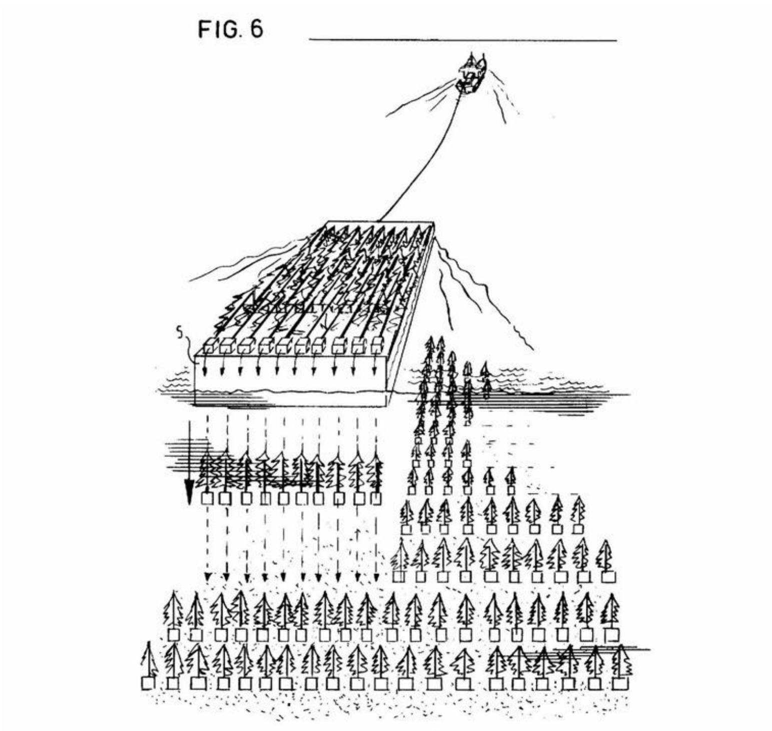

Figure 32: US4397587 "Method Of Constructing An Artificial Island And Island Constructed By The Same" (1980). Showing the process of arraying trees to form and island. (Source: European Patent Office, https://www.epo.org/en)

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[269] Sungjoo Lee, Byungun Yoon, and Yongtae Park, "An Approach to Discovering New Technology Opportunities: Keyword-Based Patent Map Approach," *Technovation* 29, no. 6–7 (2009): 481–97.
[270] YunYun Yang et al., "Text Mining and Visualization Tools–Impressions of Emerging Capabilities," *World Patent Information* 30, no. 4 (2008): 280–93.
[271] Den Velde Jan Op, Jan B. Elzerman, and Klaas Oterdoom, Method of constructing an artificial island and island constructed by the same, US4397587A, filed October 6, 1980, and issued August 9, 1983.

Patent classification searches may also provide insights about technological trends. Patent classification systems have evolved over time to group and organize patented inventions by sector. For example, the United States Patent Classification (USPC) initially contain 16 classes of technology in 1836 and by 2014 more than 430 classes were created to keep pace with technological innovation.[272] Patent classification is a system of sorting inventions and their documents into technical fields covering all areas of technology, including areas of new technology that are not yet classified. By organizing patent by classification, each document can be found based on sector as well as through keywords, etc., facilitating searches and insights about technological concepts and their relationships.[273] Benefits of patent classification systems make it easier to file and retrieve patent documents, and also to look back in time to find antecedents of technology. These classification searches played a central role in building the technical dossier as part of the Common Ground team, particularly in areas of arcane knowledge such as plashing (i.e. structurally woven hedge/fences) which were used by the design team to delineate boundaries and capture sediment in "accretion gardens," unearthing technical details and drawings such as those describing US380450A for "Hedge" (1888).[274] Today the Y02A classification scheme aims to reorganize patent classifications searches for the "technologies of climate adaptation" making the searches for related technologies more accessible and efficient.

Methods – Design Heuristics and Technical Specifications from Patents

The research and design development stages of the project utilized patent innovation mapping to establish a baseline understating of the technological landscape associated with the core issues facing the site – namely the challenge of a sediment deficit and a dearth of time to prepare land for sea level rise. The team focused research on finding more innovative ways to build land in the bay lands and create a resilience coastal ecosystem, this included budgeting existing sediment resources to greatest effect, designing ways to redirect sediment in flood

[272] Simmons, "Categorizing the Useful Arts: Part, Present, and Future Development of Patent Classification in the United States."
[273] Tiziano Montecchi, Davide Russo, and Ying Liu, "Searching in Cooperative Patent Classification: Comparison between Keyword and Concept-Based Search," *Advanced Engineering Informatics* 27, no. 3 (2013): 335–45.
[274] Mitchell james, Hedge, US380450, filed 1888, and issued April 3, 1888.

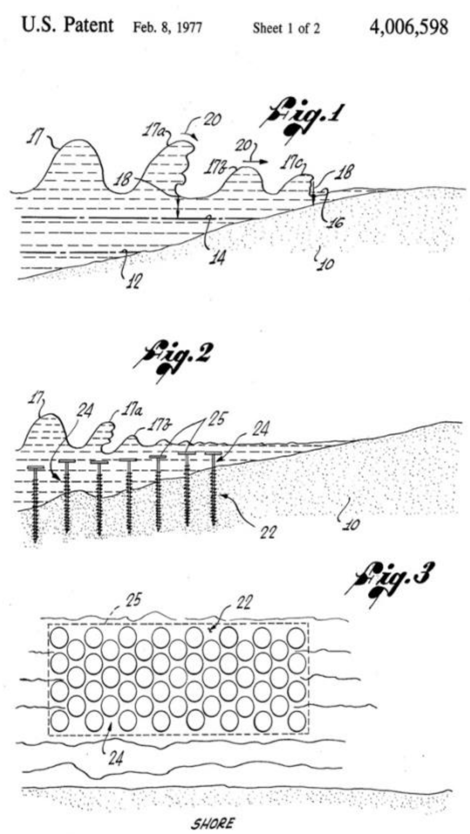

Figure 33: US4006598 "Breakwater System" - an example of patents included in the technical dossier for specific site technologies. (Source: European Patent Office, https://www.epo.org/en)

events, direct sediment through both natural and artificial processes to existing marshes and future retreat zones, the control of water, and establishment of artificial ecologies on the site.

Instead of providing fixed masterplan and rigid infrastructure for the 50,000-acre site (20,234 hectares), the contingencies and phasing of the site strategies were linked to specific site timelines and relevant technologies for accretion of sediment, benthic ecology, water regulation, and incremental adaptations to sea level rise. Each landscape condition was the linked to an innovation dossier of patented technologies that might be used to structure the site. In certain instances, specific site assemblies were suggested, and integrated into the design, showing how each technology would impact the site and future scenarios for the region.

The team adapted existing technologies to the design framework, and then made informed suggestions for future needs based on these innovation studies. For example, concepts such as "permeable dikes" were developed through patent research and design iteration, translating details from patents such as US4006598 "Breakwater System" into site strategies for structures that allowed for the flow of water while armoring site elements and building ground at the wave impacted foreshore (Figure 33).[275] Collectively This led to novel site designs at detail and regional scales, while linking geographical contingencies to technology. The knowledge infrastructure provided by patent archives and technical specifications were integral to the process, including patent drawings and technical specifications.

[275] Jobst Hulsemann, Breakwater system, US4006598A, filed November 24, 1975, and issued February 8, 1977.

In the initial net-casting phase of the design process an extensive list of possible strategies emerged through discussion and design iteration. As ideas were posited by the team specific language, sketches, and precedent images were compiled into 26 final categories, including descriptions. The concepts, keywords, and drawings, compiled during this process were used to conducted patent searches. keyword, classification, and citation network searches were conducted and from this a visual and textual dossier of “prior-art” was created to facilitate the creative ongoing process and was winnowed through discussion and revision to include a wide array of related technologies This net-casting involved a range of subject categories for conceptual development, including Channel Chamfers, Plashed Hedgerows, Structural Sediment Accumulators, Water Gates, Biomass Farming, Carbon Sequestration (soils), Micro-topographies, Sediment Train, Artificial Seaweeds, Benthic habitat / Artificial Reefs, Artificial Islands, Groundwater Recharge, and Mollusk Habitat, etc. (Figure 34 & Table 4).

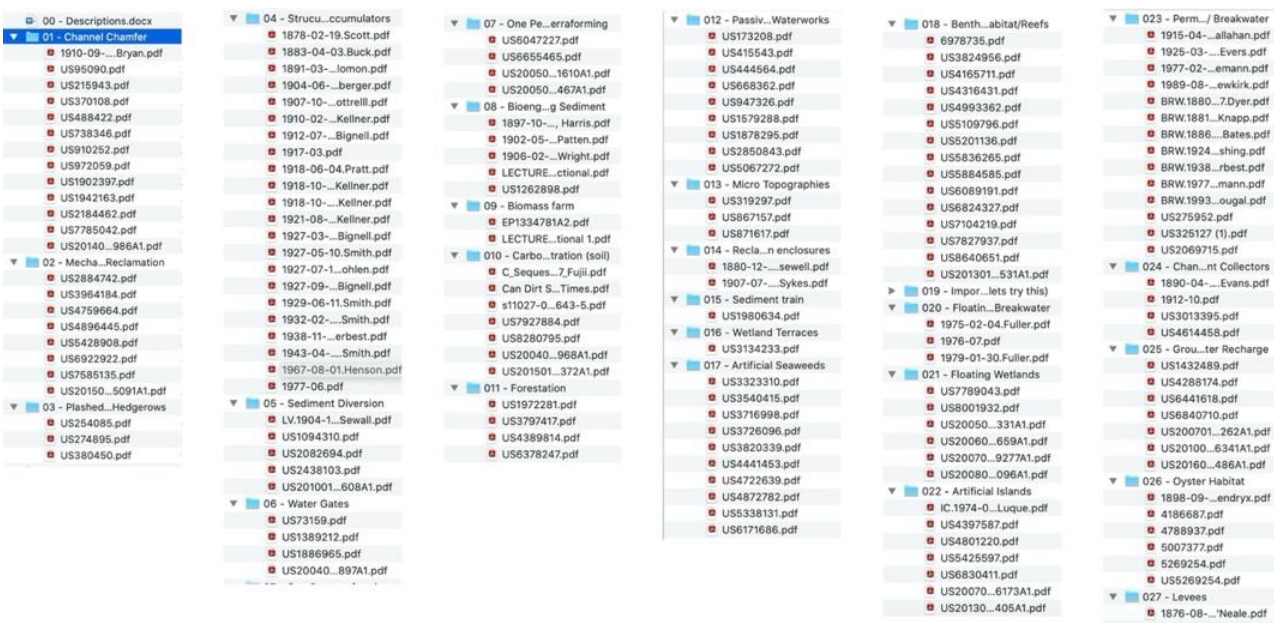

Figure 34: Patent Dossier (Text/Image) for use by the design team (Source: TLS & "Common Ground" Team, 2017-2018)

The patents related to each category functioned as carriers of innovation that create context for innovation and help define technical domains during the design process. In this context patent archiving and collating creates a heuristic from which inventors may borrow, adapt, and innovate.[276] Heuristics can become an essential method to defining new technologies or for strategic design thinking. In the field of engineering design heuristics are often used to help generate new concepts through sketching and other forms of ideation.[277] Similarly, in the fields of industrial and product design heuristic methods utilizing existing product knowledge and datasets facilitate the creation of innovative new solutions to fundamental design problems.[278] Beyond the envisioning and net-casting heuristic process, the patent innovation studies also provided technical specifications and details associated with specific coastal infrastructure, such as artificial benthic ecology and floating wetlands. These technical specifications reveal the value of patent knowledge infrastructure for the diffusion of innovation.

Living Lab - Innovation as Infrastructure

The team envision the San Pablo Baylands as a territory in process – a national experiment at the cutting edge of reclamation and adaptation to sea level rise. To accomplish this vision the team proposes a planning framework that embraces experimentation, and works to solve complex issues related to subsidence, sea level rise, and ecological degradation. The site therefore is structured as a series of experimental reclamation sites that borrow from historical precedents and leading-edge technology. The research phase involved the development of coastal landscape technologies that addressed issues related to the site. These typologies were developed during collaborative team meetings involving a range of experts, including ecologist, technologist, planners, and designers.

Central to this concept was the "living lab" as an institutional proposal for the site built on the need for ongoing innovation. A general theory of invention suggests that searching is the essential framework for discovery involving the iterative and recursive stages of stimulus, net casting, categorization, linking, and discovery.[279] It is hypothesized that in the process of searching, inventors gather information inside and outside of their domains to create mental

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[276] Stefan Bechtold, Christopher Buccafusco, and Christopher Jon Sprigman, "Innovation Heuristics: Experiments on Sequential Creativity in Intellectual Property," Ind. LJ 91 (2015): 1251.
[277] Shanna R Daly et al., "Design Heuristics in Engineering Concept Generation," 2012.
[278] Seda Yilmaz et al., "Design Heuristics in Innovative Products," *Journal of Mechanical Design* 138, no. 7 (2016).
[279] Edwards, "Knowledge Infrastructures for the Anthropocene."

schemas to link ideas, build context, and make new discoveries. The process of searching and knowledge of previous developments in a specific domain are vital to the process of new discoveries or creation of novel ideas. This process was built into the Bayland project to create adaptive capacity on the site to prepare for rising sea levels through establishment of a living lab within the masterplan founded on innovation. The proposal creates an ecological laboratory working strategically with streams and diked sloughs to incrementally re-engage sediment deposits and cultivate biodiversity though various means including “sediment trains,” hyper-accretion gardens, and artificial marine ecology. The strategy for deltaic restoration and management evolved through an iterative search, research, design testing, and revision process using patent innovation studies to develop strategies for coastal adaptation and resilience and aimed to integrate this working method into the site in perpetuity. The idea of a living lab and test-ground for innovative new technologies was a core principle of the overall design. In essence the goal was to link broad aspects of technological innovation to the site development, thus translating patent innovation into innovative strategies for coastal adaptation and resilience.

Innovative Site Strategies for building ground

Figure 35: Site diagram showing areas of hyperaccretion, and open water based on site topography and hydrology. (Image credit: TLS & "Common Ground" Team, 2018)

Strategies for restoration and management of the San Pablo Baylands evolved from a reading of the sites natural systems, cultural history, and the heuristic process evolving from patent innovation research. This process led to an innovative landscape strategy built on the creation of hyperaccretion “gardens” along existing channels, areas of open water serving as a marine ecology lab, and a fixed sediment train to distribute sediment sources throughout the site (figure 35). Working with land and topography as a medium of innovation was central to the project thesis, facilitating the conceptualization of a landscape mosaic with wetlands, sediment transport, and open water, that maximized site performance given the realities of sediment deficit and sea level rise. The three site strategies outlined below exemplify the dynamic interplay between technology and site, revealing how patent innovation studies were translated into site design and planning.

Hyper-Accretion Gardens

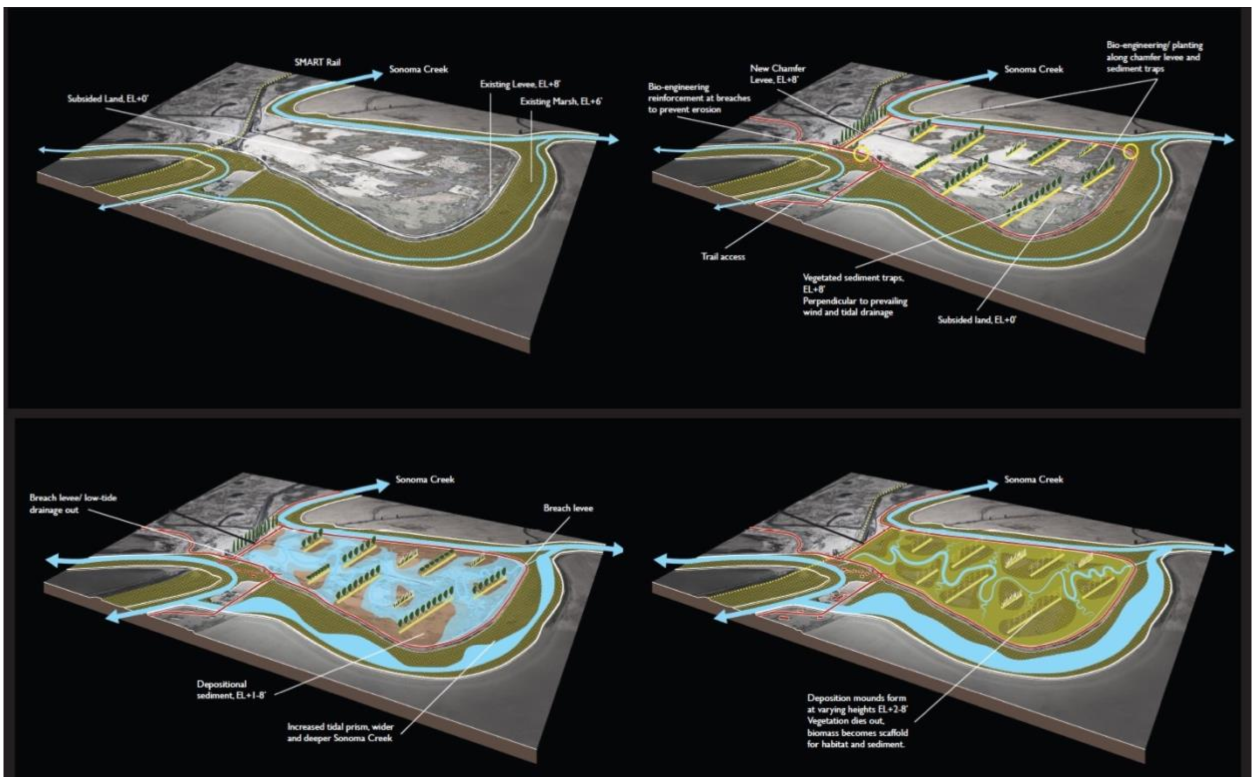

Figure 36: Diagrammatic rendering of hyperaccretion gardens located at channel bends. (Image credit: TLS & "Common Ground" Team, 2018)

Sediment capture and stabilization from naturally occurring creeks, sloughs, and waterways was essential to build and maintain ground in the Baylands. A central feature of the site strategy was modular levee breaches along elevated sloughs and waterways where sediment could accumulate at bends, or meanders in the waterway (figure 36). In principle the concept evolved from an early 20th century patent US969334A "System to prevent the overflowing of rivers" which discloses a river with two channel flows mediated by weirs and braided channels (figure 37).[280] The team referred to these in the masterplan as hyperaccretion gardens where sediment would accumulate at rates faster than adjacent areas. These discrete “gardens” were structured using experimental wattle fences, lattice berms, structural sediment capture devices, and water diversion, designed to accelerate natural sedimentation in both tidal and upland watersheds by “chamfers” in the channel to create new basins and channel geometry. At each potential site for hyper-accretion small, experimental, and innovate prototypes that are calibrated to various conditions throughout the Baylands, and a range of technologies were evaluated for suitability.

The Hyper-accretion gardens, located a channel chamfers, were sited in areas where they would work with land, topography, and water. Within the gardens were an array of systems, structured using novel devices from historical and contemporary patents, designed to maximize sediment accretion. This included specific subject covered by the technical dossier such as Sediment Diversions, Structural sediment accumulators, plashed hedgerows, and bioengineered sediment capture systems. The sediment diversions would be located in channels to capture bed load, or bottom sediment, and transport it to a sediment sink in the form of an enclosure or area of sediment deficit. Structural Sediment Accumulators would be sited in a manner to aims to slow water and control currents to promote the accretion of sediments through structural geometry that modifies flow and cause turbulence. Plashed Hedgerows were integrated to the site to block wind and capture organic material within the gardens and structure the

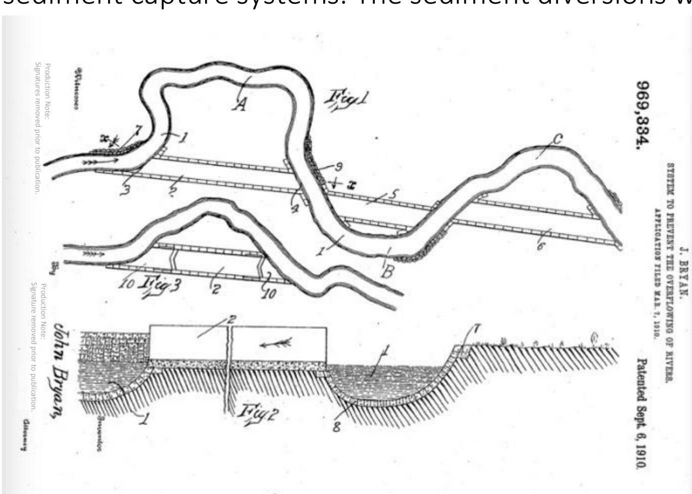

Figure 37: US969334 "System to prevent the overflowing of rivers" (1910). Conceptual and technical precedent for channel chamfers. (Source: European Patent Office, https://www.epo.org/en)

[280] John Bryan, System to Prevent the Overflowing of Rivers., US969334A, filed March 7, 1910, and issued September 6, 1910.

spaces by creating enclosure. And the Bioengineering Sediment Capture systems built experimental plots of living plant material to stabilize earth. When applied to the process of reclamation and reversal of subsidence, bioengineering dovetails effectively with the reuse of sediment slurries from hydrologic dredging. Bioengineered enclosures can retain sediment in a preformed geometry, allowing water to pass through fascines, woven wall, and living encloses, while retaining and stabilizing the sediment (figure 38).

Figure 38: Rendering of hyperaccretion garden showing the landscape configuration and embedded technologies. (Image credit: TLS & "Common Ground" Team, 2018)

Sediment Train

Central to the site's sediment budget was the creation of a "sediment train" to move vast quantities of material through the subsided landscape. The team determined that the greatest impediment to using dredge material to build subsided lands and nourish imperiled and eroding marshlands is the cost of transport and placement. In many places around the San Francisco Bay, the sites in need of sediment are not easily accessed. Thus, much of this material is dumped outside of the Golden Gate Bridge via barge. In the San Pablo Baylands, the existing and underutilized rail corridor circumnavigates the marshlands at an elevation that roughly corresponds to the 100-year high water level for sea level rise, making it ideally situated for a fixed rail sediment transportation system such as that outlined in the aforementioned patent US1980634 “Method of Building Levees”, which utilized railroad tracks and dragline excavators to coordinate levee construction and sediment management. This patent, in combination with a series of integrated technologies for sediment dewatering and movement, such as US20060162195A1 "System and method of dewatering dredge spoils using sloping drain barge” served as the core systems for bulk sediment transportation (Figure 39).[281]

Once the core technologies were understood, the team mapped the elevation capital for the marshes and found that the rail corridor is an excellent opportunity for future marsh and upland transition zones using the sediment sources available. Taking advantage of the intersection of the rail and navigable channel at the mouth of the Petaluma River, open-topped dump train cars would be filled with dredge spoils via barge and delivered to any place along the rail corridor. In places where the rail is near marsh habitats, sediment deposition would need to occur in relatively small increments or “lifts”. In addition, pairing this nourishment approach with an upland transition species plant restoration would provide future high water refugia for wildlife and provide the biomass that is critical for catching the suspended tidal sediments that will eventually reach the new sediments as sea-level rises.

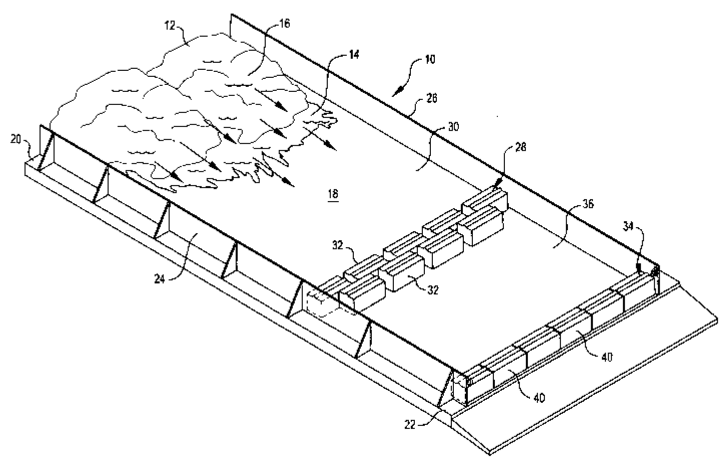

Figure 39: US20060162195A1 "System and method of dewatering dredge spoils using sloping drain barge."(2006) Part of the project technology portfolio. (Source: European Patent Office, https://www.epo.org/en)

[281] Brian B. Langdon, Kenneth a Preston, and Thomas E. Coultas, System and method of dewatering dredge spoils using sloping drain barge, US2006162195A1, filed January 26, 2005, and issued July 27, 2006.

Artificial Marine Ecology and integrated Structural systems

Figure 41: Open water benthic ecology rendering, showing the landscape morphology and technologies to be used. (Image credit: TLS & "Common Ground" Team, 2018)

As sea level rises ocean/bay water will fill the Baylands in areas below sea level even though systems are in place to ameliorate this issue. The team embraced this reality, and conceptualized open water system that would armor the site and build artificial ecologies in newly formed bodies of water (figure 40). The team proposed a series of structural interventions in the newly formed body of water, including floating breakwaters to attenuate wave suspension of mud, artificial islands, and artificial reefs in the benthic zone to rebuild ecology as the sites transition from dry to submerged habitats. Floating breakwaters would be used to increase sediment deposition and grow a shoreline as sea level rises. Artificial islands would create habitat heterogeneity and experiential interest for visitor. And the artificial reefs and habitat structures would help build new ecological communities that are essential for site colonization.

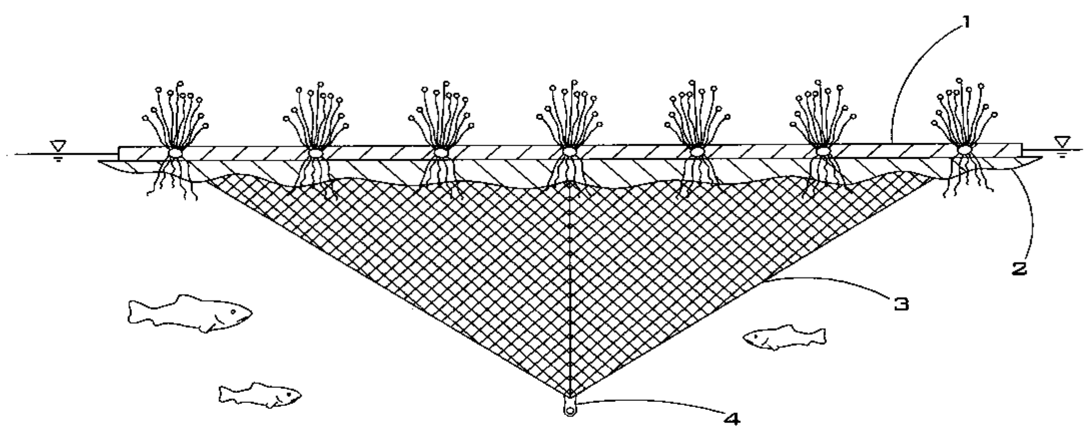

Figure 40: US20050183331A1 "Super-enhanced aquatic floating island plant habitat" – one of the many floating systems incorporated into the newly formed bodies of open water on the site. (Source: European Patent Office, https://www.epo.org/en)

Given the complexity of these systems it was envisioned that they would function as natural experiments that include monitoring and further revision of technologies used as part of the living laboratory. San Pablo Bay is clear natural laboratory for developing these ecological research programs embedded in human communities and activities as it is one of the most subsided and degraded sites in the Bay Area and one of the first predicted to me impacted by sea-level rise, meaning that knowledge can be gained rapidly in preparation for other analogous sites. The initial technologies implemented to build these systems would be evaluated through ongoing research, contributing to knowledge on the establishment of new ecologies in subsided landscapes. The patent dossiers for artificial reefs, artificial islands, and floating breakwaters, informed these decisions and helped establish a framework for ongoing innovation (figure 41).[282]

Discussion

Given the close relationship between technological innovation and the development of coastal regions the patent archive serves as a valuable dossier of visual and textual information, both historical and current, that may be interpreted and applied in the context of coastal adaptation and resilience works. Translation between the technological knowledge infrastructure of the global patent archive and the applied works planning and design presents distinct opportunities to link the sociotechnical processes of innovation to real-world project sites. The recent establishment of the Y02A has the potential to streamline this process, making knowledge about coastal innovations readily accessible and available for integration into praxis. This knowledge infrastructure can serve both heuristically to help problem solve and as a technological database to develop frameworks for innovation. During the 2017 Resilience by Design Bay Area Challenge, the Common Ground Team coupled patent-innovation studies with a heuristic process to develop innovative strategies for coastal resilience. Each landscape condition was linked to an innovation citation network of patented technologies that might structure the site. In certain instances, specific site assemblies were suggested and integrated into the design, showing how each technology would impact the site and future scenarios for the region.

[282] Bruce G. Kania et al., Super-enhanced aquatic floating island plant habitat, US2005183331A1, filed July 1, 2004, and issued August 25, 2005.

Patents are often translated in the humanities, design, and in other non-technical domains to develop broader narratives about law, society, history, and environment.[283] Similarly within design disciplines, patent drawings and images can help track the evolution of designs and develop strategies for innovative works in a particular field.[284] These translations have different outcomes depending on disciplinary scope and epistemology leading to varied forms of scholarship and creative works. Within the allied fields of environmental design and planning this knowledge infrastructure has the potential to inform site-strategies for coastal adaptation and resilience, helping to build on sequential innovation. As a form of innovation-knowledge infrastructure, the patent archive is essential in tracking progress in technical fields. It chronicles developments and establishes a precedent of prior art, archiving specifications, claims, and drawings while providing metadata for research, interpretation, and discovery. In emergent sectors such as coastal adaptation and resilience, this combinatory process is precious, contributing technical specifications, visual references, and future imaginaries to complex problems with planetary scope.

Table 4: Initial "Net Casting" categories used to initiate prior-art searches and built a patent dossier. (Source: TLS & "Common Ground" Team, 2017-2018)

01 Channel Chamfers: *This process expands the territory of sloughs and channels through the addition of an elevated levee wall that "chamfers" the channel to create new basins and channel geometry. It is conceptually based on patent US969334 which creates a secondary river channel for expeditious flow of flood water. We have modified the principles of the patent to facilitate sedimentation.*
02 Mechanical Reclamation: *Mechanical Reclamation processes involve the movement and placement of sediment using machines. Specialized marine and terrestrial vessels extract and distribute sediment slurries to facilitate land reclamation and marsh restoration. Varied techniques exist and might be tested at the San Pablo Baylands*
03 Plashed Hedgerows: *Plashing is a 19th century technique for making woven fences from living plant material. Typically plashing integrates tensile materials, such as metal wire, into the assembly given the hedges increased strength and allowing for beautiful woven patterns. Plashing is a useful tool for establishment of the Hyper accretion gardens as the bioengineered material that structures the garden may be reinforced.*
04 Structural Sediment Accumulators: *The geometry of sediment accumulators aims to slow water and control currents in an attempt to promote the accretion of sediments. The structures are open, or permeable, and aim to alter flows and cause turbulence. They area is especially well suited to the hyper accretion sites in conjunction with channel chamfer structures.*

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[283] David Reymond, "Patents Information for Humanities Research: Could There Be Something?," *Iberoamerican Journal of Science Measurement and Communication* 1, no. 1 (2021): 006–006; Hindle, "Patent Scenarios for the Mississippi River"; Mario Biagioli, Peter Jaszi, and Martha Woodmansee, Making and Unmaking Intellectual Property: Creative Production in Legal and Cultural Perspective (University of Chicago Press, 2015).

[284] Rain Chen, "Design Patent Map Visualization Display," *Expert Systems with Applications* 36, no. 10 (2009): 12362–74.

05 Sediment Diversions: *In channel sediment diversions capture bed load, or bottom sediment, and transport it to a sediment sink in the form of an enclosure or area of sediment deficit. In the San Pablo Grand Baylands, sediment from sloughs and rivers can be captured a reused in other locations with passive, or limited mechanical means, by harnessing peak flow from fluvial systems and cyclical tidal action.*
06 Water Gates: *The control, or syncopation, or moving water is essential as a new geomorphology is created at the San Pablo Grand Baylands. Automatic tide gates and water gates can control this flow to create ideal conditions for accumulation of sediment, limit the movement of saltwater, and divert fresh water into appropriate areas for irrigation and recharge of groundwater.*
07 One Percent Terraforming: *Vast areas of the Baylands are flat, and if opened to tidal exchange would become submerged mudflats and open water. Regrading the site using slopes of approximately one percent, would allow for the creation of high and low ground, increase the area of intertidal zone, and create habitat. The benefit of using gradual slopes is that no stabilization is required, and vegetation would establish. Implementing the strategy requires precise terraforming and could designed to optimize cut and fill so that no imported material is required.*
08 Bioengineering Sediment Capture: *Bioengineering used living plant material to stabilize earth. When applied to the process of reclamation and reversal of subsidence, bioengineering dovetails effectively with the reuse of sediment slurries from hydrologic dredging. Bioengineered enclosures can retain sediment in a preformed geometry, allowing water to pass through fascines, woven wall, and living encloses, while retaining and stabilizing the sediment.*
09 Biomass Farming: *Biomass farming is well suited to the Baylands site and may be integrated with reuse of sediment or treatment of biosolids. An important component of biomass farming is the Baylands is integration of the biomass into restoration and reclamation efforts. This may be accomplished through the reuse of willows in site engineering, or the creation of composts to build soil health across the site.*
010 Carbon Sequestration (soils): *Wetlands and marshes are carbon sinks. The massive subsidence on the site creates the opportunity to bank carbon on the site in the form of organic soils. Monetizing the process of banking carbon could fund reclamation efforts to reverse subsidence. Coupling of this process with biomass farming across the site is a viable option.*
011 Forestation: *Arboricultural practices and forestation of parcels of the baylands and its margins can shift landscape management practices to longer time horizons and create visual heterogeneity in the site. Trees can also be used to prepare sites for eventually flooding, create snags for wildlife habitat, and potentially become a forestry products industry.*
012 Passive Irrigation and Waterworks: *Irrigation may become an essential part of re-vegetation efforts and a component of groundwater recharge. Developing passive methods for the movement of water can help structure the site topographically and create visual interest. A series of wells, dry wells, irrigation canals, and subsurface systems could serve as vital infrastructure.*
013 Micro-topographies: *Subtle terracing, planted depressions in the soil, and furrows on sloped sites can be used to capture surface water on sloped areas of the margin and site. Micro-topographic manipulations can help water infiltration and capture on site. This is particularly well suited to areas with a slope along the margins or in areas where new landforms have been created.*
014 Reclamation Enclosures: *Predefined reclamation enclosures are used to dewater and contain sediments accumulated through sediment diversions or through mechanical dredge processes. Enclosures, or settling ponds are raised over time, by the addition of sediment rich slurries.*
015 Sediment Train: *Fixed track systems have been proposed for the construction of levees and can be adapted to the process of restoration. This would allow for the efficient distribution of dredge material, and a reduced carbon footprint when compared to trucking of material. This form of mechanical reclamation utilizes existing railroad tracks to distribute earth.*
016 Wetland Terraces: *The occurrence of wetland vegetation is determined by the relative depth of water and frequency of inundation, in addition to soil type and other environmental factors. The creation of wetland terraces in sloped and subsided areas would allow for the establishment of wetland ecology independent of sea level and flood datum. Terraces (like rice paddies) necessitate the creation of stepped landforms and allow for relatively shallow water depths on sloped sites.*

017 Artificial Seaweeds: *The Structure of the benthic zone plays an important role in ecology and sediment dynamics. Artificial seaweeds have been used in coastal areas to ameliorate erosion and may be well suited to open water areas of the site, to create habitat and stabilized sediments. These structures are particularly well adapted for use along the Napa river where tidal flux moves sediment in large areas of open water.*

018 Benthic habitat / Artificial Reefs: *Artificial reefs are an effective way to create habitat for marine and riverine species. Appropriately designed structures can create spawning areas for fish, and anchorage for marine/riverine invertebrates.*

019 Imported Organics (Hay Structures, etc.): *The site is in a material deficit due to a century, or more, or soil loss. Importing organic material to build soils and create high ground may partially reverse this process in certain areas. Large hay bales, for example, may serve as a building block for organic soil formation similar to the peaty organics soils that existed on the site prior to levees and farming.*

020 Floating Breakwaters: *Wave energy in areas of open water, or adjacent to the Napa River, cause erosion and suspend sediments. Floating breakwaters reduce this energy and may be integrated with floating walkways/wetland to provide access and multifunctional infrastructure.*

021 Floating Wetlands: *Floating wetlands allow for the establishment of wetland vegetation in open water where the bathymetry cannot support plant growth. They can be useful in the creation of habitat for birds, etc., where refuge from open water is important. Although not ideal for large-scale projects, they can be useful at San Pablo Baylands in areas of open water that are not well suited for restoration.*

022 Artificial Islands: *The construction of artificial islands can be easily accomplished in areas of open water through the construction of simple walls to enclose earth, or through bioengineering techniques.*

023 Permeable Dikes / Breakwaters: *Removing levees along the Napa river will open the area to tidal exchange. Replacing levees with permeable dikes and breakwaters would allow for the stabilization of soft sediments in adjacent subsided marsh areas and "breathability" between the cyclical flows of water in the river channel and the areas of open water.*

024 Channel Sediment Collectors: *Sloughs and channels accumulate sediment. Extracting this material not lonely keeps channels open but allows it to be placed elsewhere in support of reclamation efforts. In areas where sediment currently collects, pumps and siphons can move this material to areas where it is useful.*

025 Groundwater Recharge: *Rehydration of subsided soils and recharge of groundwater are essential to the long-term success of the baylands. Fresh groundwater is important to stop saltwater intrusion, and as a source of water for living plants. Managing the vertical exchange of water through passive, and mechanical, means are a vital component of restoration.*

026 Mollusk Habitat: *Mollusks thrive in bay and estuarine environments and can provide important structures for ecological engineering. Shellfish such as Oysters and mussels can be readily cultivated on artificial structures integrated with coastal restoration and may be well suited to the baylands in combination with artificial islands, benthic habitats, and structures for land reclamation.*

5. New infrastructure paradigms for coastal adaptation and resilience

New infrastructure paradigms promote concepts such as hybridity, decentralization, flexibility, and smallness, to rethink social-ecological-technical interactions in coastal systems, utilizing technologies such as micro-grids, robotics, artificial intelligence, and small-scale distributed systems, to build and prototype critical infrastructure in culturally and environmentally diverse regions. Patents play an important role in these novel infrastructural systems as they often involved new technologies and engage a diverse range of inventors, institutions, and other constituencies in their realization, facilitating the process of technology transferer and providing inventors rights during early phases of research and development. The Y02A patent classification scheme sheds light on these new infrastructural possibilities, foregrounding innovation of core technologies within newly created classification schemes. These new technology sectors, and their associated innovation networks, reveal entrepreneurially driven forms of coastal infrastructure that are inherently nimble and may offer alternatives to conventional mechanisms for the development of coastal infrastructure and therefore unlock novel pathways for adaptation and resilience.

As is observed in chapter 2, the actor/networks operating in the coastal development and planning space inherently confront entrenched power structures, such as the United States Army Corps of Engineers (USACE) in the process of enacting change. However, these actor networks may also coalesce into new infrastructure typologies/assemblages (referred to in this chapter as paradigms) that sidestep entrenched or slow-moving power structures, serving coastal communities and create new infrastructural possibilities through alternate pathways. This chapter explores the theory, technologies, and innovation pathways associated with new paradigms for coastal infrastructure produced by private industry, government partners, university researchers, and inventors, and their role in redefining the coastal adaptation and resilience problem space. Unifying these new infrastructure paradigms is a shift away from the heavy and fixed coastal structures that are typically associated with the word “infrastructure” towards flexible, adaptive, social, and entrepreneurial forms of infrastructure that can be innovation driven and reach diverse coastal communities through nimble and adaptive delivery strategies. Potential linkages between the

The need for novel forms of coastal infrastructure is pressing as sea levels rise, development hastens, and critical infrastructure ages. However past approaches to coastal infrastructure have prioritized grand engineering solutions - a strategy that is now widely criticized. Take as an example the extensive levee systems of southern Louisiana that control the hydrology of Mississippi River Delta. The US Army Corps of Engineers 'levees only" approach to river management promises flood protection and maintenance of shipping channels through extensive levees, flood walls, and structures built to control nature. But it has also increased the risk for catastrophic failure during extreme events, putting human lives, economy, and environment at risk through the reliance on singular flood solutions.[285] Accordingly, the levees only policy has been publicly critiqued since its earliest days of conception in the 1920's, with public debates present in news media and throughout government. [286] Yet without alternatives the problem persists.

When thinking of coastal infrastructure, it is common to recall massive breakwaters, seawalls, oil drilling platforms, ports, and the remnants of a militarized and commodified coastal development. This type of infrastructure is ubiquitous, well documented, and consistently critiqued from a range of perspectives including ecological, social, legal, and financial vantages.[287] Given the widely available critiques of conventional coastal infrastructure contemporary researchers, theorists, planners, and designers argue that these approaches to coastal infrastructure are based on outdated concepts of human-environmental interaction in coastal regions and new infrastructural paradigms need to be developed. Theorists such as Pierre Belanger argue that the integration of infrastructure with biophysical processes of regions such as the southern Mississippi Delta can expand potential typologies of landscape

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[285] John McPhee, *The Control of Nature* (Thorndike: G.K. Hall, 1999); Martin. Reuss, Designing the Bayous: The Control of Water in the Atchafalaya Basin, 1800-1995 (College Station: Texas A & M University Press, 2004).
[286] J. Arthur Holly, "FLOOD CONTROL DIFFICULTY; The Principal Trouble Believed to Be Political, Not Engineering.," The New York Times, May 21, 1927, sec. Archives, https://www.nytimes.com/1927/05/21/archives/flood-control-difficulty-the-principal-trouble-believed-to-be.html.
[287] Pilkey and Wright III, "Seawalls versus Beaches"; Darwin BondGraham, "The New Orleans That Race Built: Racism, Disaster, and Urban Spatial Relationships," *Souls* 9, no. 1 (2007): 4–18; Airoldi et al., "Corridors for Aliens but Not for Natives: Effects of Marine Urban Sprawl at a Regional Scale."

infrastructure and reformulate our understating of risk, failure, and the economy of ecology.[288] Others working in the coastal risk and resilience sector foreground the uses of computation and artificial intelligence in the development of novel infrastructure for coastal comminutes.[289] And still others working from a science and policy perspective researchers point to opportunities for integrate research instrumentation and programs with large scale marine infrastructure projects to build living labs in coastal areas.[290] Surveying this literature suggests a broadening body of literature engaging, and reconceptualizing, coastal infrastructure. Paralleling this theoretical evolution is a growing body of evidence of novel forms of infrastructure that complement these theories, a phenomenon we can observe in 'nature based" coastal infrastructures that hybridize functionality with natural systems to build social systems and achieve more resilient, innovative, and sustainable solutions.[291]

The tension between old and new strategies for coastal infrastructure obviously creates a paradox in which new infrastructure is dependent on innovation, but the innovations of the past have led to the problems of today. Bruce Glavovic refers to this *problematique* as the 'coastal innovation paradox" in which "innovation is necessary to escape the vulnerability trap that past ingenuity and prevailing endeavours have sprung upon humanity. New forms of innovation are essential to secure the safety and sustainability of coastal communities."[292] The paradoxical nature of coastal innovation does not negate the pressing need for new forms of coastal infrastructure, instead it highlights opportunities to reconsider the social, ecological, and technical systems that converge in coastal regions and develop new models that address these issues and expand the pathways for coastal adaptation and resilience.

Addressing the need for contemporary innovation in a follow-up article titled "The Coastal Innovation Imperative" Glavovic posits that a "step change" is required in the technical,

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288 Pierre Bélanger, Landscape as Infrastructure: A Base Primer (Routledge, 2016); Pierre Bélanger, "Landscape as Infrastructure," *Landscape Journal* 28, no. 1 (2009): 79–95.

289 Rabindra Lamsal and TV Vijay Kumar, "Artificial Intelligence Based Early Warning System for Coastal Disasters," in *Development in Coastal Zones and Disaster Management* (Springer, 2020), 305–20.

290 A Meriwether W Wilson, Robert Mugerauer, and Terrie Klinger, "Rethinking Marine Infrastructure Policy and Practice: Insights from Three Large-Scale Marina Developments in Seattle," *Marine Policy* 53 (2015): 67–82.

291 Ariana E Sutton-Grier, Kateryna Wowk, and Holly Bamford, "Future of Our Coasts: The Potential for Natural and Hybrid Infrastructure to Enhance the Resilience of Our Coastal Communities, Economies and Ecosystems," *Environmental Science & Policy* 51 (2015): 137–48.

292 Glavovic, "Coastal Innovation Paradox."

business, institutional, social, and belief systems, that operate within, and on, the coastal zone. The paper builds an argument for new coastal systems through the concept of transformative innovation in public policy (as proposed by Rotmans et al.[293]) involving the stages of: "(i) prolonged pre-development in niche settings; (ii) "take off" in which momentum builds; (iii) "breaking through" conflict with existing interests and systems and overcoming lock-in in prevailing economic, political, institutional, infrastructural, cognitive and ideological arenas; and (iv) stabilization of the transformed system." [294] Although Glavovic's findings and recommendations suggest that these step changes and breakthroughs primarily occur through governance and socio-political innovations, it is also noted that the innovation imperative must engage institutions, industry, and technology, to keep pace with societal shifts, climate change, and policy resulting from these new systems – a provocation that new infrastructure paradigms may address.

Technological innovation, and the Y02A classification scheme, provides a distinct entry point into debates regarding infrastructural recalibration as it points towards a paradigmatic shift in which adaptation and resilience technology gains depth and breadth as sectors expand. The need for an broadened repertoire of coastal infrastructural is timely as climate change and environmental risk reconfigure social-ecological-technical systems (SETs) in coastal regions through catastrophic events such as hurricanes, tsunami's, floods from extreme weather, etc.[295] Infrastructure that supports new social-ecological-technical relationships in coastal region will take diverse forms built through the development of alternative technologies and through shifting perspectives in what constitutes coastal infrastructure. The Y02A, and other subsections of the YO2 scheme such as Y02B covering "Climate Change Mitigation Technologies Related To Buildings" provide a framework to manage sequential innovation in these new infrastructural forms. For example, research into the household level adaptation to coastal flooding reveals a suite of technologies utilized by individual households in Europe ranging from the seemingly banal safe storage of important documents to structural modifications of buildings to adapt to

[293] Jan Rotmans, René Kemp, and Marjolein Van Asselt, "More Evolution than Revolution: Transition Management in Public Policy," *Foresight,* 2001.
[294] Glavovic, "Coastal Innovation Imperative."
[295] Lugo, "Effects of Extreme Disturbance Events: From Ecesis to Social–Ecological–Technological Systems."

flood conditions.[296] Through this study researchers reveal that adaptation to flood events is nuanced, small scale, and domestic, requiring technologies and systems for adaptation that reflect this reality. Many of the systems for adapting domestic infrastructure would be covered by the Y02A in subcategories such as 'Y02A 30/14' covering Extreme weather resilient electric power supply systems, or Y02A 10/30 covering Flood Prevention or Storm Water Management.

In practice, these new infrastructure paradigms expand the repertoire for coastal adaptation and resilience works, offering finer grained, adaptive, tailored, social, and ecologically informed solutions to emergent coastal conditions through collaborative ventures with industry partners, governments, non-governmental organizations, community members, and the practices of design and planning. Contemporary theoretical perspectives parallel this evolution and are instigating change in design principles and strategies for infrastructure development and delivery. Given that these shifts are often innovation driven, collaborative, and built through research, development, and testing by private industry and institutional partners, patent rights and technology transfer are integral to the process. This chapter explores the evolving discourses surrounding infrastructure, mechanisms for infrastructure delivery, and the role of technology transfer in collaborative works, offering examples of new infrastructural concepts and related technologies chronicled by the Y02A patent classification scheme.

Paradigmatic shifts In Infrastructure Delivery and development

Conventional approaches to infrastructure development and delivery focus on massive projects realized through complex political and financial systems over long timespans. Alternative approaches to the development of critical infrastructure rethink this essential paradigm making it possible to imagine entirely new infrastructural possibilities that engage diverse actors and constituents that may have historically operated outside the traditions of infrastructure development. In coastal regions where the pace of change is rapid, and the scale of the challenges are global, new infrastructural delivery methods and scales of intervention are one part of an expanded toolkit for adaptation and resilience.

[296] Koerth et al., "A Typology of Household-Level Adaptation to Coastal Flooding and Its Spatio-Temporal Patterns."

Infrastructure delivery is defined as the "continuum of project delivery methods regularly applied by the construction industry" to provide infrastructure for the "movement of people, goods, and information, together with facilities for basic human needs, such as water, sanitation, environmental protection, and shelter." [297] These delivery methods include a spectrum of public and private collaborative models ranging design-build to build-own-operate that exist to build critical Infrastructure. In general these infrastructure projects such as bridges, levees, airports, flood protection, and other fixed constructions that require massive investment and protracted planning and finance intertwined with policy, politics, and public interests.[298] A review of infrastructure delivery case studies for large projects reveals and obvious yet important point, that many of these public private partnerships exist between government entities and large engineering, construction, and finance companies, that specialize in complex and massive infrastructure projects.[299] The conventions of these established systems of infrastructure delivery are well documented, but they also represent a paradigm resistant to innovation and rapid change due to their size, bureaucracy, and interconnection with politics and government - a reality that often precludes or is adversarial to start-ups, community voices, novel approaches to emergent problems. However, these problems are not intractable.

New theoretical frameworks are challenging core tenets of critical infrastructure and their delivery methods in search of more resilience and flexible approaches. This includes a push towards hybrid, modular, flexible, social, and intelligent, critical infrastructure that addresses a range of project and environmental timescales.[300] Importantly, development of these new infrastructure types engages new actors in the process and necessitates new infrastructure delivery methods. For example, a recent study of decentralized rainwater technology in Europe revealed that centralized water agencies actively resisted change and that smart policies would incentivize diverse actors, such as private companies and individuals, to participate in new water

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[297] J B Miller, *Principles of Public and Private Infrastructure Delivery, Infrastructure Systems: Delivery and Finance* (Springer US, 2013)

[298] E. R. Yescombe, Farquharson, Edward,, "Public-Private Partnerships : Principles of Policy and Finance," 2018, /z-wcorg/, http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=1572333.

[299] J B Miller, Case Studies in Infrastructure Delivery, Infrastructure Systems: Delivery and Finance (Springer US, 2012).

[300] Shakou et al., "Developing an Innovative Framework for Enhancing the Resilience of Critical Infrastructure to Climate Change."

infrastructure programs.[301] Other cases show how novel economic and social structures such as business incubators, knowledge networks, entrepreneurial ventures, lead to accelerated water innovation and development of novel technology through social infrastructure.[302] Collectively, the burgeoning research on water innovation identifies mechanisms to catalyze change and also the bottlenecks to progress, highlighting the role of new environmental, social, and political actors in the realization of new water infrastructure an pointing towards a paradigm shift.[303]

The impacts of this infrastructural recalibration are widespread and ongoing across sectors and disciplines. Looking beyond water to other vital utility providers such as power grids, and communication, we can observe similar efforts to recalibrate infrastructure. High level design principles are instigating shifts in this process. For example, researchers exploring the role of modularity electrical generation are critiquing the "bigger is better" approach and have developed design criteria for small modular systems "designed to function in massively parallel configurations." These new modular systems provide clear benefits, " off-loading control functions to central controllers, simplifies functionality to minimize the need for ongoing control and maintenance, and reduces part counts by creating more integrated components." [304] Transportation networks are also being reconsidered and reformulated through paradigm shifts in infrastructure, a phenomenon most easily observed in the rapid proliferation of share bikes, scooters, and other distributed shared transportation that help solve core problems associated with urban mobility such as the first/last mile problem.[305] Together this body of literature and pilot projects provides evidence of a widespread rethinking of infrastructure delivery across sectors ranging from transportation, water supply, information/communication, and electrical systems.[306] These examples show that new infrastructures can be conceptualized and developed

[301] Lena Partzsch, "Smart Regulation for Water Innovation–the Case of Decentralized Rainwater Technology," *Journal of Cleaner Production* 17, no. 11 (2009): 985–91.
[302] Jonas Gabrielsson et al., "Promoting Water-Related Innovation through Networked Acceleration: Insights from the Water Innovation Accelerator," *Journal of Cleaner Production* 171 (2018): S130–39.
[303] Farah Ahmed et al., "Barriers to Innovation in Water Treatment," Water 15, no. 4 (2023): 773; U Wehn and C Montalvo, "Dynamics of Water Innovation: Foundations of the Field," *Journal of Cleaner Production*, 2017.
[304] Eric Dahlgren et al., "Small Modular Infrastructure," *The Engineering Economist* 58, no. 4 (2013): 231–64.
[305] Kelly Grosshuesch, "Solving the First Mile/Last Mile Problem: Electric Scooters and Dockless Bicycles Are Positioned to Provide Relief to Commuters Struggling with a Daily Commute," *Wm. & Mary Envtl. L. & Pol'y Rev*. 44 (2019): 847.
[306] Shakou et al., "Developing an Innovative Framework for Enhancing the Resilience of Critical Infrastructure to Climate Change."

outside the massive infrastructure conglomerates that have historically be responsible for development of these systems.

Innovation studies and the patent system provided unique insights about these new infrastructure paradigms. Historically we can point to start-up phase of core infrastructure, such as the electrical-grid, which was born out of entrepreneurial ventures by Thomas Edison and the Edison Electrical Illuminating Company of New York (Con Edison) who prototyped urban electrification in Pearl Street NYC in April 1881-1882.[307] The early Pearl street experiments by Edison ultimately led to an entirely new form of infrastructure and catalyzed institutional, displacing the gas industry.[308] Arguably, this step-change was born from the genius of Edison, prowess of his corporate affiliations, and the agency of patents to define the scope of this new infrastructure, including the details of an electrified urban landscape covered by US263142, granted August 22, 1882 related to layout of urban electrical infrastructure associated with the pearl street pilot project (figure 42).[309] Other notable historical examples of infrastructure delivery through patent incentives exist. In 1844, while pondering interstate communications, Congress passed acts to construct an experimental telegraph line from Washington to Baltimore following Samuel Morse's patent for invention. Similarly, in 1845, Congress approved the creation of a panel of experts to test an experimental dredge machine, patented by J.R. Putnam, for the removal of sandbars at the mouth of the Mississippi River. And in 1847, James Crutchett was commissioned to prototype and test his experimental gaslight in the nation's Capital, proving the viability of artificial lighting in the urban landscape.[310] Today with the diminished role of government in infrastructure development many of these technological innovations would be managed by the private sector, yet they provide important touchstones for in the history of infrastructure delivery and evidence of the key role patents play in establishment of new sectors.

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[307] "Milestones: Pearl Street Station, 1882," ETHW, June 14, 2022, https://ethw.org/Milestones:Pearl_Street_Station,_1882.
[308] Andrew B Hargadon and Yellowlees Douglas, "When Innovations Meet Institutions: Edison and the Design of the Electric Light," *Administrative Science Quarterly* 46, no. 3 (2001): 476–501.
[309] Thomas Edison, Electrical Distribution System, US263142, filed 1882, and issued August 22, 1882.
[310] J B Miller, *Principles of Public and Private Infrastructure Delivery, Infrastructure Systems: Delivery and Finance* (Springer US, 2013)

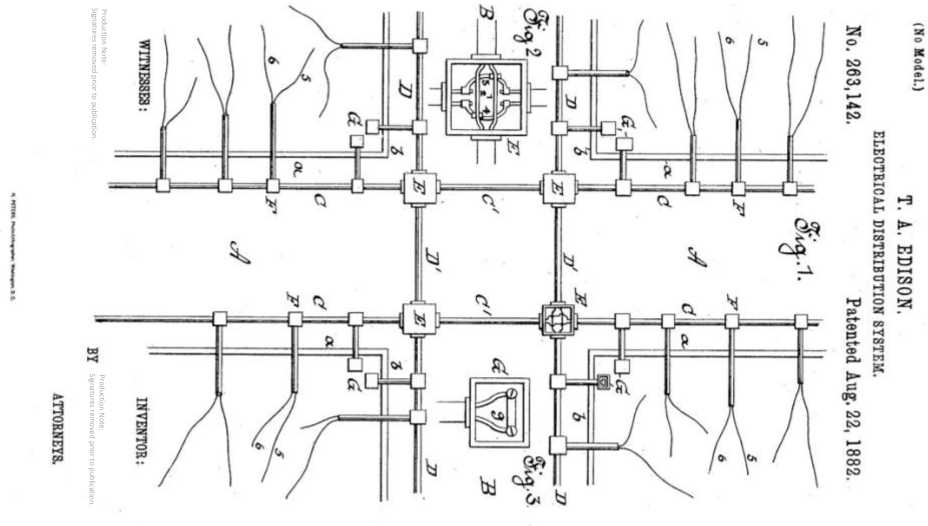

Figure 42 Thomas Edison's Patent for an urban "Electrical Distribution System" US263142 (1882) – showing the layout of electrical distribution in the urban landscape as used in the early Pearl Street Pilot Projects. (Source: European Patent Office, https://www.epo.org/en)

In the context of coastal adaptation and resilience these new infrastructure paradigms are especially important to consider as they require new frameworks and infrastructural typologies in response to climate change and ecological degradations of rivers and coasts. Consider briefly the widely publicized Sargassum mats that have washed up along beaches in Mexico, the Caribbean, and Florida after traveling across the Atlantic and circulating through the Gulf of Mexico.[311] Sargassum blooms are though to result from climate change, upwelling, and increased nutrient runoff, growing so large that they are now tracked by NASA, NOAA, and other entities so that appropriate measures may be taken in impacted areas.[312] A glut of sargassum biomass has also led to the creation of a distinct business and innovation ecosystems. Within government NASA has develop methodology and software to automatically detect Sargassum species in 30-meter LANDSAT-8 Operational Land Imager (OLI) imagery, making data and tools

[311] "A Massive Seaweed Bloom in the Atlantic," Text.Article (NASA Earth Observatory, April 7, 2023), https://earthobservatory.nasa.gov/images/151188/a-massive-seaweed-bloom-in-the-atlantic.
[312] Rafael Mendez-Tejeda and Gladys A Rosado Jiménez, "Influence of Climatic Factors on Sargassum Arrivals to the Coasts of the Dominican Republic," 2019; Sandrine Djakouré et al., "On the Potential Causes of the Recent Pelagic Sargassum Blooms Events in the Tropical North Atlantic Ocean," *Biogeosciences Discussions*, 2017, 1–20; Clifford Louime, Jodany Fortune, and Gary Gervais, "Sargassum Invasion of Coastal Environments: A Growing Concern," American Journal of Environmental Sciences 13, no. 1 (2017): 58–64.

for tracking the seaweed mats public through technology sharing.[313] A policy, business, and innovation ecosystems has also grown around sargassum events to include a range of biomass collection providers and processed products ranging from plastics and cosmetics to building blocks for low-income housing.[314] Collectively, the sargassum "problem space" develops from the work of government, industry, and communities, providing a responsive form of coastal infrastructure able to coalesce during times of heavy sargassum loads and process materials that impact coastal tourism and local economies.

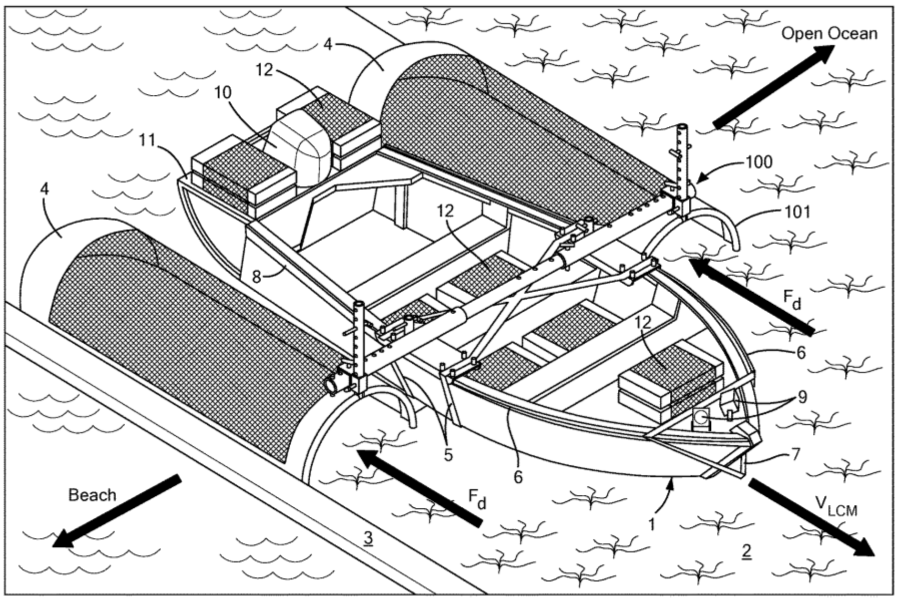

Figure 43: US20230082558A1 "Retrofitting Small Watercraft as Collection Boats for Sargassum Seaweed" A module for retrofitting a boat for collection of floating biomass has a telescoping beam that spans the width of the boat and connects to aft-ends of levers that rest on the gunwales (Source: European Patent Office, https://www.epo.org/en).

Sargassum innovation is on the uptick, with new systems being invented to collect, process, and profit from the change in ecosystems (figure 42). This includes a range of novel systems and methods spanning technology sectors in the patent office, such as US20230082558A1 for "Retrofitting Small Watercraft as Collection Boats for Sargassum Seaweed" which aims to collect floating biomass with a telescoping beam that spans the width of the boat, and US20200305540A1 for "Ecological footwear elaborated from recycled plastic fibers and recycled or disposal organic material, product and process" which utilizes sargassum

313 "Algorithm for Automated Sargassum Detection for Landsat-8 OLI Imagery (SSC-00505) | NASA Software Catalog," accessed May 3, 2023, https://software.nasa.gov/software/SSC-00505.
314 "Desrochers_et_al_2020_sargassum_uses_guide_advance. Pdf," accessed May 3, 2023, https://www.cavehill.uwi.edu/cermes/projects/sargassum/docs/desrochers_et_al_2020_sargassum_uses_guide_advance.aspx.

as admixture to rubberized soles, and patents such as US11523982B2 "Marine extract compositions and methods of use" which describes methods for industrial extraction of collagen, elastin, and hyaluronic acid from sargassum.[315]

Sargassum blooms provide one example on the unique challenges emerging within climate impacted coastal systems and the novel forms of infrastructure invented in through public/private partnership in response to changes in complex coastal systems. The Y02A patent classification scheme is uniquely situated to manage sequential innovation in these sectors and contribute to the coalescing of new paradigms for coastal infrastructure through technology transfer and protection of inventor's rights.

Patents, innovation, and new infrastructural possibilities

New paradigms in infrastructure design, development, and delivery are enabling the creation of novel social-ecological-technological assemblages in coastal regions. Surveying this emerging sector reveals how small-scale, hybrid, decentralized, and transcalar, forms of coastal infrastructure are expanding the technological toolkit and broadening networks. Many of these new systems are realized through private business ventures, spin-off partnerships with universities, NGO's, etc. Although not universal, often these new assemblages involve the development of novel intellectual property and/or transfer of technology from partners.

The cross sectoral technological advances observed within these new infrastructure paradigms are now covered by the Y02A classification scheme for "Technologies for adaptation to climate change." Patent offices around the world are preparing for innovation in climate adaptation. For instance, under a new work-sharing program to advance green technology, announced by the Biden Administration, February 23, 2023, the USPTO and NOAA employees will serve at the sister agency, therefore infusing new knowledge into both agencies. USPTO expertise will help NOAA provide intellectual property training for scientists. Conversely, NOAA experts will provide training to USPTO patent examiners to support climate efforts as the patent

[315] Luke Gray and Alexander Slocum, Retrofitting Small Watercraft as Collection Boats for Sargassum Seaweed, United States US20230082558A1, filed February 12, 2021, and issued March 16, 2023,

office builds capacity in climate adaptation and environmental "green" technologies.[316] Programs such as these build pathways for innovation between industry and government, leveraging the strengths of public and private sector through technology transfer and focus on areas of strategic importance. Similar initiatives are also underway in the European Patent Office with a series of focused reports on the changing environment. The most recent, published online in 2023, highlights Innovation in fire prevention, firefighting, wildfire control and forest restoration.[317]

The following section explores new infrastructure concepts and links these concepts to technologies organized by the Y02A, establishing linkages between the evolving discourse on infrastructure and innovations covered by the Y02A. In these discrete studies we can observe an evolving discourse on infrastructure, new networks addressing these issues, and innovative technologies being invented to translate theory into practice. Integral to each is the role of private industry, universities, government, and other partners in the formulation of new infrastructure paradigms.

Decentralization

Decentralization is a buzzword in water innovation sectors. The push to decentralize takes many forms, from small scale rainwater harvesting to reverse osmosis technology, a shift that requires the development of new technologies and smart regulations that support safe distributed water systems. Decentralized water infrastructure, such as rainwater harvesting, reveals the interplay between diverse actors, new technologies, and policy, that challenges the conventional notion of centralized water distribution and entrenched infrastructure paradigms.[318] A recent report suggests that innovation in water infrastructure in developed nations, such as the United States, is stagnating due to entrenched water policies and systems

[316] "NOAA, U.S. Patent and Trademark Office Create Work-Sharing Program to Advance Green Technology," Welcome to NOAA Research, accessed May 2, 2023, https://research.noaa.gov/article/ArtMID/587/ArticleID/2944/NOAA-US-Patent-and-Trademark-Office-create-work-sharing-program-to-advance-green-technology.
[317] European Patent Office, "Firefighting Technologies," accessed July 10, 2023, https://www.epo.org/news-events/in-focus/firefighting.html.
[318] Partzsch, "Smart Regulation for Water Innovation–the Case of Decentralized Rainwater Technology."

that make pathways to innovation difficult.[319] Yet in the developing world new water systems are addressing critical need and innovative new technologies are being implemented through water innovation partnerships that aim to address the unique cultural and technological contingencies while implemented smart water systems that improve resilience.[320]

In the context of coastal resilience, the need for decentralized water infrastructure is acute. Salt-water intrusion resulting from sea level rise severely impacts freshwater supplies in Bangladesh. Most freshwater in the coastal regions is produced through groundwater sources making the issue widespread, with future projections suggesting that the problem will only increase.[321] The lack of centralized water infrastructure in combination with brackish groundwater necessitates that new forms of critical water infrastructure be developed that can address the unique social and environmental contingencies.[322] The search for low-cost and easily implementable solutions has led to a series of pilot projects conducted by universities, NGO's, and private companies testing viable solutions such as reverse osmosis and solar still technology. Solar stills evaporate freshwater from a saline water source and collect fresh water and have been tested as low cost and small-scale alternatives to centralized desalination systems.[323] Other pilot project involve the use of reverse osmosis technology that removes salts using specialized filters and pressure. Pilot projects indicate that reverse osmosis is a viable alternative for small scale desalination in Bangladesh.[324] The development of desalination technology in Bangladesh reveals the unique conditions of infrastructure delivery in the region.

Companies such as Fcubed and Dessol are working in this innovation space, developing decentralized water infrastructure for remote regions (table 5). Fcubed is an Australian company working on small scale solar desalination with applications around the world and pilot projects in

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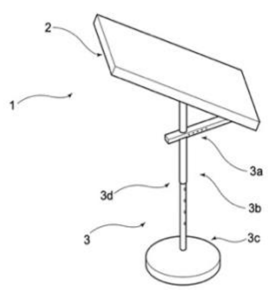
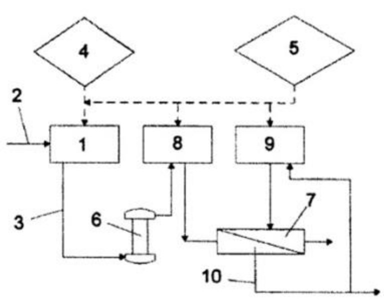
[319] Newsha K Ajami, Barton H Thompson Jr, and David G Victor, "The Path to Water Innovation," *Woods Institute for the Environment*, Stanford, Working Paper, 2014.
[320] Silas Mvulirwenande and Uta Wehn, "Promoting Smart Water Systems in Developing Countries Through Innovation Partnerships: Evidence from VIA Water-Supported Projects in Africa," in *ICT for Smart Water Systems: Measurements and Data Science* (Springer, 2019), 167–207.
[321] Shume Akhter, M Hasan, and ZH Khan, "Impact of Climate Change on Saltwater Intrusion in the Coastal Area of Bangladesh," 2012, 20–24.
[322] Asiful Basar, "Water Security in Coastal Region of Bangladesh: Would Desalination Be a Solution to the Vulnerable Communities of the Sundarbans?," *Bangladesh E-Journal of Sociology* 9, no. 2 (2012): 31.
[323] Asiful Hoque, Ashif Hasan Abir, and Kironmoy Paul Shourov, "Solar Still for Saline Water Desalination for Low-Income Coastal Areas," *Applied Water Science* 9, no. 4 (2019): 1–8.
[324] Shamsuzzoha, Rasheduzzaman, and Ghosh, "Building Resilience for Drinking Water Shortages through Reverse Osmosis Technology in Coastal Areas of Bangladesh."

Malaysia. The company's focus on remote geographies and localized water infrastructure making them a unique privately funded business model, offering alternatives to massive water infrastructure.[325] Working in a similar vein, Dessol technologies builds photovoltaic powered desalination plants for small communities' remote locations, including islands and inland areas with water sources from brackish seas/aquifers. The technology was invented and patented by Instituto Tecnologico De Canarias, Spain, with pilot projects in the Canary Islands and Tunisia.[326] Both companies are essentially small utility providers working with private, and university funded research, to address the needs of remote coastal communities.

 FIG 5 *Figure 44: AU2019312560B2 "Improvements to multifunction solar utility panels" (2019)*	Decentralization Ex.1 FCubed The Australian company FCubed has been working in remote regions, such as Sabah Malaysia, to deliver solar desalination. The Carocell Direct Solar Powered Desalination Technology is one of the most efficient and cost-effective products of its kind in the world. The system produces safe, high quality potable water from any water source, including, polluted, contaminated, industrial wastewater, brackish ground water, saline aquifers, and sea water. The system receives impure water by gravity or pump into a feeder pipe at the top of the unit. The input water slowly runs down the solar collector/evaporator being evenly dispersed. Solar energy heats the water, it vaporizes and then condenses on the inside of the composite plastic panel enclosure. Droplets of distilled water run down into a pure water outlet at the bottom of the unit.
 FIG. 1 *Figure 45: ES2299396B1 "Desalination System by Invested Osmosis Fed by Solar Energy." (2009)*	Decentralization Ex.2 Dessol__ The DESSOL technology offers a solution for the supply of drinking water, using photovoltaic solar energy in isolated coastal and inland environments with availability of sea water or brackish water. The technology operates isolated from the electrical network, requiring only a source of salt water with sufficient flow to meet the demands. The systems were developed by Instituto Tecnologico De Canarias, Spain. The system has been tested on location in the Canary Islands and also in Ksar Ghilène (Tunisia), where it operated for 8 years continuously. The DESSOL technology was patented by Instituto Tecnologico De Canarias, Spain and licensed globally.[327]

[325] Robert James Pyman, Richard William Thomson, and Darren Geoffrey Dunn, Improvements to Multifunction Solar Utility Panels, AU2019312560B2, filed September 25, 2019, and issued December 10, 2020.
[326] Izquierdo Gonzalo Piernavieja et al., Sistema De Desalacion Por Osmosis Inversa Alimentado Por Energia Solar, ES2299396B1, filed December 21, 2004, and issued April 1, 2009.
[327] Baltasar Penate et al., "Uninterrupted Eight-Year Operation of the Autonomous Solar Photovoltaic Reverse Osmosis System in Ksar Ghilène (Tunisia)," Desalination and Water Treatment 55, no. 11 (2015): 3141–48.

Table 5: Patented Technology for Decentralization of Water infrastructure

Hybridity: Wave Energy Generation, Datacenters, and Coastal Protection

Hybrid forms of coastal infrastructure may provide new opportunities for coastal adaptation and resilience. The advent of new polyfunctional systems create opportunities to couple systems and find synergies between coastal and social forces. For example, new technologies designed to provided coastal protection and wave energy generation promise to simultaneously reduce energy production cost suggest that such as those technologies for wave energy generation and coastal protection.[328] In this hybrid space the co-benefits of electrical production can help offset the cost of building infrastructure and provide vital technological assets, thus building local resilience.[329] In the context of sea level rise the development of hybrid infrastructure can be coupled with updates to existing infrastructure. For example, upgrades to a harbor breakwaters and seawalls often require raising the top of wall elevation, often this can be accomplished through addition of a modular power generation unit.[330] The ocean is also an important source of cooling and can be coupled with computer infrastructure such as data centers.

Companies such as Microsoft are investing in this hybrid infrastructure space, developing technology for data storage that creates reefs and cools computer servers. These new systems advance coastal infrastructure by seeking co-benefits between essential electrical and computer infrastructure and coastal structures. As is observed in other novel technology sectors, patents play an important role in defining the problem space and instigating primary research and development. Interestingly, patents may also help ensure the technology spreads and is freely available. For example, The Microsoft Datacenter reef is now part of the low carbon pledge to accelerate climate adaption technologies. The Low Carbon Patent Pledge currently includes 597 patents, 14 organizations, 13 countries. Including pledges from Hewlett Packard, Microsoft, Meta, Amazon, Lenovo, JP Morgan Chase. The low carbon participants help accelerate adoption

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[328] Rafael J Bergillos, Cristobal Rodriguez-Delgado, and Gregorio Iglesias, *Ocean Energy and Coastal Protection: A Novel Strategy for Coastal Management Under Climate Change* (Springer, 2020).
[329] Muhammad Adli Mustapa et al., "Wave Energy Device and Breakwater Integration: A Review," *Renewable and Sustainable Energy Reviews* 77 (2017): 43–58.
[330] Diego Vicinanza et al., "Review of Innovative Harbor Breakwaters for Wave-Energy Conversion," *Journal of Waterway, Port, Coastal, and Ocean Engineering* 145, no. 4 (2019): 03119001.

of low carbon technologies, foster collaborative innovation, and facilitate sustainable breakthroughs by making critical intellectual property broadly available without charge around the world. According to the website "Pledgor grants a royalty-free license to any person or entity that wishes to accept it ("Licensee") under the Pledgor's Pledged Patents to practice the patented technologies for the use, generation, storage, or distribution of low-carbon energy from solar, wind, ocean, hydropower, or geothermal sources. The license is non-transferable, non-sublicensable, non-exclusive, worldwide, fully paid-up, and for the entire term of each of the Pledged Patents."[331] This cooperative agreement makes leading edge technology freely available to anyone and expands the reach of partners in the venture.

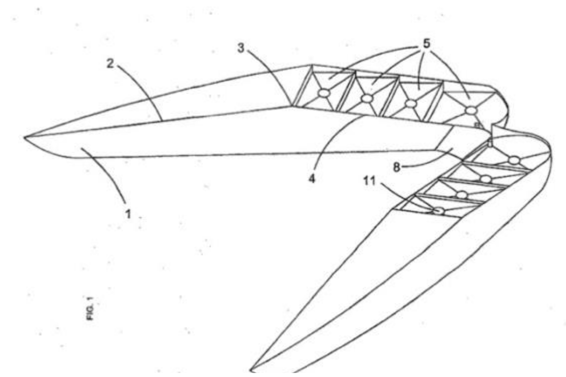
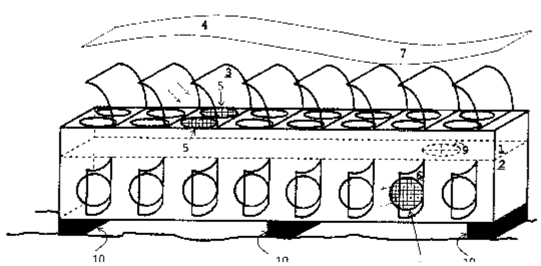
Other examples of hybrid infrastructure include the WaveCat, REEFS, Biomechanical Mangrove systems, which aim to protect coasts while generating electricity and sometimes promoting habitat development (table 6). The WaveCat system developed by researchers at the university of Santiago Chile, aims to protects coasts and generates wave energy through anchored pontons that sever as a breakwater and translate dissipated wave energy into electricity. Similarly, the REEFS system aims to capture energy from breaking waves, acting as a natural reef would to reduce energy that reaches the shoreline. The systems are in university research trial and is supported by private investment and a network of researchers promoting the system and developing test sites.[332] Perhaps the most experimental, or speculative, of the systems is the biomechanical mangrove systems (US8511936B2) "Method and apparatus for coastline remediation, energy generation, and vegetation support" developed by Keith Van de Riet of the Rensselaer Polytechnic Institute (RPI) in 2011. The patent claims to mimic the structure of mangrove roots to protect from storm surges while potentially harnessing energy and allowing for the growth of living mangrove plants. The technology was developed by

[331] "The Pledge," Low Carbon Patent Pledge, August 26, 2021, https://lowcarbonpatentpledge.org/the-pledge/.

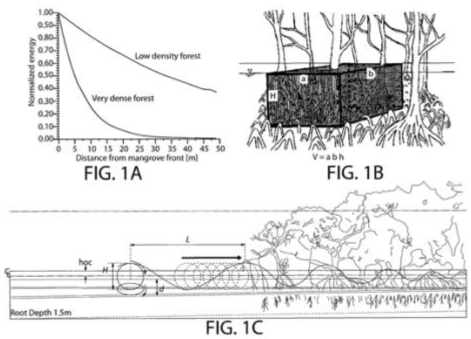
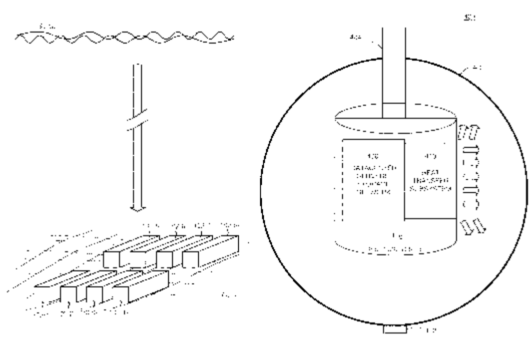
[332] De Gouveia Lopes De Almeida José Paulo Pereira, Artificial coastal-protection reef with energy generation unit with or without direct contact with seawater, US10233894B2, filed November 11, 2014, and issued March 19, 2019; Keith Van de Riet, Jason Vollen, and Anna Dyson, Method and apparatus for coastline remediation, energy generation, and vegetation support, United States US8511936B2, filed November 30, 2011, and issued August 20, 2013, Benjamin F. Cutler et al., Artificial reef datacenter, US10524395B2, filed May 27, 2016, and issued December 31, 2019; Sole Javier Mas and Rodriguez Gregorio Iglesias, Wave energy capture system by means of compressed air storage in depth, ES2398121A1, filed November 27, 2012, and issued March 13, 2013.

university researchers and given broad media attention through the Holcim Foundation Awards in 2011/12.[333]

Table 6: Patented Hybrid Coastal Infrastructure

 *Figure 46: ES2398121A1 "Floating device for harnessing swell energy by lateral overflow"*	**Hybridity EX.1 Wavecat** WaveCat is a floating wave energy converter intended for operation in intermediate water depths (50-100 m). Like a catamaran, it consists of two hulls-from which it derives its name. The difference with a conventional catamaran is that the hulls are not parallel but convergent; they are joined at the stern, forming a wedge in plan view. The WaveCat was patented by researchers at the university of Santiago Chile and has been developed through a series of physical and digital models that confirm its functionality. [334] This includes detailed studies of the WaveCat's functionality using wave data and bathymetry from the Case study with wave farms off a beach in southern Spain.[335]
 *Figure 47: US10233894B2 "Artificial coastal-protection reef with energy generation unit with or without direct contact with seawater"*	**Hybridity Ex. 2 REEFS** REEFS: are a novel technology for wave energy generation and coastal protection. REEFS can harness both, potential energy as well as kinetic energy, of sea waves. Its structure consists of a nearshore fixed submerged caisson placed on the seabed at low depth, located along the shore as a natural reef may be. REEFS can contribute to shore protection because it causes waves to break like natural reefs do but converts this energy into electricity.[336] Recent laboratory studies were conducted to compute preliminary power output, and a simplified computational model also confirms the systems viability.[337]

[333] "Reinforced Mangrove Protective Infrastructure," accessed May 23, 2023, https://www.holcimfoundation.org/projects/reinforced-mangrove-protective-infrastructure-miami-fl-usa.
[334] Hernan Fernandez et al., "Optimization of the Wavecat Wave Energy Converter," *Coastal Engineering Proceedings*, no. 33 (2012): 5–5.
[335] Rafael J Bergillos et al., "Wave Energy Converter Configuration in Dual Wave Farms," Ocean Engineering 178 (2019): 204–14.
[336] JPPG Lopes De Almeida, "REEFS: An Artificial Reef for Wave Energy Harnessing and Shore Protection–A New Concept towards Multipurpose Sustainable Solutions," *Renewable Energy* 114 (2017): 817–29.
[337] JPPG Lopes de Almeida, JRCB Abrantes, and JGSES Bento, "A Simplified Model for Expedient Computational Assessment of the Novel REEFS Wave Energy Converter Power Output," Renewable Energy 157 (2020): 43–54; JPPG Lopes de Almeida, B Mujtaba, and AM Oliveira Fernandes, "Preliminary Laboratorial Determination of the REEFS Novel Wave Energy Converter Power Output," *Renewable Energy* 122 (2018): 654–64.

 *Figure 48: US8511936B2 "Method and apparatus for coastline remediation, energy generation, and vegetation support*	**Hybridity Ex.3 Biomechanical Mangroves** The biomechanical mangrove system was developed by Keith Van de Riet of the Rensselaer Polytechnic Institute (RPI) based in Troy, NY. The system is known as it received a Holcim Awards "Next Generation" 1st prize in 2011 for its forward looking strategy to strengthen mangrove forests along coastlines to reinforce the natural protection of the coastal communities against the threat of tsunamis.[338] The speculative technology builds a coastal armature that can support plant growth and also generate electricity through the a complex structural system that mimics the structures of mangrove roots growing commonly in tropical coastal zones.
 *Figure 49: US10524395B2 "Artificial reef datacenter"*	**Hybridity Ex. 4 Microsoft Artificial Reef** Microsoft developed an underwater datacenter hybridized with a reef. The scope of the is the subject is covered by US10524395B2 for an "Artificial reef datacenter" submitted in 2016 and granted in 2019. A Prototype of the system were developed under the name "Project Natick" with phase 1 tested of the pacific coast or the United States in 2015 and Phase 2 in 2018 in Scotland. During the second trial a 40-foot-long datacenter was with 12 racks containing a total of 864 servers and associated cooling system infrastructure. The datacenter was assembled and tested in France and shipped on a flatbed truck to Scotland where it was attached to a ballast-filled triangular base for deployment on the seabed. As the patent indicates, these submerged data centers can be hybridized with reef ecology to provide habitat for marine and cooling to the data center

Smart Coasts: Mapping, Sensing, and Artificial intelligence as coastal infrastructure

Digital technology may be used to improve social-ecological resilience in coastal systems. As coastal systems change, and risks associated with coastal development are exacerbated social resilience will be an increasingly important form of coastal infrastructure for "buffering the effects of extreme natural hazards and promoting social reorganization." [339] Digital technology offers one pathway through which to increase social resilience. For example, Integration of artificial intelligence with early warning systems for coastal disasters can help mitigate risk and hasten response times in a range of flood scenarios, including in-city flooding caused by

[338] "Reinforced Mangrove Protective Infrastructure."
[339] Adger et al., "Social-Ecological Resilience to Coastal Disasters."

tsunamis, and coastal flooding due to waves and storm surge. [340] [341] In this sector a novel technology is used to sense and notify of coastal hazards, including everything from data collected from twitter to the global navigation satellite systems (GNSS) and even new remote sensing systems and autonomous drones designed to detect and destroy invasive marine species.[342] [343] Industry plays an active role in this new form of infrastructure. For example in the assessment of coastal risk assessment companies such as True Flood Risk have developed AI-driven property risk management platforms that offer property owners and insurance companies detailed risk assessment using image analysis (table 7).

Much of the innovation in the innovation in artificial intelligence is being led by research rich sectors such as agriculture to medicine, however it promises to impact a host of related environmental sectors.[344] As a recent European patent office report on the "space-borne sensing and green applications" shows, innovation in these areas are expanding rapidly a projected market of 2.7-5 billion Euros within the sector.[345] As the internet of things (IOT) expands into the adaptation approach to flood risk and environmental, new systems will be invented and tested to address a range coastal issues and linking global risk to networks of innovative sensing infrastructure. For example, the Deep-ocean Assessment and Reporting of Tsunamis (D.A.R.T) system was invented by NOAA to establish early warning systems for tsunamis. Because the U.S. wanted to make this technology available to all nations, NOAA licensed the patents for the technology and a commercial DART was manufactured by a U.S. private company that currently provides DART technology to foreign countries. The intellectual property of DART is owned and maintained by the NOAA National Weather Service National Data Buoy Center, though DART modules are now licensed and transferred to industry partner SAIC,

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[340] Lamsal and Kumar, "Artificial Intelligence Based Early Warning System for Coastal Disasters."
[341] Claudio Iuppa et al., "Coastal Flooding Risk Assessment Through Artificial Intelligence" (Euro-Mediterranean Conference for Environmental Integration, Springer, 2019), 2005–9.
[342] Carsten Falck et al., "The GNSS-Based Component of the German-Indonesian Tsunami Early Warning System (GITEWS): Overview, First Operation Results and Current Developments" (2010 IEEE International Geoscience and Remote Sensing Symposium, IEEE, 2010), 134–37; Rabindra Lamsal and TV Vijay Kumar, "Classifying Emergency Tweets for Disaster Response," International Journal of Disaster Response and Emergency Management (IJDREM) 3, no. 1 (2020): 14–29.
[343] José J Lahoz-Monfort and Michael JL Magrath, "A Comprehensive Overview of Technologies for Species and Habitat Monitoring and Conservation," BioScience, 2021.
[344] Iain M Cockburn, Rebecca Henderson, and Scott Stern, 4. *The Impact of Artificial Intelligence on Innovation: An Exploratory Analysis* (University of Chicago Press, 2019).
[345] "Space-Borne Sensing and Green Applications - Patent Insight Report," n.d.

who builds and sells DART systems. Oceanic data collection aids emergency preparedness and early detection of tsunamis helps public safety.[346] In essence the DART systems continuously record and transmit oceanic measurements for use in forecasting and alerts, establishing vital infrastructure through corporate and global partnership. Partnerships that spur new warning delivery systems and protect coastal populations.

Table 7: Examples of Smart-Coast Technologies covered by the Y02A.

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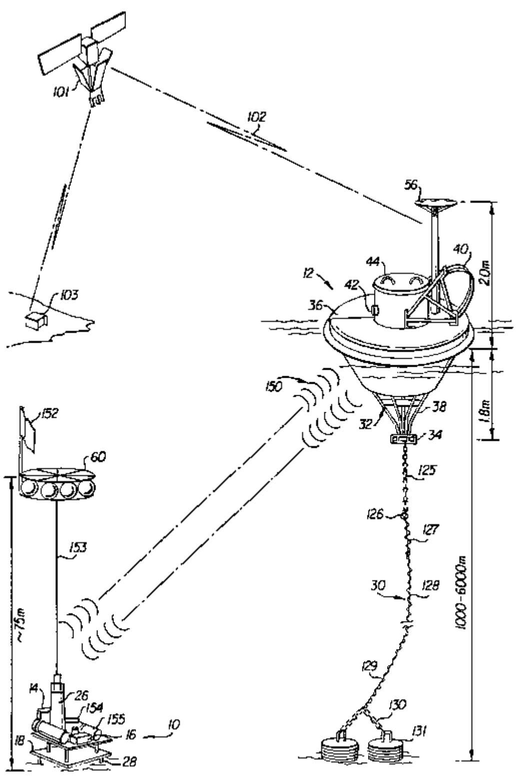


Figure 50: US7289907B2. “System for reporting high resolution ocean pressures in near real-time for the purpose of Tsunami monitoring” This invention is the NOAA Deep Ocean Assessment and Reporting of Tsunami (DART) system
</td>
<td>
Smart Coasts EX.1 D.A.R.T. - National Oceanic and Atmospheric Association (NOAA)
The Deep-ocean Assessment and Reporting of Tsunamis (DART) As part of the U.S. National Tsunami Hazard Mitigation Program (NTHMP), deep-ocean tsunameters have been developed for the early detection, measurement, and real-time reporting of tsunamis in the open ocean. Tsunameters were developed by Project DART® (Deep-ocean Assessment and Reporting of Tsunamis) at NOAA's Pacific Marine Environmental Laboratory (PMEL). These systems have been strategically deployed near regions with a history of tsunami generation, to ensure measurement of the waves as they propagate towards threatened U.S. coastal communities and to acquire data critical to real-time forecasts. National Oceanic and Atmospheric Administration (NOAA) had completed the research and development, including an operational prototype, by October of 2003, when the technology was transferred to NOAA operations.[347] The first generation Deep-ocean Assessment and Reporting of Tsunamis (DART I) array consisted of six stations strategically located off Alaska, Oregon, and near the equator to detect tsunamis originating in the Chile/Peru area.[348]
</td>
</tr>
</table>

[346] “SAIC | Sensor Buoys Help the World Track Tsunamis,” accessed May 7, 2023, https://www.saic.com/features/Sensor-Buoys-Help-The-World-Track-Tsunamis.

[347] Eddie N Bernard and Christian Meinig, “History and Future of Deep-Ocean Tsunami Measurements” (OCEANS’11 MTS/IEEE KONA, IEEE, 2011), 1–7.

[348] Christian Meinig et al., System for reporting high resolution ocean pressures in near realtime for the purpose of Tsunami monitoring, US7289907B2, filed May 20, 2005, and issued October 30, 2007.

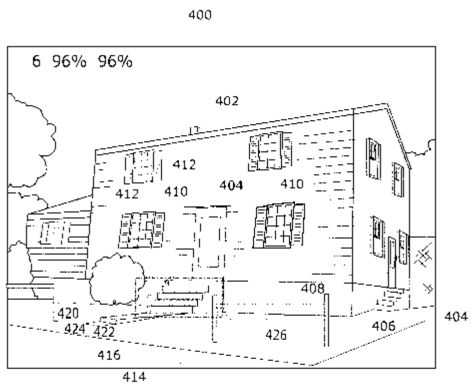


Figure 51: US11120557B1 "System and method for detecting objects in images" The system uses AI to calculate first floor elevation or height of the structure.

Smart Coasts EX.2 True Flood Risk

True Flood Risk is an AI-driven property risk management platform that provides individual property level data & real time analytics to help current and prospective property owners, insurers, banks, contractors, risk mitigation experts and other identify and quantify the financial impact of flood risk. The companies patented data analytics tools serves as a catalyst to help educate to start conversations on ways to mitigate global flood risk starting on a local level.[349] The system uses AI to calculate floor elevations in buildings from images and survey sources, making this data usable to wider audiences and professionals assessing risk.[350]

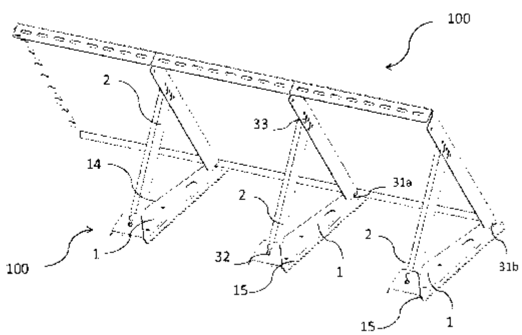
Small & Localized: Household level Flood Infrastructure

Adaptation to extreme weather and flooding impacts the daily lives and homes of people in flood zones. Many adaptation strategies involve small and localized responses that operate at domestic or household level and are realized through modifications local structures and sites.[351] These types of individual and domestic responses operate along a spectrum of timescale and responses, from long-term proactive adaptation and short-term reactive coping. For example in Semarang Bay, Indonesia, research suggests that at each step engaging a range of social and technical infrastructure, and that investment in household level early warning systems or even submersible infrastructure and floating buildings could further improve flood resilience.[352]

Comprehensive studies of property-level flood risk adaptation (PLFRA) measures suggest that a range of technologies can be implemented to effectively adapt properties and households to flood and climate change. This includes flood-proof paints, siding, and electrical sockets that reduce risk and damage, and that larger investment in individual infrastructure such as flood

349 Shelly Klose, System and method for detecting objects in images, US11120557B1, filed February 10, 2021, and issued September 14, 2021.
350 "True Flood Risk - Global AI-Driven Risk Management Platform," accessed May 24, 2023, https://truefloodrisk.com/#/.
351 Koerth et al., "A Typology of Household-Level Adaptation to Coastal Flooding and Its Spatio-Temporal Patterns."
352 Lisa-Michele Bott and Boris Braun, "How Do Households Respond to Coastal Hazards? A Framework for Accommodating Strategies Using the Example of Semarang Bay, Indonesia," *International Journal of Disaster Risk Reduction* 37 (2019): 101177.

barriers and anchored flood resilient oil tanks, can improve the resilience of individual sites.[353] A suite of technologies to address the localized concerns of property owners and site managers are now covered by the Y02A, including modular levee systems such as the Inero Flood Barriers and the Arx Pax SAFE Foundation System (Self Adjusting Floating Environment) which floats according to flood levels and allows for large developments in areas with high water tables. Each provide examples of private industry developing localized solutions to flooding and risk mitigation in the built environment (table 8).

 *Figure 52: US10458084B2 Water barrier foot element, a water barrier shield support element, a water barrier shield system and a method for manufacturing a water barrier foot element (2019).*	**Small & Localized Ex.1 Inero Flood Barriers** INERO is a flood barrier system made from marine-grade aluminum for seawater resistance. The material has high durability and withstands extremely tough outdoor conditions. flood barriers are easy to assemble, even with no previous knowledge. Six people can install 328ft of complete barrier in about an hour. The unique shape of the footing system beam provides stability and an optimal grip on all sorts of substrates, and the sections interlock using a patented quick connector to form a continuous flexible barrier that adapts to all common substrates, such as concrete, grass, gravel, and asphalt[354]. They can also be curved 90° through the use of corner sections. The barriers stop and withstand both standing and rushing water and can be assembled directly in the water in the case of rapid flooding.[355]

353 Marie-Sophie Attems et al., "Implementation of Property-level Flood Risk Adaptation (PLFRA) Measures: Choices and Decisions," *Wiley Interdisciplinary Reviews: Water* 7, no. 1 (2020): e1404.
354 Ingvar Nero, Water barrier foot element, a water barrier shield support element, a water barrier shield system and a method for manufacturing a water barrier foot element, US10458084B2, filed September 13, 2016, and issued October 29, 2019.
355 "US-INERO-Flood-Barriers.Pdf," accessed May 24, 2023, https://floodcontrolinternational.com/wp-content/uploads/2020/11/US-INERO-Flood-Barriers.pdf.

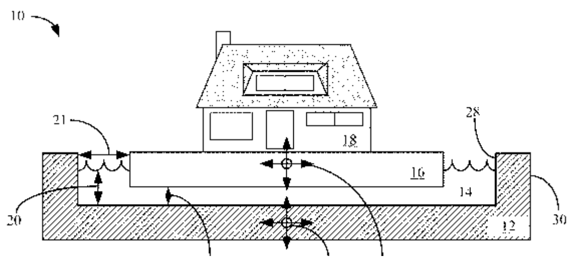
 *Figure 53: US10711478B2 "Self-adjusting floating environment (SAFE) system for earthquake and flood protection."*	Small & Localized Ex.2 Arx Pax SAFE The Arx Pax SAFE Foundation System (Self Adjusting Floating Environment) provides a more floating building foundation for at-risk homes, properties, and communities. The system varies in scale but can be configured to support individual residences in flood zones or even larger developments. Arx Pax enables affordable housing and more sustainable construction techniques by separating the buildings, infrastructure, and open spaces of communities from destructive forces. Instead of spending billions on rebuilding after disasters the system can be used to build responsibly and sustainably in risk prone locations.[356]

Table 8: Examples of Small & Localized infrastructure covered by the Y02A.

Transcalar: Micro/Macro Infrastructure for Plastics in the ocean

Plastics waste is accumulating in the ocean at alarming rates, killing marine life, and breaking down to microplastics that now exist in food chains, sediments, and water columns globally. Timothy Morton refers to this type of pollution as a hyperobject, the "sum of all the whirring machinery of capitalism" which is simultaneously something that we can sense locally but persists at scales beyond our comprehension from the microscopic to the global.[357] Plastic pollution exists in our bodies, in the seafood we eat, and the salts we consume while simultaneously supporting new ecological assemblages.[358] This type of systemic pollution requires infrastructure beyond the conventions of waste management – leading to a range of innovative technologies to address the challenges.

A Recent survey of innovation in plastic pollution technology reveals a range of strategies and technologies ranging from point source intervention in rivers to systems that remove particles. These technologies include removal of plastic waste and microplastics from storm and wastewater through filtering, large-scale ocean booms to collect garbage, drones and robots, computer aided filtering, river booms, sand filters, and an array of pumps and vacuums. [359]

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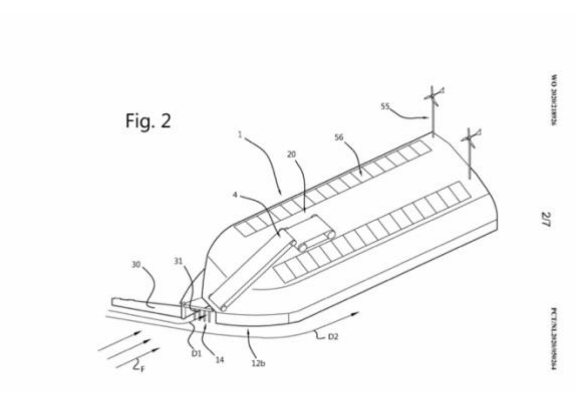
356 D. Gregory Henderson, Self adjusting floating environment (SAFE) system for earthquake and flood protection, US10711478B2, filed April 18, 2019, and issued July 14, 2020.
357 T. Morton, *Hyperobjects: Philosophy and Ecology after the End of the World, Posthumanities* (University of Minnesota Press, 2013),
358 "The Ocean's Biggest Garbage Pile Is Full of Floating Life - The New York Times," accessed May 6, 2023, https://www.nytimes.com/2022/05/06/science/great-pacific-garbage-patch-pollution.html.
359 Emma Schmaltz et al., "Plastic Pollution Solutions: Emerging Technologies to Prevent and Collect Marine Plastic Pollution," Environment International 144 (2020): 106067.

Innovation in this sector has taken off in recent years, resulting in a wealth of new devices and processes to remove plastic from waterways and terrestrial systems. This ranges from electrically charged filters that capture micro-plastic in sand, to barrier systems for entire rivers that filter flowing water with the use of air bubbles. The high-profile Ocean Cleanup project initiated by Boyan Slat has brought global attention to issues of plastic pollution, bringing together venture capital, social media, to fund select pilot projects including efforts to clean the great pacific garbage patch. At the other end of the scale spectrum is the Plastic Removal system, developed by Marc Ward in Oregon, who engages local communities in plastic particle removal using his patented screen system. Perhaps the most interesting system is the Great Bubble Barrier, invented by a European research consortium, and developed through corporate research (table 9).[360]

 *Figure 54: Figure 54: WO2020218926A1 "A free flowing water cleaning system" (2020)*	Ex.1 Ocean Cleanup Tech The high-profile Ocean Cleanup project lead by entrepreneur Boyan Slat is working towards removing plastics from the ocean and rivers around the world. The team has developed floating boom technologies to capture plastic material from the great pacific garbage patch, and also an interceptor unit designed specifically for rivers. In the ocean the team uses coastal dynamics to capture materials, by creating a relative speed difference between the cleanup system and the plastic. This effectively creates an artificial coastline to concentrate the plastic. During the systems pilot project phase and a patent (NL201882B1 & EP3622119A1) were submitted by corporate entity Ocean Cleanup Tech BV in 2018 but were since abandoned.[361] The Newest technology advances the system focusing on river systems and other flowing bodies of water. The Interceptor is a river cleanup technology. The Interceptor is a high-tech solution with solar-powered mechanics, smart processing, and connectivity for easy performance tracking. It is designed partnership with Konecranes to be autonomous and have a large cleaning capacity. The systems are deployed in Indonesia, Malaysia, the Dominican Republic, Vietnam, USA (California). The scope of the invention is covered by WO2020218926A1 A free flowing water cleaning system.

[360] Boyan Damir Slat et al., A Free Flowing Water Cleaning System, WO2020218926A1, filed April 28, 2020, and issued October 29, 2020; Francis Rosita Agnes Zoet et al., Watercourse Provided with a Bubble Screen, and Bubble Screen Therefore, WO2021075962A1, filed October 14, 2020, and issued April 22, 2021; Peter Ceglinski, Waste collection device, US10954642B2, filed December 6, 2017, and issued March 23, 2021.

[361] "Espacenet – Search Results," accessed May 24, 2023, https://worldwide.espacenet.com/patent/search/family/059381661/publication/NL2018882B1?q=pn%3DNL2018882B1.

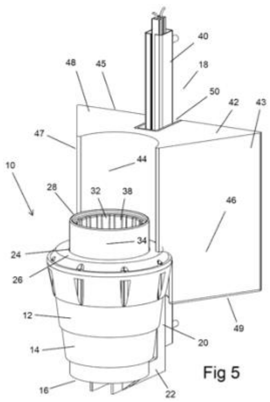


Figure 55: US10954642 "Waste Collection Device" (2021)

Ex.2 Seabins

Seabins are modular waste removal systems developed by an Australian team to address localized plastic pollution. The Seabin units are intended to be installed in the water of Marinas, Yacht Clubs, Ports, to address local pollution. In essence they act as a floating garbage bin by skimming the surface of the water and collecting material through filter fabric bags installed on the interior of the device. The Seabin capture floating debris, macro and micro plastics, along with organic debris. By changing the type of filter, the Seabin is also able to absorb petroleum-based surface oils and detergent. A single Seabin can catch an estimated 3.9 Kgs of floating debris per day or 1.4 tons per year, with the aggregative effect being impactful over multiple sites and timescales.

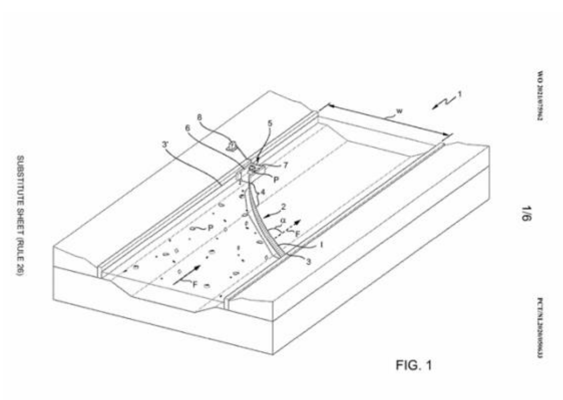


Figure 56: WO2021075962A1 "Watercourse provided with a bubble screen, and bubble screen therefore." (2021).

Ex.3 Great Bubble Barrier

The concept of the great bubble barrier is quite simple. A bubble curtain is created through installation of perforated tube on the bottom of the waterway. Pressurized are air is pumped through, generating a screen of bubbles that blocks plastics and directs suspended plastics to the surface. The bubble curtain is placed diagonally in the waterway, thus guiding plastic waste to the side and into the catchment system. Three main components constitute the system: a bubble curtain, the compressor, and the catchment system. In the fall of 2019, the first Bubble Barrier was implemented in Amsterdam and will undergo extensive testing. More recently in 2023, The Great Bubble Barrier will be implementing in the Porto region in Portugal. This Bubble Barrier will be constructed as part of project MAELSTROM which is an EU co-funded project dedicated to the mitigation of marine litter impact in coastal ecosystems.

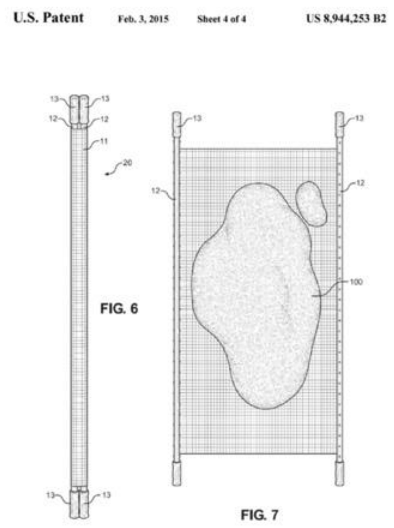
 *Figure 57: US8944253B2 "Marine microplastic removal tool" (2015)*	Ex.4 Microplastics Removal System The Microplastic Filtration System uses a statically charged filter fabric to remove microplastics as small as a grain of sand. The screens used are made from a polymer material that emits a low level of electrostatic charge, so when the screens are loaded with dry sand and plastic users manually filter the sand through the screen. The 0.7-millimeter mesh captures material mechanically, but the low static charge, also binds to smaller materials of 50 micrometers.[362] The social aspect of the project aims to clean beach landfall sites for plastics that can be cleaned by volunteers. Founder of the project, Marc Ward is based in Seaside Oregon and Has been developing the system and the project documented at Marine Microplastics since 2008 through the Blue Wave Response Team [363]

Table 9: Examples of Micro/Macro Infrastructure for Plastics in the ocean

The Role of Universities, research partners, and technology transfer

New infrastructure paradigms, and their novel pathways for delivery, engaged a range of inventors, business entities, communities, and government resources. In this emergent innovation space, patents and the patent system offer a distinct form of agency, protecting the research & development of new technologies, and the eventual transfer of a new technology between partners. These two key functions are particularly important for new infrastructural forms that exist in prototype, pilot, and early phases of development commonly associated with innovative technologies. In the context coastal infrastructure this may prove valuable in efforts to flatten pathways for innovation, coordinate knowledge for technological breakthroughs, and in projects that aim to broaden the toolkit of coastal technologies that reach culturally and environmentally diverse regions – thus allowing for the development of novel infrastructural

[362] Marc Ward, Marine microplastic removal tool, US8944253B2, filed November 21, 2013, and issued February 3, 2015.
[363] "About the System," Microplastic Removal Systems (blog), accessed November 24, 2021, https://microplasticremovalsystems.com/about-the-system/.

systems with the potential to operate outside conventional, or less nimble, approaches to infrastructure delivery.

The role of patent rights in the research and development on new technologies is well documented. Western patent law was founded on the idea that patents would incentivize invention and disclosure of new technologies to improve society.[364] Throughout history patent rights have been integral to early phase inventions and establishment of new business, helping to incentivize research and development in vital sectors. This is most evident in innovation rich and competitive areas of technology like healthcare.[365] Small firms and start-ups also benefit from patents during the early phases of business and research development as intellectual property may help secure funding.[366] Critics argue that the patent system inhibits innovation or is exploited and does not achieve its stated goals and may in fact inhibit certain innovations.[367]

Technology transfer is the is the process of transferring technology from the person or organization that owns or holds it to another person or organization. These transfers may occur between universities, businesses, governments, and across geopolitical borders, making them integral to linking the research and development of new technologies to new markets or end users. In the context of climate change, technology transfer is an important mechanism through which sustainable technologies a shared between partners in geographically and culturally diverse regions as the effort to mitigate and adapt to coastal change. Evidence exists that an effective patent system facilitates resilience through the transfer of environmentally sensitive technology from advanced economies to least developed countries.[368] This means that technologies developed in one region can effectively be transferred to other regions as needed which is vital given the scale and scope of the global climate crisis and necessity for new forms of critical infrastructure. As is observed in chapter 3 through the transfer of artificial reef technology between the Japan and United States, this process can lead to the creation of entirely new sectors of technology and shape national policy, In the contemporary context of

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[364] Scotchmer, “Patents as an Incentive System.”
[365] Henry G Grabowski, Joseph A DiMasi, and Genia Long, “The Roles of Patents and Research and Development Incentives in Biopharmaceutical Innovation,” *Health Affairs* 34, no. 2 (2015): 302–10.
[366] Christian Helmers and Mark Rogers, “Does Patenting Help High-Tech Start-Ups?,” *Research Policy* 40, no. 7 (2011): 1016–27.
[367] Jaffe and Lerner, *Innovation and Its Discontents: How Our Broken Patent System Is Endangering Innovation and Progress, and What to Do about It.*
[368] Azam, “Climate Change Resilience and Technology Transfer: The Role of Intellectual Property.”

climate adaption and mitigation research indicates that rates of technology transfer are higher than expected and play a vital role in adaptation projects worldwide while cautioning of emphasis of global north/south transfer bias and the need for localized solutions.[369]

Critics of the patent system in green technologies argue that stringent patent rules limit technology transfer by increasing the cost of new technologies in developed regions. Conversely proponents suggest that the extensive research and development investment needs to be incentivized. These debates are ongoing and important to consider, however as a recent report by the World Bank reveals, the mechanisms are vital to building climate ready technologies in the most vulnerable regions being disproportionately impacted by climate change.[370] When coordinated with policy and funding, these sociotechnical mechanisms become instrumental. Programs such as the United Nations Decade of Ocean Science for Sustainable Development (2021-2030) known as the "Ocean Decade" explicitly addresses this as part of their Implementation plan which includes provision for technology transfer and development of technological capacity for Small Island Developing States (SIDS) Accelerated Modalities of Action (SAMOA Pathway). The plan aims to undertake marine scientific research and develop the associated technological capacity of small island developing States, including through the establishment of dedicated regional oceanographic centers and the provision of technical assistance, linking small island states to global innovation networks.[371]

The broader innovation networks engaged through the patent system are also important to note. Institutional partners are central to the development of new technologies in established and emergent sectors, including climate adaptation and resilience. Universities are central to the knowledge economy and innovation through technology transfer and is closely related to the concepts of academic engagement, academic entrepreneurship, or science commercialization. The mechanisms through which university disseminate technical knowledge has many pathways, including publishing, collaborations, public engagement, and the more traditional pathways of

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[369] Bonizella Biagini et al., "Technology Transfer for Adaptation," *Nature Climate Change* 4, no. 9 (2014): 828–34.
[370] Antoine Dechezlepretre et al., "Invention and Global Diffusion of Technologies for Climate Change Adaptation," 2020.
[371] "Samoa_pathway.Pdf," accessed May 20, 2023, https://www.un.org/ohrlls/sites/www.un.org.ohrlls/files/samoa_pathway.pdf; "Publications – Ocean Decade," accessed May 20, 2023, https://oceandecade.org/decade-publications/.

intellectual property (i.e. patents).[372] Beyond their role in the transfer of new technology from the university to other partners, patents are a major indices of university research outputs togethers with publications and a broad range public service activity.

In the United States the technology exchange between universities and industry has a long history, however it received a boost In the 1980's from the Bayh-Doyle legislation permitting ownership by contractors of inventions arising from federal government-funded research, essentially removing barriers for technology transfer from a university (largely supported by federal grants) to private sector business and government.[373] In Europe a more heterogenous situation exists with regards to university research and intellectual property. In some cases, universities may not be named on patents resulting from faculty research, or vise-versa, leading to suggestions of policy experts for Bayh-Doyle "like" legislation to strengthen and streamline technology transfer.[374] Of course, patents are not the only one way in which knowledge is transferred from the university to general public and that inventiveness by an individual faculty member or lab does not always lead to patented inventions. However, university research and patents are key components of the knowledge economy and are known to contribute to the entrepreneurial ecosystems outside the university, including the creation of entirely new sectors such as biotechnology.[375]

Although much of what is known about the process results from innovation rich sectors, such as healthcare, examples of university research, development, and transfer of intellectual property also exist in the coastal adaptation and resilience space. Take for example the development of oyster substrates and coastal infrastructure in the Gulf Coast of the Southeastern United states. Students and faculty working at Louisiana State University developed collaborative research and educational ventures focused on "growing" living coastal infrastructure through the fabrication and design of oyster habitats integrated with breakwaters.

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[372] Christopher S Hayter, Einar Rasmussen, and Jacob H Rooksby, "Beyond Formal University Technology Transfer: Innovative Pathways for Knowledge Exchange," *The Journal of Technology Transfer* 45 (2020): 1–8.
[373] David C Mowery et al., *Ivory Tower and Industrial Innovation: University-Industry Technology Transfer before and after the Bayh-Dole Act* (Stanford University Press, 2015).
[374] Bart Verspagen, "University Research, Intellectual Property Rights and European Innovation Systems," Journal of Economic Surveys 20, no. 4 (2006): 607–32.
[375] Marco Guerzoni et al., "A New Industry Creation and Originality: Insight from the Funding Sources of University Patents," in *Universities and the Entrepreneurial Ecosystem* (Edward Elgar Publishing, 2017).

Students developed master's thesis research, evaluating bioengineered submerged breakwaters, analyzing bioengineered concrete, and investigating the use of bioengineered oyster reefs as a method of Shoreline Protection and Carbon Storage.[376] Faculty advisors and collaborators guided the projects, eventually leading to the development of three patented technologies for ecological concrete mixture, breakwater systems, and 3-d printed reefs.[377] Importantly, the university led research enabled the creation of a spin-off corporation, ORA, to manage the entrepreneurial venture resulting from development of intellectual property.[378] This is noteworthy in the context of oyster-tecture (discussed in chapter 1), as the first patent submitted by the ORA team for a biological active concrete (US8312843B2 Artificial Material Conducive To Attract And Grow Oysters, Mollusks Or Other Productive And/Or Stabilizing Organisms) substrate was submitted in 2006, with related 'living-breakwater' structural systems submitted in 2014 under the title "Mature Modular Reef" US9144228 (figure 58).[379]

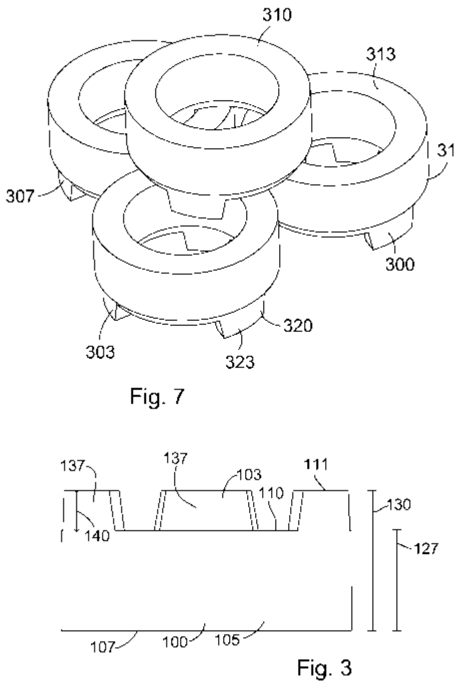

Figure 58: US 9,144.228 B1 "MATURE MODULAR REEF" (2015). Developed by ORA technolgies. (Source: European Patent Office, https://www.epo.org/en)

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[376] Matthew Dwain Campbell, Analysis and Evaluation of a Bioengineered Submerged Breakwater (Louisiana State University and Agricultural & Mechanical College, 2004); Tyler Ray Ortego, Analysis of Bioengineered Concrete for Use in a Submerged Reef Type Breakwater (Louisiana State University and Agricultural & Mechanical College, 2006); Matthew Byrum, Optimizing Bioengineered Coastal Materials (Louisiana State University and Agricultural & Mechanical College, 2014).

[377] Tyler R. Ortego et al., Artificial material conducive to attract and grow oysters, mollusks or other productive and/or stabilizing organisms, United States US8312843B2, filed June 30, 2006, and issued November 20, 2012, Matthew D. Campbell, Robert L. Beine, and Steven G. Hall, Biologically-dominated artificial reef, United States US7144196B1, filed December 28, 2005, and issued December 5, 2006, Matthew Dwain Campbell et al., Three-dimensional printing, United States US9962855B2, filed September 13, 2016, and issued May 8, 2018, h.

[378] Steven G Hall et al., "Growing Infrastructure: Entrepreneurial Thought and Action to Develop Coastal Bioengineering Technologies, From Education to Sustainable Production," 2019.

[379] Tyler R. Ortego et al., Artificial material conducive to attract and grow oysters, mollusks or other productive and/or stabilizing organisms, US8312843B2, filed June 30, 2006, and issued November 20, 2012; Tyler R. Ortego and Matthew D. Campbell, Mature modular reef, US9144228B1, filed March 24, 2014, and issued September 29, 2015.

The core technology, OysterBreak is a patented technology designed to use the oyster's inherent nature of clustering to enhance a strategic coastal protection structure for coastal and estuary shorelines. Since its invention it has been licensed, manufactured, installed, and promoted, by a series of companies, Including ORA Estuaries, Wayfarer Tech, and currently NAtrx adaptive infrastructure who manufacture 3-d printed reefs. The initial system was developed by Tyler Ortego during a Master of Science thesis at Louisiana State University in 2006 following hurricane Katrina in 2005 and in the context of ongoing subsidence in the state. The Oysterbreak technology has been tested at the Rockefeller Wildlife Sanctuary after receiving funding from the Funding from Nature Conservancy, having signed a contract for a 3,000-foot reef at the Biloxi Marsh.[380] It has also been published in Fast Company, was a finalist in design competitions. Looking back, we can observe how catastrophic environmental events catalyze the need for innovation and how incentives such as seed finding, experimental pilot projects, and awards lead to tangible novel technologies for coastal adaptation and resilience. [381][382]

Discussion

A shift away from large-scale and centralized approaches to critical coastal infrastructure reveals alternate pathways for infrastructure delivery as these infrastructure types come together through the efforts of diverse actors and agencies including university researchers, private companies, community groups, NGOs, and other constituencies, operating within distinct geographies and cultural contexts. These new infrastructure paradigms utilize technologies such as micro-grids, robotics, artificial intelligence, and small-scale distributed systems, to build and prototype critical infrastructure in culturally and environmentally diverse regions – making them highly relevant to strategies for coastal adaptation and resilience. Innovation is vital within this sector and patented technologies are often utilized to prototype these new infrastructural

[380] dylan, "A Closer Look at The Natrx OysterBreak System," Natrx Adaptive Infrastructure (blog), March 1, 2021, https://natrx.io/the-natrx-oysterbreak-system.
[381] "OysterBreak, a New Coastal Restoration System, to Appear in Entrepreneur Week's Water Challenge | Business News | Nola.Com," accessed November 4, 2022, https://www.nola.com/news/business/article_da9e3221-0d12-5c2c-80a2-f594f1c50aa7.html.
[382] Steven G Hall et al., "Growing Living Shorelines and Ecological Services via Coastal Bioengineering," in *Living Shorelines* (CRC Press, 2017), 249–70.

systems both as part of ongoing research and pilot projects. Furthermore, patent rights are also integral to the transfer of technology between partners and countries addressing global issues of climate change adaptation highlighting the actors, agencies, and role of patents emergent sectors of coastal infrastructure. Patent innovation studies provide unique insights into these new forms of infrastructure, indicating novel pathways for infrastructure delivery and new assemblages of inventors, industry, engages in environmental problem solving within coastal zones.

Ongoing evolution of new infrastructural possibilities can be traced throughout academic literature and the Y02A, with the opportunity to link theory to practice through actionable technologies in a range of coastal locations and cultures. In remote pacific Island nations, like Fiji, energy independence and resilience are central to livelihoods and have become a critical issue for health and safety, leading to innovations in off-grid energy generation and desalination that are modular, flexible, and decentralized – reflecting not only the reality of life on an archipelago but also the form of dwelling in adynamic coastal zone.[383] The discrete water technologies would be covered By Y02A 20/124 Water Desalination, Y02A 20/108 Rainwater Harvesting, with the solar electrical covered most effectively by Y02B10/00 Integration of renewable energy sources in buildings. Alignments between theory and technical patent classifications can be observed across a range subject areas. Within the discrete fields of coastal & marine science, new research surveys suggests that mapping, sensing, and education, are vital forms of infrastructure for adaptation to climate change in coastal systems – placing these systems of communication and data collection on the same footing as fixed physical infrastructures.[384] Innovations in this emergent infrastructural space would likely be covered by Y02a 10/40 for Monitoring floods and Hurricanes, including mapping systems, or the broader Y02A 90/00 covering "Technologies having an indirect contribution to adaptation to climate change" which includes those technologies for forecasting and climate simulation.

[383] Hills, Michalena, and Chalvatzis, "Innovative Technology in the Pacific: Building Resilience for Vulnerable Communities."
[384] Klein et al., "Technological Options for Adaptation to Climate Change in Coastal Zones."

6. The YO2 Patent Scheme as Anticipatory Framework for Coastal Planning and Design Praxis

The Y02A patent classification scheme was launched by the European Patent Office in April 2018 to organize climate adaptation technologies, including those related to coastal systems, flood control, adaptation of existing infrastructure, human health, and technologies for mapping and sensing the environment. The YO2A scheme is highly relevant to Coastal adaptation and resilience activities as it tags and organizes innovation in a range of coastal and riverine technologies and provides cross-sectoral insight into technological trends - functioning as an anticipatory framework for governance in these emergent sectors. As a mechanism for the management of sequential innovation the Y02A scheme also builds adaptive capacity within the coastal adaptation and resilience space through the diffusion of technological information, increased searchability, and focused patent classifications specifically addressing climate adaptation in coastal, riverine, and urban systems. These core functions address a broad range of coastal issues and can be inform planning and design praxis about technological trends as the dossier continues to grow – contributing to disciplinary capacities for scenario building and strategic planning for probable, plausible, pluralistic, and performative futures. As is observed in the previous five chapters, the struggle to define new coastal futures through technological innovation is a perennial and powerful societal effort that will continue in the context of climate change and perceived environmental risk. Patents provide unique insights about future scenarios and can therefore build adaptive capacity in the face of uncertainty.

Integration of the Y02A with spatial planning and design praxis does raise distinct questions about the role of technology to the allied professions of environmental design and planning, challenging conventions of professional practice limits of disciplinary scope. However, the Y02A's organizational structure and origins in the policy initiatives of the Paris Agreement and Kyoto Protocol can help governments, and planners, make informed decisions about the future of the environment by linking theory to actionable technologies and helping to anticipate technological trends as the cross sectoral technologies of coastal adaptation and resilience are foregrounded by the Y02A. For example, Y02A 30/60 covers "Planning or Developing Urban Green Infrastructure" which now contains almost 22,000 patents from around the world, with

19,583 from China alone. Refined searches reveal some potentially valuable new ideas and business ventures including a system developed by an Australian company DirtSat Inc, for smart city integrated urban roof agriculture[385] (figure 59), and a SunPave Inc modular solar paving system described in the patent GB2588296B "Paver with solar panel".[386]

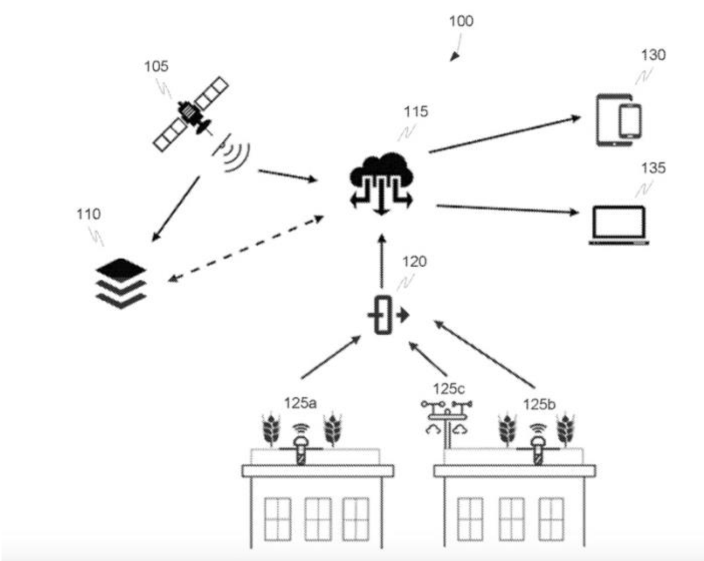

Figure 59: AU2021344973A "Systems and methods of urban rooftop agriculture with smart city data integration" (2023) – a pending patent submitted by DirtSat Inc, included in the new classification for green infrastructure. (Source: European Patent Office, https://www.epo.org/en)

Other subsections of the classification scheme show similar potential, including Y02A10/30 covering “Flood prevention and storm water management, Y02A90/10 covering “Information and communication technologies supporting adaptation to climate change” which organizes the weather forecasting or climate simulation systems essential to the analysis of a changing climate. Together the Y02A categories create an institutional mechanism for the diffusion of innovation in coastal adaptation and resilience technologies and may help greenlight actionable technology by bridging any perceived, or real, lags between new policies and future work in the coastal adaptation and resilience space. As is observed elsewhere in the “green” economy, the patent system can play an important role in expediting innovation through fast-tracked reviewed and coordinated efforts across office dealing with critical and emergent sectors such as green technology.[387] Viewing the Y02A patent scheme through the lens of coastal adaptation and

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385 Christine Tiballi, Systems and methods of urban rooftop agriculture with smart city data integration, AU2021344973A1, filed September 16, 2021, and issued March 30, 2023.

386 “SUNPave – Tomorrow’s Energy Today,” accessed June 21, 2023, https://sun-pave.com/; “DirtSat | Green Roof Marketplace for Urban Sustainability,” accessed June 21, 2023, https://www.dirtsat.com/.

387 Lane, “Building the Global Green Patent Highway: A Proposal for International Harmonization of Green Technology Fast Track Programs.”

resilience planning reveals its capacities as an anticipatory framework for management of innovation in emergent environmental sectors.

Origins of Y02 and Y02A Patent Classification Scheme

The Y02A was born out of the need to understand technological trends in emergent climate technologies. In 2009/2010 the European Patent Office created a novel computer algorithm to automatically identify, track, and organize all low-carbon technologies in a searchable database accessible to patent examiners as reference for emergent technologies.[388] The algorithm created real-time technical dossiers and provided insights regarding emergent, and existing, low-carbon and climate change mitigation tech technologies (CCMTs). In this manner the algorithm helped build responsive and predictive capacities within the patent office targeted on a specific sector of environmental technologies while tracking trends and helping the office keep pace with a rapidly developing technology. The Y02 scheme evolved from this nascent internal research tool, helping to build reference dossier for patent examiners, and establishing an anticipatory framework for technological evolution in climate adaptation sectors – thus linking technological innovation to global policy initiatives.

Essential functions and scope of the Y02 were made public in June 2010 at the UNFCCC's 32 Subsidiary Bodies Session in Bonn, Germany, and since this time the initiative has received ongoing support from the UNFCC as a mechanisms through which to link innovation in climate mitigation technologies to global policy and funding initiatives.[389] Ratification of the Paris agreement in 2015 foregrounded the need for technological solutions to climate change, leading to the further development of the Y02 classification scheme and implementation globally. These explicit provisions are evident in the official European Patent Office description, which states; "This class (Y02) covers selected technologies, which control, reduce or prevent anthropogenic emissions of greenhouse gases [GHG], in the framework of the Kyoto Protocol and the Paris

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[388] Raphael Calel, "Adopt or Innovate: Understanding Technological Responses to Cap-and-Trade," *American Economic Journal: Economic Policy* 12, no. 3 (2020): 170–201; Raphael Calel, "Adopt or Innovate: Understanding Technological Responses to Cap-and-Trade Online Appendix," 2019.

[389] Victor Veefkind et al., "A New EPO Classification Scheme for Climate Change Mitigation Technologies," *World Patent Information* 34, no. 2 (2012): 106–11.

Agreement, and also technologies which allow adapting to the adverse effects of climate change.” Today the Y02 patent scheme has expanded to including a range of technologies that extend beyond the original low-carbon focus, tagging patents related to climate adaptation, flooding, infrastructure, health, mapping, etc. under a range of subclasses that address the breadth of climate adaptation and mitigation technologies.

Organizationally this new patent data is organized using the special “Y” designation assigned to monitor new technological developments and to tag cross-sectional technologies that do not fit in a single other section of the International Patent Classification (IPC) and Cooperative Patent Classification (CPC) or have been classified elsewhere. In essence, the Y02 scheme organizes existing, and future, technologies in broadly related and emerging sectors of climate adaptation to provide insights about existing technological capacities and anticipatory framework to track future trends. Having emerged from an algorithm to track, organize, and inform the patent office staff about novel areas of technology in which little is known, the Y02 classification scheme establishes the leading edge of technological trends building adaptive capacity in emergent problem spaces - including the cross-sectoral technologies of coastal adaptation and resilience.

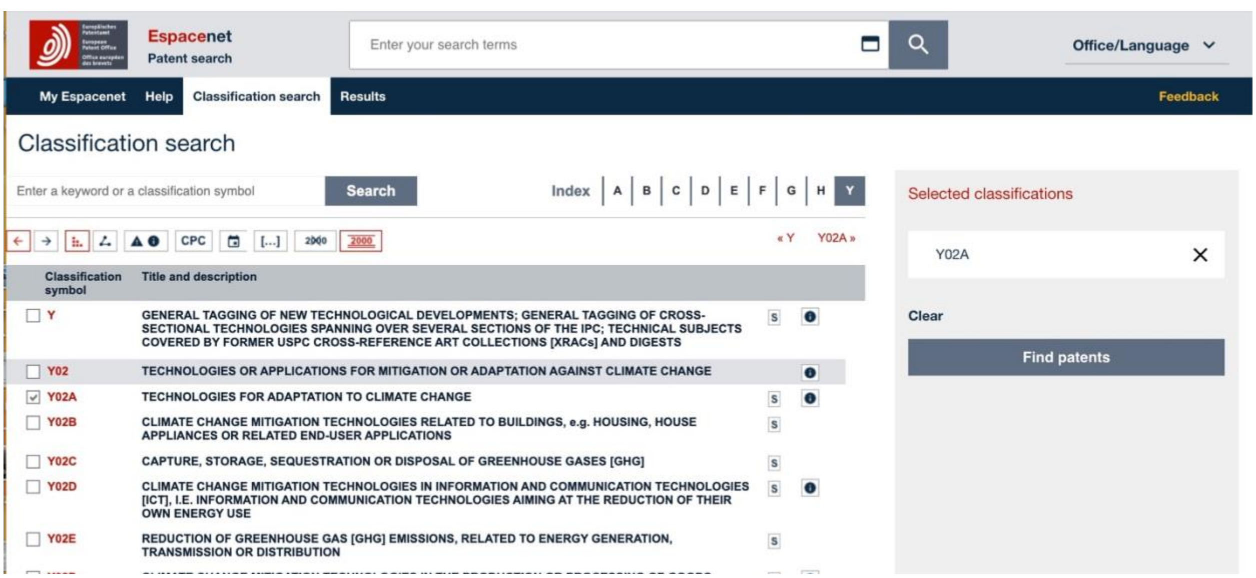

Figure 60: Search Page for the Y02 patent classification scheme on the European Patent Office Website. Easily accessible and free to the public. (source https://worldwide.espacenet.com)

The Y02 classification scheme is also public facing (figure 60). The rapid diffusion of technology is also central to the Y02 initiative as well as the policy frameworks of the Paris

Agreement and Kyoto Protocol. As a mechanism for diffusion of technical information the Y02 initiative aims to catalyze innovation through the functions of search and discovery that a publicly accessible database of climate adaptation and mitigation technologies can provide. A recent publication describes is the Y02 initiative as a "dedicated classification scheme for climate change mitigation technologies (CCMTs), where relevant patent publications are "tagged" and classified into a separated scheme which is fully integrated within the Cooperative Patent Classification (CPC). This allows for non-patent experts to search for climate change-related technologies in a more user-friendly fashion."[390] Provisions for user friendly searches mean that technological information can be searched and collated easily, facilitating the diffusion of innovation, and helping inventors, governments, and end users to find relevant technologies and their owners, providing technical, legal, and business information to support strategic decision-making in the field of climate change. This is most clearly accomplished through efficient and freely accessible searches through the EPO https://worldwide.espacenet.com/patent/cpc-browser#!/CPC=Y02 where users can develop detailed searches, apply filters, and build technical dossiers with limited prior knowledge.

Sectors covered Y02 are far reaching. The Y02 designation now includes eight distinct subclasses Y02A, Y02B, Y02C, Y02D, Y02E, Y02P, Y02P, Y02W, (See table 1 for details) broadly covering the technologies or climate adaption including building systems, carbon technologies, information and communication systems, energy, manufacturing, transportation, waste management, and interconnected sectors of environmental systems including water, green infrastructure, etc. Organizing these technological classes under a single classification heading links socio-technical aspects of patent innovation to the global policy initiatives of the Kyoto Protocol and the Paris Agreement, expanding the technical capacities and knowledge of these initiatives (table 10).

[390] Stefano Angelucci, F Javier Hurtado-Albir, and Alessia Volpe, "Supporting Global Initiatives on Climate Change: The EPO's 'Y02-Y04S' Tagging Scheme," *World Patent Information* 54 (2018): 02.

Y - GENERAL TAGGING OF NEW TECHNOLOGICAL DEVELOPMENTS; GENERAL TAGGING OF CROSS-SECTIONAL TECHNOLOGIES SPANNING OVER SEVERAL SECTIONS OF THE IPC; TECHNICAL SUBJECTS COVERED BY FORMER USPC CROSS-REFERENCE ART COLLECTIONS [XRACs] AND DIGESTS
Y02 - TECHNOLOGIES OR APPLICATIONS FOR MITIGATION OR ADAPTATION AGAINST CLIMATE CHANGE
Y02A - TECHNOLOGIES FOR ADAPTATION TO CLIMATE CHANGE
Y02B - CLIMATE CHANGE MITIGATION TECHNOLOGIES RELATED TO BUILDINGS, e.g. HOUSING, HOUSE APPLIANCES OR RELATED END-USER APPLICATIONS
Y02C - CAPTURE, STORAGE, SEQUESTRATION OR DISPOSAL OF GREENHOUSE GASES [GHG]
Y02D - CLIMATE CHANGE MITIGATION TECHNOLOGIES IN INFORMATION AND COMMUNICATION TECHNOLOGIES [ICT], I.E. INFORMATION AND COMMUNICATION TECHNOLOGIES AIMING AT THE REDUCTION OF THEIR OWN ENERGY USE
Y02E - REDUCTION OF GREENHOUSE GAS [GHG] EMISSIONS, RELATED TO ENERGY GENERATION, TRANSMISSION OR DISTRIBUTION
Y02P - CLIMATE CHANGE MITIGATION TECHNOLOGIES IN THE PRODUCTION OR PROCESSING OF GOODS
Y02T - CLIMATE CHANGE MITIGATION TECHNOLOGIES RELATED TO TRANSPORTATION
Y02W - CLIMATE CHANGE MITIGATION TECHNOLOGIES RELATED TO WASTEWATER TREATMENT OR WASTE MANAGEMENT

Table 10: Y-Y02 Classification Scheme Subject Titles

Y02A and Climate Adaptation

The Y02A scheme was launched by the European Patent Office in April 2018, and was rolled out internationally over the next few years as patent offices around the world integrated specifics of the classification scheme into their systems. The Y02A is unique among the eight subclasses of the Y02 for its focus on environmental and urban systems, infrastructure, and human health, riverine and coastal systems, making it highly relevant to a wide range of adaptation efforts in coastal zones and the broader built environment. The categories cover technologies for coastal and riverine systems, water management, infrastructure adaptation, agriculture, human health, and technologies for mapping, forecasting, and sensing (table 11). The breadth of the initiative is astounding with 702,210 patents covered by the classification, and 394,99 new patents tagged under then since January 1st, 2018.[391] This current snapshot provides a glimpse of innovation across the 6 sub sections covered by the Y02A. To date the top 8 contributors of Y02A patents include China 568,601, United States 124,377, Japan 114,923, Korea 60,269, International WO 50,940, European Patent 48,948, 34,270, Canada 28,915. It is

[391] "Espacenet – Search Results," accessed May 17, 2023, https://worldwide.espacenet.com/patent/search?q=cpc%20%3D%20%22Y02A%22%20AND%20pd%20%3E%20%2201%2F01%2F2018%22.

important to note the nearly fourfold quantity of Chinese patents that potentially skew the data through a glut of lower quality patents.

Tracking innovation within the Y02A classification can help national governments and planners make informed decisions about the future of the environment and technology, helping to collate data, analyze trends, and forecast technological capacity. For example, in the United Kingdom the recently published national "Ten Point Plan for a green revolution" sets out the approach government will take to "build back better " by supporting green jobs, and accelerating the path to net zero through renewable energy, sustainable buildings, and the protection of nature. The plans commitments to protection of nature includes specific language and financial earmarks for flood protection, stating "We will invest £5.2 billion in a six-year programme for flood and coastal defences including new innovative approaches to work with the power of nature to not only reduce flood risk, but deliver benefits for the environment, nature and communities."[392] Pursuant to the plan, the UK Intellectual Property Office published a report on patent activity in the flood and coastal defense sectors using the Y02A classification to analyze trends in flood adaptive technologies. The report notes an uptick in patent activity in this area with a majority patented technologies being developed in China and less activity domestically within the UK.[393]

The Y02A classification is also helping organizations such as the World Bank develop macroeconomic reports and technological forecasts related specifically related to climate adaptation effort. The Global Facility for Disaster Reduction and Recovery (GFDRR) recently (2020) published a global survey of technological innovation and diffusion for climate adaptation, providing the first global analysis of technological trends within sectors of technology covered by the Y02A. Authors of the report found "that a high number of patents in this random sample (89 percent) were indisputably related to adaptation to climate change as described by the UNFCCC, providing reassurance as to the quality of the Y02A tagging scheme." [394] The report offered insight about global invention and diffusion of climate adaptation technologies, including

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[392] "The Ten Point Plan for a Green Industrial Revolution" (HM Government), https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf.
[393] "Flood and Coastal Defences," n.d., 24.
[394] Antoine Dechezlepretre et al., "Invention and Global Diffusion of Technologies for Climate Change Adaptation," 2020.

observations that technologies for adaptation were concentrated within a limited number of countries such as China, Germany, Japan, the Republic of Korea, and the United States, low levels of international technology transfer, a mismatch between a countries adaptation needs and their technological capacity, and hinderances in the market resulting from a misalignment between local adaptation needs and market demands. The report also offers guidance on how these issues may be remedied through more tightly coordinated global efforts and additional research addressing adaptation technologies in specific regions.

Y02A TECHNOLOGIES FOR ADAPTATION TO CLIMATE CHANGE
10/00 AT COASTAL ZONES; AT RIVER BASINS
20/00 WATER CONSERVATION; EFFICIENT WATER SUPPLY; EFFICIENT WATER USE
30/00 ADAPTING OR PROTECTING INFRASTRUCTURE OR THEIR OPERATION
40/00 ADAPTATION TECHNOLOGIES IN AGRICULTURE, FORESTRY, LIVESTOCK OR AGROALIMENTARY PRODUCTION
50/00 IN HUMAN HEALTH PROTECTION, E.G. AGAINST EXTREME WEATHER
90/00 TECHNOLOGIES HAVING AN INDIRECT CONTRIBUTION TO ADAPTATION TO CLIMATE CHANGE

Table 11: Y02A Category Headings

Anticipatory Governance and Climate Change Technologies

Collectively the organizational structure of the special "Y" designations of the Y02 predictive algorithms used to track innovation, global patent office infrastructure, and publicly accessible data, including rapid searching, represent a form or anticipatory governance for climate adaptation. Within climate change planning and scientific literature anticipatory governance has emerged as a concept to comprehend and approach climate change through "anticipation and futures analysis, creation of flexible adaptation strategies, and monitoring and action."[395] Anticipatory governance refers to the process of governing in the present to adapt to or shape uncertain futures. A widely cited definition of anticipatory governance defines it as "a broad-based capacity extended through society that can act on a variety of inputs to manage emerging knowledge-based technologies while such management is still possible. It motivates activities designed to build capacities in foresight, engagement, and integration – as well as through their production ensemble."[396] Given the focus on future trends, anticipatory

[395] Ray Quay, "Anticipatory Governance: A Tool for Climate Change Adaptation," *Journal of the American Planning Association* 76, no. 4 (2010): 496–511.
[396] Guston, "Understanding 'Anticipatory Governance.'"

governance is theorized to build capacities in foresight, engagement, and integration within institutions, government, and society, making it particularly useful when conceptualizing approaches to problems such as climate change, national defense, and technological innovation, therefore helping government agencies and other institutions establish future trajectories for investment and innovation.[397]

Anticipatory governance is now a central feature of climate action. A pivotal moment in climate change debates was the ratification of the Paris Agreement, a legally binding international treaty on climate change. It was adopted by 196 Parties at the Conference of the Parties (COP 21) in Paris, on 12 December 2015, with a stated goal "to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels." By establishing future benchmarks, the agreement instigated the need for a global "politics of anticipation" in which contested choices for climate futures could be "woven into the technical elaboration of alternative pathways".[398] The politics of climate anticipation has evolved since ratification of Paris Agreement as global, national, and local; entities attempt to develop strategies to address climate change.

The concept of anticipatory governance challenges notions of planning as a fixed linear process, and instead integrates complexity and change into possible future scenarios – a framework that is proving valuable in sectors planning for climate change. A recent survey article states the following:

"It is becoming evident that the traditional planning paradigm that I [the author] term "predict and plan" will not be adequate to address the highly complex and uncertain issue of climate change. Uncertainty, and the extended planning horizon that climate change calls for, will likely still exist at the time governance decisions are required. In response to this problem, a new approach is emerging in literature and practice. Anticipatory governance, a new model of decision making under high uncertainty based on concepts of foresight and flexibility, uses a wide range of possible futures to anticipate adaptation strategies, and then monitors change and uses these strategies to guide decision making" [399]

[397] Ramos, "Anticipatory Governance: Traditions and Trajectories for Strategic Design."
[398] Silke Beck and Martin Mahony, "The IPCC and the Politics of Anticipation," Nature Climate Change 7, no. 5 (2017): 311–13.
[399] Quay, "Anticipatory Governance: A Tool for Climate Change Adaptation."

Since no singular strategy can address all possible climate adaptation scenarios the concept of anticipatory governance offers a forward-looking approach to develop plans that address a wide range of futures. With regards to governance structures, it seeks institutional, policy, and planning strategies that build adaptive and anticipatory capacity in society, helping to guide decision making and integrate systems. Anticipatory frameworks have proved valuable in planning possible environmental futures for climate change adaptation and engaging the legal and social aspects of climate resilience planning including possible urban, technological, and environmental futures. [400] In this context, anticipatory governance becomes integral to social-ecological resilience and that effective management of this process can lead to increased ecological knowledge by building adaptive capacity in the face of climate change and providing future foresight about appropriate responses to environmental risk, etc.[401] This includes technological scenarios and strategies for climate adaptation.

The concept of anticipatory governance is widely applicable to problems with complex and varied possible futures including climate change, national defense, and technological innovation. New and emergent technologies are often created through complex interactions and co-practices between inventors, intuitions, and broader societal assemblages making anticipation of the future a vital component of innovation networks.[402] Since the future of technology is unknown it is important to create space for new discoveries and track innovation within diverse environmental sectors. These are core and well-established functions of the global patent system and a specific objective of the Y02 scheme. Take for example the recent advances in artificial intelligence that promise to revolutionize climate mitigation and adaptation efforts by making climate models and integrated responses more effective. Innovation in this emergent sector is most effectively tracked through analysis of patent data now organized by the Y02 scheme, revealing evidence of knowledge spillover between advances in AI and adaptation technology.

In the context of climate adaptation and mitigation, technological innovation and patent trends offer distinct insights about future environmental scenarios while simultaneously

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[400] Edward W De Barbieri, "Urban Anticipatory Governance," Fla. St. UL Rev. 46 (2018): 75.
[401] Boyd et al., "Anticipatory Governance for Social-Ecological Resilience."
[402] Alvial-Palavicino, "The Future as Practice. A Framework to Understand Anticipation in Science and Technology."

revealing the role of the patent system of adaptive governance and new knowledge infrastructures. For example, in sectors such as climate engineering the 1.5-degree threshold for global temperature increase is central to the discussion of polycentric and anticipatory frameworks for coordinated actions to mitigate climate change.[403] Theoreticians in this space have been grappling with how to govern and track this emergent and contested sector of technology. A recent article summarizes the issue "We characterize governance of solar geoengineering as an anticipatory challenge here because the very contours of the 'object of governance' remain uncertain and largely even unknowable."[404] Importantly, knowledge and anticipation of these trajectories has planetary implications as geoengineering technologies propose to alter the earth's climate through technical intervention and insights about this process can be gained through patent analysis.[405] As these performative futures take shape, technology, and the Y02A, have the potential to contribute to future discourse, envisioning, and practices.

Although no universal framework exists for anticipatory governance in practice, a recent survey article Karlijin et al. summarizes the possible approaches that have emerging from research and literature on the subject. The authors neatly organize this into four approaches that capture the range of anticipatory governance and the mechanisms through which they may be applied, which they summarize as follows: 1) Probable futures, strategic planning, and risk reduction, 2) Plausible futures, enhanced preparedness, and navigating uncertainty. 3) Pluralistic futures, societal mobilization and co-creating alternatives. 4) Performative futures, critical interrogation, and political implications.[406] The range of approaches outlined by the authors provide insight into the practices of anticipatory governance and help comprehend how the approaches to a spectrum of "futures" can become essential component of environmental design and planning praxis.

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[403] Simon Nicholson, Sikina Jinnah, and Alexander Gillespie, "Solar Radiation Management: A Proposal for Immediate Polycentric Governance," *Climate Policy* 18, no. 3 (2018): 322–34.
[404] Aarti Gupta et al., "Anticipatory Governance of Solar Geoengineering: Conflicting Visions of the Future and Their Links to Governance Proposals," *Current Opinion in Environmental Sustainability* 45 (2020): 10–19.
[405] Paul Oldham et al., "Mapping the Landscape of Climate Engineering," *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 372, no. 2031 (2014): 20140065.
[406] Karlijn Muiderman et al., "Four Approaches to Anticipatory Climate Governance: Different Conceptions of the Future and Implications for the Present," *Wiley Interdisciplinary Reviews: Climate Change* 11, no. 6 (2020): e673.

Y02A as an Anticipatory Framework for the probable, plausible, pluralistic, and performative futures

The allied fields of environmental design and planning are integral to climate adaptation, and coastal resilience efforts. The well-defined disciplinary scopes, and working methods, of landscape architecture, architecture, urban and regional planning, and civil and environmental engineering inextricably link them to real world sites and environmental systems through praxis – making them a vital link between global strategies for adaptation and the contingencies of coastal sites. However, pressing questions remain regarding the relationship of these allied disciplines to technology, innovation, and patented technologies. Inclusion of specific sub-classes in the Y02A classification scheme for technologies related to the built environment and coastal adaptation present an opportunity to link professional practice to broader technological trends.

The relative newness of the Y02A (implemented 2018-2020) classification scheme, and general obscurity of the patent system within the discourses of coastal adaptation and resilience, create a unique situation. On one hand, the existence of a global framework for the management and diffusion of innovation in coastal sectors is a provocation, or call-to-action, with the possibility to facilitate positive change in communities and ecosystems. On the other, the mechanisms and processes through which novel adaptation and resilience technologies are invented, tested, and implemented through environmental/spatial design, planning, and engineering praxis are nascent. Given this recent emergence of the Y02A it is reasonable to look towards the Y02 (super-classification of Y02A originating c. 2015) scheme for indications of trajectory within the field. Research shows the Y02 has the potential to function as part of a complex assemblage of how cities, regions, and countries develop approaches to climate adaptation. For example, southwest European cities are using data from the Y02 scheme to help guide research and development activities in the region.[407] Recent studies at the intersection of climate change and patent data suggest that policymakers can use the Y02 results to get greater clarity on how to allocate resources for R&D and support climate change technologies.[408] In this

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[407] Şiir Kılkış, "Sustainable Development of Energy, Water and Environment Systems Index for Southeast European Cities," *Journal of Cleaner Production* 130 (2016): 222–34.
[408] Su Jung Jee and Sugandha Srivastav, "Knowledge for a Warmer World: A Patent Analysis of Climate Change Adaptation Technologies" (arXiv. org, 2021).

manner Y02, and its sub-classifications including Y02A, helps provide foresight and is integral to measuring and analyzing environmental innovation and creates a feedback loop between environment and technology. Supporting global, and local, initiatives on climate adaptation and mitigation through technology forecasting.[409]

In essence anticipatory framework create space for emergent and unforeseen changes and aims to build foresight and predictive capacity within a broad range of systems, including technological, urban, and environmental systems impacted by climate change. Anticipatory approaches therefore help conceptualize scenarios for the future and imagine the tools required to achieve goals, creating processes for governing in the present while adapting to uncertainty. As Karlijn Muiderman et al. argue this relates to a spectrum of activates, such as scenario building, that help frame probable futures, plausible futures, pluralistic futures, and performative futures.[410] Diving deeper into this range of approaches reveals how technological innovations covered by the Y02A can contribute to, and help conceptualize, these coastal futures through the practices of design and planning.

Probable Futures consider as a starting point that "futures are scientifically uncertain and complex, but still assessable in terms of probable and improbable future risks."[411] In the assessment of probable futures, the anticipation is to assess these risks, to inform strategic policy trajectories on how to minimize future risks. This often involves cost/pricing scenarios, forward-looking information services, economic modeling, technological forecasting, analysis of climate statistics, environmental impact assessments, etc. Essentially the types of everyday planning and forecasting that governments and other agencies are regularly involved in as they consider approaches to coastal adaptation and resilience.

Practical projects, such as budgeting for a seawall replacement, storm clean-up, and issues related to predictable flooding are all part of a probable future and can be understood through the lens of technology. Take for example the processes of seawall upgrades in Sydney

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[409] Germà Bel and Stephan Joseph, "Climate Change Mitigation and the Role of Technological Change: Impact on Selected Headline Targets of Europe's 2020 Climate and Energy Package," *Renewable and Sustainable Energy Reviews* 82 (2018): 3798–3807.
[410] Muiderman et al., "Four Approaches to Anticipatory Climate Governance: Different Conceptions of the Future and Implications for the Present."
[411] Muiderman et al.

harbor which aim to increase biodiversity. New material and design standards can be informed by technological innovation, helping to align advanced technologies with the pragmatics of local planning. Novel concrete mixtures like ecological concrete, By Econcrete Tech Ltd. (US9538732B2 & AU2014217435B2 Methods and matrices for promoting fauna and flora growth) are engineered to meet international construction standards and can be effectively integrated into marine construction projects (figure 61). Importantly, by tracking innovation in ecological concrete, or a range of other applicable technologies planners and designers can develop an understanding of leading-edge systems that can serve as an anticipatory framework for probable futures.

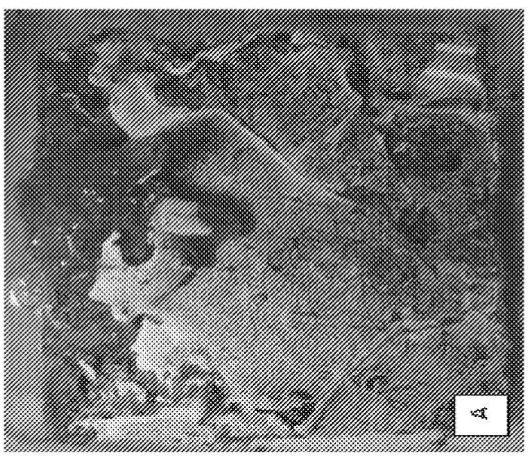

Figure 61: Patent image of biological growth on concretes using mixtures from US9538732B2 & AU2014217435B2 "Methods and matrices for promoting fauna and flora growth." (Source: European Patent Office, https://www.epo.org/en)

The detailed categories of the Y02A (tables 12-17) facilitate the exchange of technical information across a range of interrelated systems relevant to the planning of probable futures. This includes Y02A10/00 covering 'at coastal zones; at river basins," and a range of subclasses that directly link patent innovation to Y02A 20/404, Y02a 20/144 Wave Energy, Y02a 30/254 Roof Garden Systems, and Y02A 30/60 Planning or developing urban green infrastructure. Within these categories a dossier of established, and novel, technologies are available for integration into the pragmatics of planning and design. As technologies evolve, planners, governments, and communities may track innovation and build networks through metadata associated with patent submissions, linking innovators to potential partners. For example, Fresh Creek Technologies Inc and its partner StormTrap, manufacture a range of modular stormwater management systems that city managers can integrate into projects.[412] Knowledge of StormTrap technologies, such as US9695584B2 'Inclined plates for Combined

[412] "Stormwater Liter, Trash & Debris Removal | CSO Trash Control," Stormtrap, accessed June 21, 2023, https://stormtrap.com/products/trashtrap/.

Sewer Outflow' (CSO), can obviously be communicated through advertising, conferences, and word of mouth, but the metadata about inventors, and assignee, associated with the patent can also provide links to inventors and corporate entities actively engaged in developing new forms of urban infrastructure (figure 62).[413]

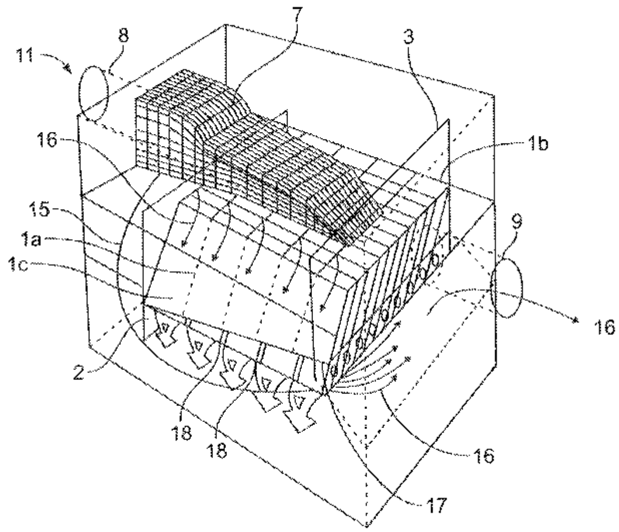

Figure 62: US9695584B2 Inclined plates for Combined Sewer Outflow (CSO) (2017) – metadata from the patent and technical details can inform planners of advances in the field. (Source: European Patent Office, https://www.epo.org/en)

Plausible Futures consider that "the future contains irreducible uncertainties and that multiple plausible future trajectories are feasible."[414] In this approach, anticipation becomes a mechanism for deliberation, thus building adaptive capacities and preparedness that allows for uncertain futures as their trajectories unfold. This involves a range of options built on shared knowledge between experts and other constituencies. This may be accomplished by processes of mapping, participatory modeling, and other actions that involve the exchange of information based on local and subject area expertise. Technology transfer is among the methods that are prioritized here including local knowledge holders and facilitate bottom-up community involvement in decision-making and those that are expert-driven. Technology transfer is a central function of the Y02A, helping to build technical capacities through the exchange of expertise.

Mechanisms for enabling the transfer of knowledge and development of plausible coastal futures range in scope and complexity from the SAMOA pathways of the United Nations that aims to build technical capacity in Small Island Developing States, to localized participatory mapping exercises, or even recurring conferences that bring together scientists, community, and

[413] Dennis R. Moran, Walter C. Trnka, and Hans De Bruijn, Inclined plates for CSO, US9695584B2, filed October 24, 2013, and issued July 4, 2017.
[414] Muiderman et al., "Four Approaches to Anticipatory Climate Governance: Different Conceptions of the Future and Implications for the Present."

industry, to approach large scale costal planning initiatives. Similarly, the 100 Resilient Cities initiative, supported in part by the Rockefeller Foundation and partners, aims to build urban resilience through social and technical pathways. The network of 100 cities spans continents, aiming to link urban resilience networks and catalyze innovation. The projects statement on technology looks at urban centers for the development of resilience technology and also the end user, focusing primarily on digital technology for smart cities, analytics, and mapping. Sectors covered by Y02A 90/10 Information and communication technologies [ICT] supporting adaptation to climate change through weather forecasting or climate simulation.

Withing the discrete domains of coastal planning anticipatory frameworks for plausible futures are common and widespread, making them vital to the implementation of innovative planning strategies and technologies. We can look towards sustained long term planning conferences, such as the State of the Coast conference in Louisiana, that aims to create an "interdisciplinary forum to exchange timely and relevant information on the dynamic conditions of Louisiana's coastal communities, environment, and economy and to apply that information to existing and future coastal restoration and protection efforts, policies, and decision-making." In addition to the plenary session and keynote lecture, a robust list of donors and exhibitors showcase new technologies that address the audiences and practical elements of initiating Louisiana's coastal masterplan. Technologies exhibited at the conference help communicate a range of technological options that address the plausible futures discussed at the conference. Exhibitors such as Tetratech, Louisiana State University, ORA, all have intellectual property covered by the Y02 and achieve knowledge

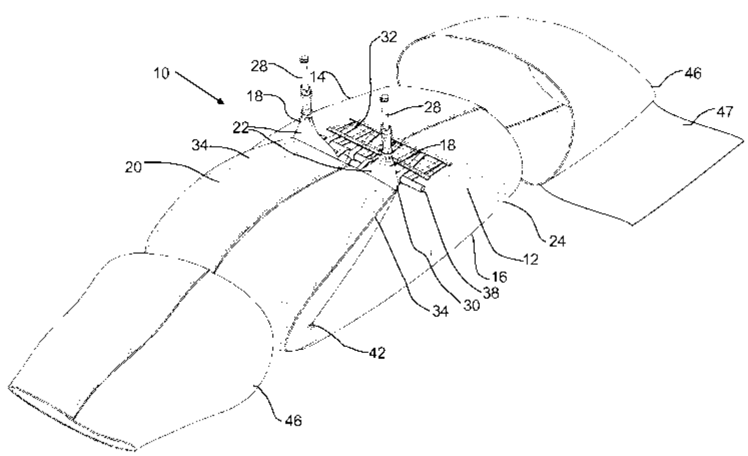

Figure 63: US9297133B2 "Fluid fillable structure" (2016). Flexible flood infrastructure exhibited a State of the Coast. (Source: European Patent Office, https://www.epo.org/en)

transfer through this process. Consider briefly the water filled flood control structures US9297133B2 "Fluid fillable structure "manufactured by Aqua Dams Gulf Coast (figure 63).[415] Their rapidly deployed coffer dams, exhibited at the State of the Coast in 2014, inform end users in subsided and flood prone lands how to protect their property using the system.[416] This type of entrepreneurial approaches to addressing plausible coastal futures integrate technology into practice through community engagement and knowledge exchange as part of regionally specific conferences.

Pluralistic futures consider "embedding multiple future worlds, shaped by interaction, and dependent on diverse interpretations of the world."[417] This pluralism is achieved by mobilizing diverse societal actors that may collectively develop actionable pathways for change. This type of co-creating enables the conceptualization of new and transformed futures through the process of creating experiential futures in simulations, envisioning, or other immersive experience. In practice this may include processes such as design workshops that integrate futures into present day environments or design competitions that help mobilize collective action towards a desired state. Envisioning through visual representation and narrative is now common practice in coastal adaptation and resilience planning, particularly through the professional practices of architecture, landscape architecture, and urban planning who embrace future projections as agents of change. This is readily observable in the range of design and planning competitions addressing the issue including the widely cited Resilience By Design program and others such as the Changing Course competition that developed pluralistic futures for the Mississippi River Delta.[418] As is discussed in chapter 1 & 5, design and planning competitions not only lead to the creation of novel technology such as oyster-tecture but may also be informed by patent innovation studies through the creation of technical dossiers and analysis of patented technology.

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[415] "Gulf Coast AquaDams in Abbeville, LA," Web Leads, accessed June 21, 2023, https://GULFCOASTAQUADAMS.COM/.
[416] James Andrew Mills and Gregory Allan Parrent, Fluid fillable structure, US9297133B2, filed September 5, 2014, and issued March 29, 2016.
[417] Muiderman et al., "Four Approaches to Anticipatory Climate Governance: Different Conceptions of the Future and Implications for the Present."
[418] "Changing Course," accessed April 9, 2022, http://changingcourse.us/; "Changing Course," Restore the Mississippi River Delta, accessed June 19, 2023, https://mississippiriverdelta.org/changing-course/.

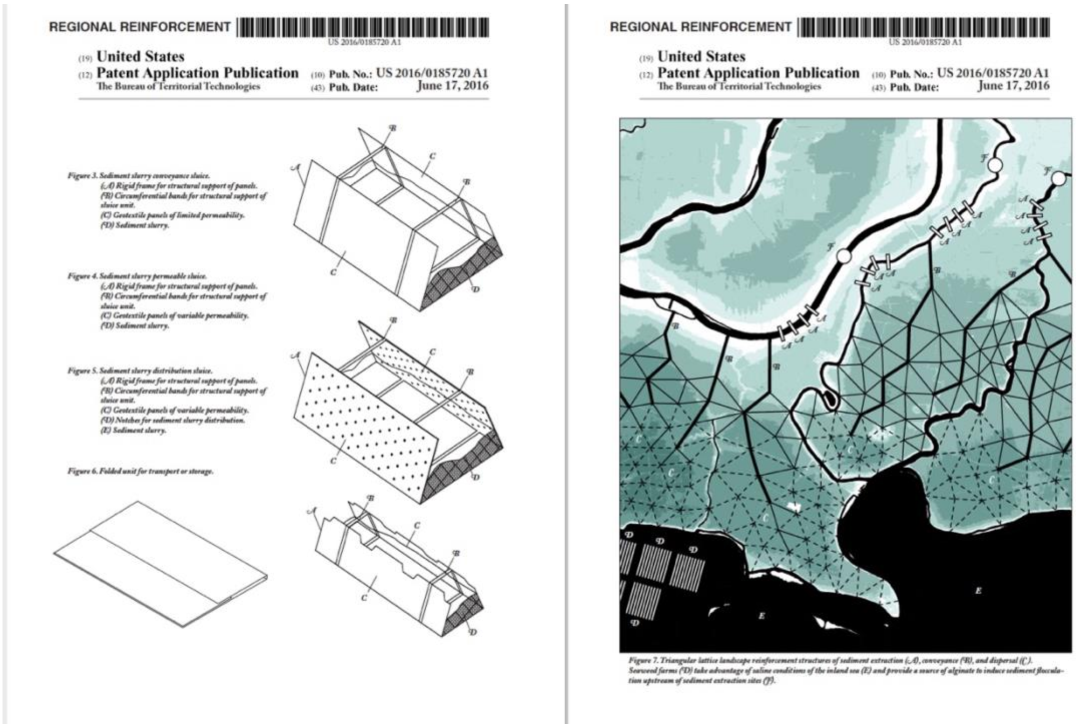

Figure 64: A speculative technology for "Regional Reinforcement" developed by the design team during Dredgefest California

Pluralistic futures are also central to design and planning pedagogy which sometimes addresses issues of coastal adaptation and resilience. These projects can be designed with innovation and patent research as a central theme. For example, In the summer of 2016, the author (Richard Hindle) and Neeraj Bhatia (CCA) led a workshop as part of DredgeFest California, focused on sedimentation and earthworks in the California Delta. During the weeklong workshop, participants and workshop leaders were asked by the DredgeFest organizers to develop responses to a series of scenarios that covered the pluralistic futures in the delta. After a short initial exercise exploring existing technologies from the patent archive and extrapolating their territorial impact, four new technologies were created by the team who operated under the pseudonym "Bureau of Territorial Technologies."[419] Each invention addressed issues ranging from subsidence and accretion of sediment to aquifer recharge and levee reinforcement (figure 64). By developing a specific technology and understanding how it would alter the broader the landscape, it allowed designers to quickly understand the implications of their design proposals, moving back and forth between technological invention, and pluralistic regional transformation,

[419] Richard L Hindle and Bhatia Neeraj, "Territorial Technologies," 2016.

ultimately facilitated design experimentation at the scale of the territory and at the detailed scale of a specific technology developed by the designer.

Performative futures engage the future through "fabrications, or sociotechnical imaginaries that are speculative, but still performative in calling into being certain privileged visions of the future." Their capacity for speculation allows for alternate readings and potential to emerge and for their political implications and material consequences to be investigated. Methods such as narrative, image making, serve as heuristics that allow for diverse futures to explored and analyzed for their political and social implications by opening discourse and framing new potential. Performative futures are often central to the realization to environmental scenarios and new ecologies and can be tracked through technological innovations in the Y02A. Take for examples the debate around invasive species in which new environmental scenarios for managing wildness and autonomy are conceived.[420] Theorists in this space look towards technologies such as the RangerBot, designed by scientists in Queensland Australia to attack invasive starfish, as examples of integrated robotics and computation employed in the management of invasive species – evoking a novel form of Anthropocene wilderness. A specific patent subclass Y02A 90/40 covers the "Monitoring or fighting invasive species" which includes a range of related technologies such as rovers to collect invasive lionfish or devices for the filtering of algae blooms (figure 65).[421]

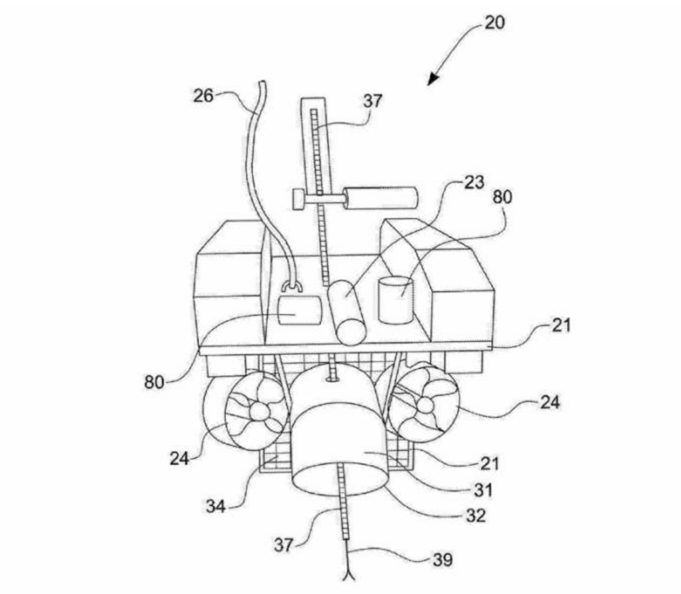

Figure 65: GB2567452A "Method apparatus and system for controlling fish" – one of the numerous autonomous vehicles designed to hunt invasive species. (Source: European Patent Office, https://www.epo.org/en)

Given the projective nature of technology, and the anticipatory capacities of the patent

[420] Cantrell, Martin, and Ellis, "Designing Autonomy: Opportunities for New Wildness in the Anthropocene."
[421] Alan Martin Darius et al., Method apparatus and system for controlling fish, GB2567452A, filed October 12, 2017, and issued April 17, 2019.

system, performative futures weave a distinct thread through the Y02, and Y02A classification. Patent trends offer insights about future environmental scenarios while simultaneously revealing the role of the patent system of adaptive governance and new knowledge infrastructures. Knowledge and anticipation of these trajectories has planetary implications as is evident in evolving discourse and debate on geoengineering. In the emerging geoengineering sector few laws or government entities are in place to manage developments given the extraterritorial nature of the proposals and global impact making foresight of future trends important. According to a recent paper on the subject, "In the absence of a governance framework for climate engineering technologies such as solar radiation management (SRM), the practices of scientific research and intellectual property acquisition can de facto shape the development of the field." [422] In this speculative technological space new frameworks patent law are also being proposed including patent pools that ensure the free use and diffusion of technologies to "save the planet."[423] Irrespective of the validity of existing geoengineering technology, it is interesting to take note, just in case these projections of future climate solutions take shape. We can see this debate taking shape in the context of coastal adaptation and resilience through the emergence of coral reef restoration technologies. A recent survey article reveals a disconnect between coral reef restoration patents and trends in scientific literature, pointing towards the need to peer-reviewed science to be translated into actionable technologies.[424] Of course these issues should be addressed, but a review of recent reef patents raises questions of a geopolitical nature. For example,

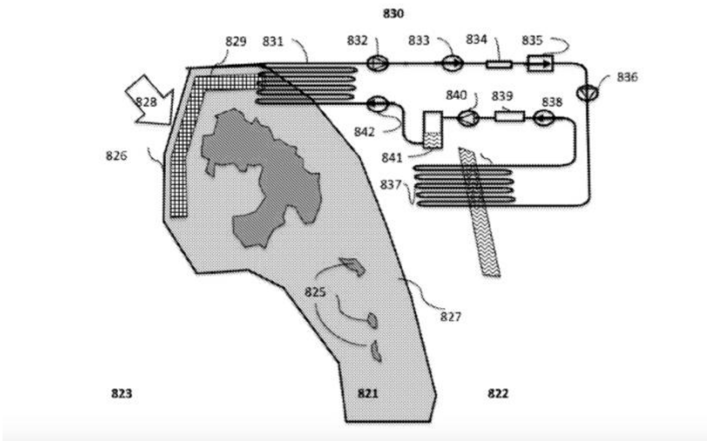

Figure 66: WO2022091107A1 "system and method for reducing temperature of water in coral reef and adjacent ocean" – an example of speculative environmental engineering patents that aim to save coral reefs. (Source: European Patent Office, https://www.epo.org/en)

[422] Oldham et al., "Mapping the Landscape of Climate Engineering."
[423] Anthony E Chavez, "Exclusive Rights to Saving the Planet: The Parenting of Geoengineering Inventions," *Nw. J. Tech. & Intell. Prop.* 13 (2015): 1.
[424] Cassandra Roch, Sebastian Schmidt-Roach, and Carlos M Duarte, "Coral Restoration Patents Are Disconnected from Academic Research and Restoration Practitioners," 2023.

WO2022091107A1 “system and method for reducing temperature of water in coral reef and adjacent ocean” and the now abandoned patent AU2016101704A4 “A method for saving coral reefs from bleaching by cloud intensification” initially submitted by the Sydney Institute of Marine Science, both require the existence of global technologies, and political actors, capable of altering marine environments and atmospheric systems (figure 66).[425]

Discussion

The YO2A scheme is highly relevant to Coastal adaptation and resilience activities as it tags and organizes innovation in a range of coastal and riverine technologies and provides cross-sectoral insight into technological trends. As a mechanism for the management of technological innovation the Y02A scheme builds anticipatory capacity within the coastal adaptation and resilience space through the diffusion of technological information, increased searchability, focused patent classes specifically addressing climate adaptation in coastal, riverine, and urban systems. Tagging patents related to climate adaptation essentially collates large datasets of past, present, and future patented technologies related to the subject area and helps structure searches, citations, and build knowledge infrastructure. Tracking innovation in climate adaption technologies also allows for the diffusion (i.e., sharing) of innovation to be streamlined and identification of technological trends to emerge in distinct categories. In this manner the Y02 scheme serves as an anticipatory governance framework for managing technological innovation in the context design and planning praxis, providing technical insights for probable, plausible, pluralistic, and performative futures.

Coastal Adaptation and resilience planning cuts a distinct transect through technologies covered by the Y02A classification scheme. Within design, planning, and scientific communities it is widely accepted that coastal adaptation and resilience requires a wholesale reconfiguration of how we live with water and organize the social, ecological, and technical systems that converge in coastal zones. A recent publication on coastal “structures” states this succinctly; “Coastal resilience necessitates not only new infrastructural strategies but a fundamental

[425] Sunit Tyagi, System and Method for Reducing Temperature of Water in Coral Reef and Adjacent Ocean, WO2022091107A1, filed December 24, 2020, and issued May 5, 2022.

transformation in understanding how cities might relate to the water around them."[426] This paradigm shift suggest a more expansive list of technologies extending though cities, regions, and natural systems to reformulate the water, sediment, nutrient flows, and natural process that interact within coastal anthromes in which human and natural systems are coupled, including agriculture, human settlement (i.e. buildings and infrastructure), engineered coastlines, river systems, etc.[427] From this perspective, the Y02A provides insights regarding a range of interconnected coastal technologies in addition to those structures directly related to the coastline – building anticipatory governance through the adaptive capacities of technological innovation.

Table 12 Y02A/10 Technologies for Adaptation to Climate Change at coastal zones and river basins

Y02A 10/00 AT COASTAL ZONES; AT RIVER BASINS
Y02A 10/11 HARD STRUCTURES, E.G. DAMS, DYKES OR BREAKWATERS
Y02A 10/23 DUNE RESTORATION OR CREATION; CLIFF STABILISATION
Y02A 10/26 ARTIFICIAL REEFS OR SEAWEED; RESTORATION OR PROTECTION OF CORAL REEFS
Y02A 10/30 FLOOD PREVENTION; FLOOD OR STORM WATER MANAGEMENT, E.G. USING FLOOD BARRIERS
Y02A 10/40 CONTROLLING OR MONITORING, E.G. OF FLOOD OR HURRICANE; FORECASTING, E.G. RISK ASSESSMENT OR MAPPING

Table 13 Y02A 20/00 Water conservation; Efficient water supply; Efficient water use

Y02A 20/00 WATER CONSERVATION; EFFICIENT WATER SUPPLY; EFFICIENT WATER USE
Y02A 20/108 RAINWATER HARVESTING
Y02A 20/124 WATER DESALINATION
Y02A 20/131 REVERSE-OSMOSIS
Y02A 20/138 USING RENEWABLE ENERGY
Y02A 20/141 WIND POWER
Y02A 20/142 SOLAR THERMAL; PHOTOVOLTAICS
Y02A 20/144 WAVE ENERGY
Y02A 20/146 USING GREY WATER
Y02A 20/148 USING HOUSEHOLD WATER FROM WASH BASINS OR SHOWERS
Y02A 20/15 LEAKAGE REDUCTION OR DETECTION IN WATER STORAGE OR DISTRIBUTION
Y02A 20/152 WATER FILTRATION
Y02A 20/20 CONTROLLING WATER POLLUTION; WASTEWATER TREATMENT
Y02A 20/204 KEEPING CLEAR THE SURFACE OF OPEN WATER FROM OIL SPILLS
Y02A 20/208 OFF-GRID POWERED WATER TREATMENT
Y02A 20/211 SOLAR-POWERED WATER PURIFICATION
Y02A 20/212 SOLAR-POWERED WASTEWATER SEWAGE TREATMENT, E.G. SPRAY EVAPORATION
Y02A 20/30 RELATING TO INDUSTRIAL WATER SUPPLY, E.G. USED FOR COOLING
Y02A 20/40 PROTECTING WATER RESOURCES
Y02A 20/402 RIVER RESTORATION
Y02A 20/404 SALTWATER INTRUSION BARRIERS

[426] Catherine Seavitt Nordenson Nordenson, Guy, Chapman, Julia, *Structures of Coastal Resilience*., 2018.
[427] Kurth et al., "Defining Resilience for the US Building Industry"; Lazarus, "Toward a Global Classification of Coastal Anthromes."

Y02A 20/406 AQUIFER RECHARGE
Y02A 20/411 WATER SAVING TECHNIQUES AT USER LEVEL

Table 14 Y02A 30/00 Adapting or protecting infrastructure or their operation.

Y02A 30/00 Adapting or protecting infrastructure or their operation
Y02A 30/14 Extreme weather resilient electric power supply systems, e.g., strengthening power lines or underground power cables
Y02A 30/24 Structural elements or technologies for improving thermal insulation
Y02A 30/242 Slab shaped vacuum insulation
Y02A 30/244 using natural or recycled building materials, e.g. straw, wool, clay or used tires
Y02A 30/249 Glazing, e.g. vacuum glazing
Y02A 30/254 Roof Garden systems; Roof coverings with high solar reflectance
Y02A 30/27 Relating to heating, ventilation or air conditioning [HVAC] technologies
Y02A 30/272 Solar heating or cooling
Y02A 30/274 using waste energy, e.g. from internal combustion engine
Y02A 30/30 in transportation, e.g. on roads, waterways or railways
Y02A 30/60 Planning or developing urban green infrastructure

Table 15 Y02A 40/00 Adaptation technologies in agriculture, forestry, livestock or agroalimentary production

Y02A 40/00 Adaptation technologies in agriculture, forestry, livestock or agroalimentary production
Y02A 40/10 in agriculture
Y02A 40/13 Abiotic stress
Y02A 40/132 Plants tolerant to drought
Y02A 40/135 Plants tolerant to salinity
Y02A 40/138 Plants tolerant to heat
Y02A 40/146 Genetically Modified [GMO] plants, e.g. transgenic plants
Y02A 40/20 Fertilizers of biological origin, e.g. guano or fertilizers made from animal corpses
Y02A 40/22 Improving land use; Improving water use or availability; Controlling erosion
Y02A 40/25 Greenhouse technology, e.g. cooling systems therefor
Y02A 40/28 specially adapted for farming
Y02A 40/51 specially adapted for storing agricultural or horticultural products
Y02A 40/58 using renewable energies
Y02A 40/60 Ecological corridors or buffer zones
Y02A 40/70 in livestock or poultry
Y02A 40/76 using renewable energy
Y02A 40/80 in fisheries management
Y02A 40/81 Aquaculture, e.g. of fish
Y02A 40/818 Alternative feeds for fish, e.g. in aquacultures
Y02A 40/90 in food processing or handling, e.g. food conservation
Y02A 40/924 using renewable energies
Y02A 40/926 Cooking stoves or furnaces using solar heat
Y02A 40/928 Cooking stoves using biomass
Y02A 40/963 Off-grid food refrigeration
Y02A 40/966 Powered by renewable energy sources

Table 16 Y02A 50/00 in human health protection, e.g. against extreme weather

Y02A 50/00 in human health protection, e.g. against extreme weather
Y02A 50/20 Air quality improvement or preservation, e.g. vehicle emission control or emission reduction by using

catalytic converters
Y02A 50/2351 Atmospheric particulate matter [PM], e.g. carbon smoke microparticles, smog, aerosol particles, dust
Y02A 50/30 Against vector-borne diseases, e.g. mosquito-borne, fly-borne, tick-borne or waterborne diseases whose impact is exacerbated by climate change

Table 17 Y02A 90/00 Technologies having an indirect contribution to adaptation to climate change.

Y02A 90/00 Technologies having an indirect contribution to adaptation to climate change
Y02A 90/10 Information and communication technologies [ICT] supporting adaptation to climate change, e.g. for weather forecasting or climate simulation
Y02A 90/30 Assessment of water resources
Y02A 90/40 Monitoring or fighting invasive species

Conclusion

As anthropogenic and urbanized coastal systems become more technologically advanced, networked, logistical, ecologically novel, and integrated, a strategy is required for the allied disciplines of environmental design and planning to engage the socio-technical processes that operating within these complex systems. This dissertation illustrates how the patent system, and innovative technologies disclosed within it, have impacted the biology, morphology, and development patterns of coastal systems for centuries and how this trend is projected to continue in the context of a changing climate. However paradoxical, innovation is a vital societal response to environmental risk and is imperative for coastal adaptation and resilience planning efforts occurring in cities and regions around the world. Leveraging the distinct agency of patented technology, and the patent system, offers one strategy for the advent and advancement of novel environmental technologies – operationalizing broad sociotechnical processes to help build more sustainable, adaptive, and equitable coastal Anthromes.

Establishment of Y02A patent classification scheme (circa 2018-20) for "Technologies for Adaptation to Climate Change" resolves one small, yet important, piece of the wicked problem of coastal resilience and adaptation, providing knowledge infrastructure for the adaptive capacities of technology to contribute to global efforts. The relative newness of the YO2A and the perceived distances between patents, innovation, and the allied professions of environmental design and planning, presents a distinct opportunity to shape coastal futures. Many questions remain regarding the invention, prototyping, testing, and implement the environmental technologies of the future – yet this work is imperative, and the allied profession of environmental design and planning are poised to be instrumental in the invention application of this new technological substrate through professional practices, research and development, and strategic partnerships. Facilitating the translation of coastal innovation into praxis, this research documents the scales, scope, complexity of implementing innovative technologies in large-scale coastal works and points towards the potential hybrid vigor between the domains of technological innovation and professional practices of urbanization, planning, design, and coastal management. The Y02A has created an entirely new system to track innovations in green infrastructure, artificial coral reefs, river restoration, etc., and now requires ground-level strategies to operationalize the most promising advances into coastal, urban, and landscape systems. Within this new paradigm are opportunities to expand disciplinary scope, build better coastal infrastructure, and link advanced technology to coastal development practices.

Observations and Reflections on Research Case Studies

The case studies presented as part of this dissertation document the scales, actors, and agency, of the patent system and patented technologies, operating within coastal system and their impact of the morphology, biology, and development of coastal Anthromes. Optimists may see the potential for novel technology to help build more sustainable and equitable coastal futures in the face of climate change and sea level rise. Pessimists may see industrial progress and economic imperatives reshaping environmental systems and extracting profit. Both possibilities exist simultaneously and are true, yet the intellectual, cultural, and policy, climate emerging around issues of climate adaptation and resilience will undoubtedly define which of these plausible futures become a reality. Take for example the case of artificial reef technology discussed in chapter 3 which embodies the dialectic. In Japan artificial reef technologies emerged through collaborative ventures between governments and private industry, leading to the birth of an ecological technology industry to support fisheries. Comparatively, In the United States the artificial reef sector was born out of a joint waste-management program with the automobile industry and Environmental Protection Agency (EPA) to build reefs from scrap tires, contributing to skepticism about the claims and objectives of artificial reef programs in the United States. Today, in the context of coastal adaption and the Y02A we observe a shift in artificial reef technology, from systems designed to augment fishing grounds, towards systems that aim to project coastal ecosystems and restore coral reefs through advanced research and technological innovation. Within this relatively well-known example the *problematique* and imperatives of coastal innovation are clear, chronicling how the cultural awareness of ocean health and sustainability leads to shifts in the technical substrate that defines coastal anthromes.

Among the cautionary tales of corporate interest, or the failed attempts to find alternative coastal stabilization technologies, readers of this dissertation may also see the upsides of a productive collaboration between technological innovation and coastal adaptation and resilience efforts. The research documents the advent of novel technologies through planning practices, diverse actors and inventors engaged in the process of systemic change, the parallel evolution of theoretical horizons and related technology, actionable pathways for new coastal infrastructure paradigms, and the productive collaborations between patent knowledge infrastructure and the anticipation of future scenarios across scales, geographies, and cultures. Today, with the existence of the Y02A classification scheme, a distinct opportunity exists to integrate these processes to the built environment and coastal systems though the design and planning praxis – helping to implement and invent the next layer of coastal infrastructure. Planners, designers, and governments will all play a role in the application, and invention, of critical climate adaptation technology making initiatives such as the Y02A central to evolution of these technical fields.

As is documented in chapter 1 through the advent of oyster-tecture the processes of coastal adaptation and resilience planning does lead to the creation of new intellectual property and novel technologies. However, these inventive processes do not occur in a vacuum, and analysis of patent innovations in the oyster-tecture and living breakwater sectors reveal that prototyping of related technologies began in the 1980's and advanced through the 1990's with pilot projects and patents by Mark and Sherwood Gagliano and August Muench. Geography separated these processes of invention, having emerged through the unique environments observed in Florida and Louisiana. However the core technologies were further siloed by social networks and professional practices that overlooked prior-art and advanced seemingly novel oyster-tecture systems developed in the as part of the coastal resilience planning processes in response to Super-Storm sandy by SCAPE, SeArc, ad Econcrete. The 20–40-year lag, or chasm, is cause for concern and further discussion as it appears technological innovation chronicled by patent innovation outpaced the rate of discovery in design and planning. Precedents for living breakwaters have existed in patent form and proposals to the USACE through the work of Edmund Boots and the Sebecon Reef Association in 1973, yet these groundbreaking works remain entirely unknown, instead of part of the canon for how to build with nature. The Y02A classification presents the opportunity to close this chasm and foreground innovative technologies by making them easier to find and disseminate by collapsing geographical boundaries and issues of accessibility, making innovation accessible to all – including planning professionals engaged in adaptation and resilience work.

Scale also presents a significant challenge to coastal adaptation and resilience works, with no single government organization or private entity equipped to comprehensively address the challenges of a changing coastline. The detailed cases presented in chapter 2 explore how issues of scale and entrenched practices of large engineering monopolies, such as the United States Army Corps of Engineers (USACE), are confronted by new actor-networks attempting to develop new standards and practices in coastal systems through the advent of technology. An actor-network perspective on coastal adaptation and resilience efforts also directly addresses issues of geographical scale by recasting the problem space as a question of network size, thus linking efforts and integrating broad constituencies typically consider outsiders in the realm of coastal engineering. In this reformulation patents serve as important intermediaries, representing and taking the place of actors, in these new assemblages as network capacity is being built. In this system the potential contribution of the Y02A is clear, as it serves to organize innovation in coastal sectors and build new networks through the communication of technical information related to issues with enormous geographical scales. By engaging broader constituencies in the process of envisioning new forms of coastal infrastructure, layers of sociotechnical ingenuity can contribute to collective envisioning of coastal futures.

Of course, It is wise and prudent to be weary of corporate interest and involvement in environmental planning. Patents have a long been intertwined with industrial revolutions and capitalism, but also with the birth of entirely new sectors of ecological technology. As discussed in Chapter 3, corporate ecologies are doubled edged with the capacity for manipulation and environmental tragedy or becoming foundational to national identity. Reflecting on the positives outcomes with examples from the Japanese ENSEI, suggests an alternate narrative in which coordinated planning efforts for marine innovation hubs, including social programs, research institutes, private/public partnerships helped found an ecological technology sector - resulting in the invention of hundreds of artificial reef modules, upwelling devices, and a modernized fishing industry. Looking towards the future of ecological engineering in marine systems, the ENSEI program provides a valuable precedent addressing the scale and complexity through layered planning that builds expertise and technical capacity across government and industry. Patents played an important role establishing the field, offering prospect and opportunity, to Japan's largest manufacturing companies. This know how was eventually transferred to the United States through a series of international conferences and translation of Japanese patents for manufacturing by high level government consultants. In the emergent sectors of coastal adaption and resilience coordinated planning is also required across disciplines, social network, and industry partners, to build everything from artificial reefs to new mapping software.

The adaptive capacities of technology are perennial and ongoing – a process tracked, archived, and managed by the patent system. Since no "textbook" exist for global coastal adaptation and resilience the adaptive, and archival, capacities of the patent system are especially valuable, and they serve as innovation knowledge infrastructure for coastal sites and systems. As is discussed in chapter 4, the technical database of the patent system can provide reference for the iterative steps of discovery as well as a heuristic for solving complex environmental problems such as those related to subsidence and sea-level rise at a detailed site-level. The perceived distances between the patent system and local adaptation and resilience planning creates a significant barrier that may be partially overcome by the Y02A as the distinct categories of technology, and accessibility, couched within the language of climate adaption provide reference for future works. In the case of the 2017 Bay Area Challenge, technical dossiers and detailed analysis of landscape typologies integrated with technology, showcase the potential of leveraging innovation knowledge infrastructure to help solve coastal adaptation challenges. The team's broader vision for the San Pablo Baylands and Grand Bayway was shaped in dialogue with innovative technologies, including proposals to utilize the site as a living lab to further innovation in coastal adaption and resilience. This process linked the probable future of sea-level rise to the plausible future of strategic site redevelopment, helping to project new coastal scenarios through grounded research.

Paradigm shifts are afoot, including in the way in which infrastructure is conceived of and developed. Largeness and permanence have been replaced with ideas of modularity, flexibility, decentralization, localized, and hybrid forms of infrastructure. These novel design principles are altering critically important infrastructure such as water, telecommunications, and electricity, as well as coastal infrastructure. Chapter 5 explored this phenomenon through the lens of coastal adaption and resilience, foregrounding how new paradigms in infrastructure are paralleled by innovation in patented technologies. As theoretical frontiers are established one may imagine this mutualism to continue with leaders in the field inventing new technologies and technologists advancing theory through praxis. The adaptive capacities of technology are central to this formulation in which theories of coastal resilience keep pace with, or reflect, new developments in technology and planning. Examples of this run throughout the YO2A, especially in newly established areas of innovation, such as green infrastructure where advances in artificial intelligence and living systems promise to transform management of the urban landscape.

As society plans for probable, plausible, pluralistic, and performative coastal futures, frameworks for anticipatory governance will continue to gain relevancy as a mechanism to prepare for the unknown and the likely scenarios arising from a changing planet. Technological change is among the factors resulting from, and informing, this process of anticipating change. The Y02A operates as an anticipatory governance framework for climate adaptation technologies and is uniquely situated to contribute to this evolving dialectic in the complex social-ecological-technical systems converging in coastal zones by linking planning and envisioning processes to technological change. At the most pragmatic level coastal managers and city planners can stay abreast of technology, such as ecological sea walls or concrete mixtures, for integration into near-term projects. On the planetary scale, innovation in climate engineering or ocean-based carbon sequestration can be tracked through patents, helping to define the contours of speculative and performative coastal futures.

Together the case studies, histories, and convergent narratives, intersecting with the patent system and future prospects of the YO2A offer a timely provocation to expand and integrate environmental design and planning praxis with broader sociotechnical processes. The perceived distance between technological innovation and the professional standards of architecture, planning, and allied disciplines has long been a subject of debate. The eminent architect Richard Buckminster Fuller raises the issue poetically in 'An operating manual for spaceship earth' where he situates the ongoing need for innovation against the ongoing trajectories of further specialization. For Fuller this begins with the great anticipatory voyages of the "sea masters" established the need specialization and disciplinarity, thus he posits Leonardo da Vinci as the lauded archetype of the "comprehensively anticipatory design scientist" who may liberate humanity. Fuller's meta critique of disciplinary scope and boundaries continues through the essay, concluding with a suggestion to architects, planners, and engineers to think outside the conventions of practice, stating "you are accustomed to thinking only in dots and lines and a little bit in areas does not defeat the fact that we live in omnidirectional space-time and that a four dimensional universe provides ample individual freedoms for any contingencies."[428] A not so subtle hint that the operating manual for spaceship earth may in fact be found through the utilization of appropriate technology and not conventions of professional practices – a notion he famously explored through his Guinea pig-b experiments and 28 patented inventions.[429]

Within the confines of architectural discourse, the issue of patented technology has periodically, and contentiously, emerged. In 1890, the British architects Flockton & Gibbs submitted a patent to protect their "invention" of a new spatial organization, improving the plans of government buildings and institutions through novel spatial and structural configurations. The patent was met with intense criticism by architects and patent examiners on both sides of the Atlantic who viewed it antithetical to conventions of professional practice, and, soon after, the discipline rapidly and unanimously dropped the patenting of architectural plans.[430] More recently, the polemic between spatial planning, architectural praxis. and patented technology, was explored by the Office of Metropolitan Architecture in a series of "Universal Modernization Patents" in which the office describes social condensers, strategies for the void, timed erasure, loop tricks, variable speed museums, skyscraper loops, and other ideas that defined OMA's original contributions to architecture.[431] Today the discipline of architecture is addressing issues of ownership and authenticity in the context of the digital age and researchers offers critical reflections on open source and 3-d printing technology that promise to disrupt

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[428] R.B. Fuller, Operating Manual for Spaceship Earth, A Clarion Book (Southern Illinois University Press, 1969),
[429] Buckminster R. Fuller, Inventions: The Patented Works of Buckminster Fuller (New York: St. Martins Press, 1983).
[430] "Patenting Plans," American Architect and Architecture. xxx (November 29, 1890): 137–38.
[431] Rem. Koolhaas, Content: OMA-AMO,. London: Taschen, 2004.

traditions.[432] These contentious and speculative forays exploring the interrelationship between patents and architecture posit architecture as opposed, or contrary, to the patent system through their engagement with spatial planning, urban dynamics, and open source.

Societal and environmental shifts are underway that may necessitate that the relationship between professional practice and patent technology innovation be reconsidered. The Y02A classification scheme, and its cousin Y02B "Climate Change Mitigation Technologies Related To Buildings," have the potential to help shape praxis, pedagogy, and link the allied fields of environmental design to a range of initiatives that expand disciplinary scope. For example, In the United States there is a nationwide effort is afoot for Landscape Architecture to be designated a S.T.E.M (science, technology, engineering, and math) discipline. S.T.E.M designated programs are academic programs that fall under at least one of the approved categories from the United States Department of Homeland Security (DHS). To support this effort, the American Society of Landscape Architects (ASLA) has pursued STEM designations through advocacy with DHS. One criterion used by the DHS to evaluate STEM is innovation, research, and the development of patented technology. A recent white paper published by the ASLA and authored by a consultancy, aims to link the profession to innovation in climate adaptation technologies through the classifications established by the Y02A patent classification scheme. The authors of the white paper find that "Within Y02A are more detailed categories of technologies to support climate change adaptation. An ASLA analysis of the technologies in Y02A shows that at least 22 of them relate directly to topics covered in the landscape architecture curricula or have been the subject of research and innovation projects by landscape architecture students and faculty." [433] Similar changes are afoot in professional practice where the legal statutes that define professional licensure in New York State, Ohio, and Missouri, now include clauses for patent works contributing to maintenance of professional standards.[434] Within this we see a concerted effort to expand the technical capacities, and perceptions, of landscape architecture.

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[432] Antoine Picon and Wendy W Fok, Digital Property: Open-Source Architecture (John Wiley & Sons, 2017).
[433] "2022_ASLA_STEM_White_Paper.Pdf," accessed May 11, 2023, https://www.asla.org/uploadedFiles/2022_ASLA_STEM_White_Paper.pdf.
[434] "Missouri," accessed June 6, 2019, https://www.asla.org/uploadedFiles/CMS/Government_Affairs/State_Goverment_Affairs_and_Licensure/State_Documents/Missouri2015.pdf.

As professions such as landscape architecture, architecture, and planning approach the complex challenges of coastal adaptation and resilience more robust, open, and comprehensive approaches to innovation are required. These shifts in technological capacity are occurring at exactly the time when they area needed the most. Coastal regions continue to be impacted by climate change and new policies and plans are implemented, technological innovation will parallel this process. At the global level strategic initiatives are now in place for technology transfer and expansion of technical capacity for Small Island Developing States (SIDS), with opportunities to address critical issues of sea-level rise and adaptation through spatial planning coupled with technological innovation. Countries such as Canada and the United Kingdom have resilience and "green revolution" plans in place that aim to leverage the innovation in fire, flood, and coastal infrastructure through public private partnerships. And at the city level the network of 100 Resilient Cities, and their satellite municipalities, are poised for an influx of resilience technology resulting from innovation in hardware, software, and fixed infrastructure.

Contemporary Snapshot: technological pathways for climate adaptation and resilience

The context for coastal adaptation resilience work is changing in real-time as global initiatives and local action plans take shape with Y02A poised as a productive partner for the coordination of sequential innovation in emergent environmental problem spaces. Coastal systems are "ground zero" for the impacts of climate change, and therefore emblematic of and layers of society, governance, professional practice, and policy are being strategically reorganized to coordinate adaptation within these complex social-ecological-technical systems. The context for adaptation and resilience works are changing and the pathways are being built at national and international levels to facilitate the transition in economy, policy, and society – ushering in an organizational shift from early phase resilience planning to coordinated global efforts.

A snapshot of contemporary initiatives, provided below, situates this dissertation in the context of local, national, and international adaptation and resilience planning – positing that the allied disciplines of environmental design and planning, dialogue with the Y02A, are a pivotal lynchpin grounding technological pathways in coastal sites and systems. This transition is timely as the pioneering adaptation and resilience works of the past two decades phases out. Initiatives such as the 100 resilient cities, funded for a 5-year period, have built networks around resilience planning but also reached expiry in 2019 – leaving a void in global strategic planning. Design and planning competitions such as the Resilience by Design completion is now more than a decade old, and related resilience programs such as the Bay Area challenge occurred more than five years ago. In this "beta" phase we can observe nascent responses to long-term challenges built through discrete programs, but as the issue of climate adaptation become more acute global initiatives are taking shape to align with local efforts. Y02A is one part of this assemblage, operating at the global sociotechnical level to coordinate innovation and provide knowledge infrastructure to a range of local, national, and global, initiatives that will reshape coastal regions, economies, and society. This includes a range of events and plans that will define the next phases of adaptation and resilience planning, such as:

- The Department of Commerce's U.S. Patent and Trademark Office (USPTO) and the National Oceanic and Atmospheric Administration (NOAA) announced on February 28th, 2023, a collaborative work program to promote and advance further innovation in climate and "green" technology areas. This was enacted by executive order by Biden administration to build technical capacity in response to climate adaptation. The focus of the program is of the collaboration is a work-sharing initiative that focuses on the intersection of intellectual property (IP) and climate and environmental technologies. The program, featuring the exchange of employees over the course of up to a year, will enhance cooperation among the agencies and strengthen their respective work to incentivize greater innovation in these critical areas.[435]

- The Canadian Government Publishes the final draft of its first climate adaptation strategy in June 2023, outlining the layers of governance and social action required to meet targets for carbon mitigation and responses to climate events such as wildfires, food, heatwaves, and thawing permafrost. Central to the plan are the adaptation of infrastructure, innovation through public private partnerships, and revision to professional standards across disciplines. As a pretext the Canadian Intellectual property office (CIPO) published a report on climate mitigation technologies to assess domestic technological capacities.[436]

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[435] "NOAA, U.S. Patent and Trademark Office Create Work-Sharing Program to Advance Green Technology."
[436] "Patenting-Climate-Change-Mitigation-Technologies-En.Pdf," accessed June 27, 2023, https://ised-isde.canada.ca/site/canadian-intellectual-property-office/sites/default/files/attachments/2022/patenting-climate-change-mitigation-technologies-en.pdf.

- The heads of the five largest intellectual property (IP) offices, including the European Patent Office (EPO), Japan Patent Office (JPO), Korean Intellectual Property Office (KIPO), China National Intellectual Property Administration (CNIPA), and United States Patent and Trademark Office (USPTO), collectively known as the IP5 Offices, met in June 2023 to discuss the role of IP5 in addressing climate change through an accessible and inclusive IP system. The meeting included a tour of the National Oceanic and Atmospheric Administration's (NOAA), a review of the joint working programs between USPTO and NOAA, and focused panels of innovations in climate adaptation and the blue economy.

- In November 2020 the UK government released a 'ten-point' plan for a green industrial revolution. The plan states that innovation has a key role in helping to achieve carbon net zero and makes provision for climate adaption and resilience technology. As part of the plan, the UK Patent office developed a series of technical reports for sectors of adaptation technology, including the worldwide patent landscape in relation to flood and coastal defense patents to assess capacities and guide investment. The report documents innovation in a variety of flood and coastal defense methods including dams, levees, weirs, sea walls and diversion canals, and points towards the need for regional innovation.[437]

- The United Nation's strategic plan for a "Decade of Ocean Science for Sustainable Development" known as the "Ocean Decade" was launched in 2021, foregrounding the need for coordinated global planning around issues of ocean health and management. The plan explicitly addresses issues of technology and innovation this as part of their Implementation plan which includes provision for technology transfer and development. This aims to address critical issues such as ocean pollution, as well as build technological capacity for Small Island Developing States (SIDS) and others in critical need. Science, innovation, and policy, are the major drivers of the Ocean Decade.[438]

- In 2020 the World Bank Publishes "Invention and Global Diffusion of Technologies for Climate Change Adaptation: A Patent Analysis" using data collected from the Y02A classification scheme. The report analyzes technological capacities across a range of sectors related to global adaptation efforts, thus validating the efficacy of the Y02A in tracking innovation in these emergent sectors. In the report the World Bank makes specific recommendations related to building technological capacities in developing nations through more efficient technology transfer and targeted innovations are required to address issues such as flooding and drought.[439]

- World Intellectual Property Organization (WIPO) organizes regional workshops on innovation and sustainable development for Small Island Developing States (SIDS) to provide updates on "Leveraging IP in the Blue Economy Sectors". The series of virtual

[437] "A Worldwide Overview of Flood and Coastal Defence Patents," GOV.UK, accessed July 10, 2023, https://www.gov.uk/government/publications/a-worldwide-overview-of-flood-and-coastal-defence-patents.
[438] "Ocean Decade – The Science We Need For The Ocean We Want," accessed July 10, 2023, https://oceandecade.org/.
[439] Dechezlepretre et al., "Invention and Global Diffusion of Technologies for Climate Change Adaptation," 2020.

workshops was organized by the WIPO in cooperation with the University of the West Indies (UWI), the Japan Patent Office (JPO) and the Caribbean Climate-Smart Accelerator, with the support of financing from the Funds-In-Trust Japan Industrial Property Global.[440]

- European Patent Office launches a series of focused reports on the changing environment. The most recent, published online in 2023, highlights Innovation in fire prevention, firefighting, wildfire control and forest restoration. Bringing to attention the innovation landscape associated with specific adaptation sectors chronicles how access to the technical information contained in patents can respond to global climate challenges. Importantly, the series of focused adaptation reports from the EPO will continue across a range of sectors and global issues.[441]

- The 100 resilient cities initiative concluded in 2019 after 5 years of funding. The organization published a series of reports the summarize key findings of the program, including a special report on technology. The study finds that cities are integral to technological innovation and that innovation in resilience technology will continue to expand as demand increases, stating "In looking for solutions to resilience challenges, it is clear that the ability of technology to play a meaningful role in both better understanding and mitigating shocks and stresses is increasing every day as new products and services are brought to market and mature" [442]

As global, national, and regional approaches to climate adaptation and resilience take shape through the policies, initiatives, reports, and strategical plans, outlined above, important questions remain regarding the grounding and testing of novel technologies in real-world sites and systems. Bridging between global technological change and coastal systems, the YO2A and professional practices of environmental design and planning become integral to the translation of technical knowledge and coastal development and management practices. As this dissertation argues, patented technology and the patent system are intertwined with coastal systems and this parallel evolution of systems can be operationalized to advance adaptation and resilience works. The key findings of this research project not only reveal the latent role of patented technology in coastal systems but also the structural changes required to strategically leverage innovation networks though design and planning praxis.

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[440] European Patent Office, "IP5 Offices Discuss Office-Led Initiatives on Climate-Related Innovations," accessed July 10, 2023, https://www.epo.org/news-events/news/2023/20230621.html.
[441] Office, "Firefighting Technologies."
[442] "Resilience-Point-of-View-Technology.Pdf," accessed June 29, 2023, https://resilientcitiesnetwork.org/downloadable_resources/UR/Resilience-Point-of-View-Technology.pdf.

Key Findings & Recommendations from Case Studies

- Patented technologies impact coastal systems and development patterns across a range of scales, from satellite linked tsunami forecasting to ecologically engineered materials that enable establishment of marine organisms on coastal infrastructure.

- Technological innovation provides one of several viable pathways to operationalize coastal adaptation and resilience across a range of scales and geographies. The Y02A has the potential to unlock this pathway as global resilience planning takes shape through establishment of innovation knowledge infrastructure.

- Coastal Anthromes are impacted by a range of human activities, requiring innovation in coastal adaptation and resilience technologies across a range of sectors, from aquaculture to construction of urban storm water systems. Sub-classes of the Y02A organize sequential innovation across these sectors.

- The process of technological innovation in the coastal adaptation and resilience problem space is ongoing, and occurs with, or without, the involvement of planning and design professionals. Increased involvement by the allied professions of environmental design and planning has the potential to shape coastal futures and build new pathways.

- Design and planning competitions generate new technologies through innovative planning programs. This process needs to be better understood and managed to lead to more efficient outcomes and resource allocations.

- Design and planning competitions have the potential implement and foreground new technologies through the integration of patent studies and knowledge infrastructure into project development. Without innovation studies and development of prior-art dossiers, lags, or chasms, in invention and diffusion may occur. The Y02A provides an effective mechanism for the diffusion of innovation and may help prevent lags or chasms in the process of discovery and invention.

- Diverse actors and networks are involved in the process of coastal innovation. Engaging these broad constituencies in the process of coastal innovation helps shape coastal futures and catalyze systemic change within entrenched power structures. Patents serve as intermediaries in this process, helping to build network capacity.

- New categories of technology covered by the Y02A focus on green infrastructure, water, coastal technology, etc., making them highly relevant to the cross sectoral technologies of climate adaptation and resilience, including those that interact with coastal systems. As information regarding these new systems expands, the Y02A provides an anticipatory governance framework for the planning of coastal futures. This includes the pragmatics of planning for probable environmental risk and scenario building for pluralistic futures.

- New paradigms for coastal infrastructure require new forms of technology. Innovations organized by the newly established subclasses of the Y02A keep pace with evolving paradigms in infrastructure development. Novel forms of coastal infrastructure have the potential to impact a diverse range of coastal communities.

Y02A as Praxis: an innovation model for coastal adaptation and resilience

The preceding case study chapters document the ongoing role of patented technology, and the patent system in coastal systems, arguing that this process and can be operationalized to advance adaptation and resilience efforts through the creation of new technological pathways and establishment of knowledge infrastructure for future problem solving. Observations made during the case study research make it clear that although persistent, the role of patents and innovation in the coastal adaptation and resilience problem space is often messy, incongruent, and seemingly uncoordinated. In response, an innovation model, posited in here, makes strategic recommendations to build adaptive capacities and resilience in coastal systems through integration of spatial planning and design praxis with the Y02A patent classification scheme. The relative newness of the Y02A, and perceived distance between sequential innovation within the allied disciplines of environmental design and planning practice, creates a unique situation that the innovation model aims to address through the integration of patent datasets and novel technologies into praxis. Evidence in support of strategic model that integrate the Y02A into praxis is found throughout the case study research. For example, the technical knowledge infrastructure of the patent system, discussed comprehensively in chapter 4, remains siloed from the work of landscape architecture and urban/environmental planning yet has the potential to integrate with other robust spatialized knowledge infrastructure, such as Geographical Information Systems (GIS) - linking patent dataset and technical details to planning workflows to facilitate modeling and knowledge transfer. Of course, establishment of the Y02A patent classification scheme raises other issues related to operationalization and implementation that are highlighted by the case studies. Most

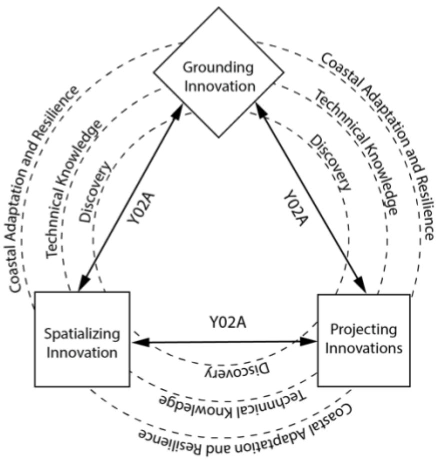

Figure 67: Diagram of a three-part problem space addressing the need to integrate patented technology and patent data into design and planning praxis.

notably is the distance between the intuitional mechanisms of the patent system and the inherently spatial, environmental, social, political, and durational, biological, and planetary systems operating in coastal zones and other anthromes. As is documented by the case studies, bridging between these domains has the potential to create link technological innovation to coastal futures through the praxis of planning and design. Take for example the invention of oyster-tecture, discussed in chapter 1, which chronicles the invention of novel ecologically informed coastal infrastructure developed within the context adaptation and resilience planning efforts and also the existence of prior-art in the field, revealing a chasm in the realization of core technologies. Addressing this, and other concerns highlighted by the case study research, the innovation model makes strategic recommendations for linking the Y02A to professional practice and built works to build network capacity and problem solve critical issues in coastal adaptation and resilience.

Integrating the Y02A classification scheme to the process of coastal adaptation and resilience (i.e. the innovation model) is conceptualized as a three-part problem space involving; 1) Spatializing Innovation: the integration of Y02A patent data and metrics into planning and design praxis so it may inform development and management of coastal systems at geographical scales, 2) Grounding Innovation: building innovative coastal systems through pilot projects, testing, and implementation of novel technologies and new social assemblages, integrated with the Y02A and environmental planning and design praxis, 3) Projecting Innovations: developing core technologies and establishing technological frontiers in adaptation technology categories of the Y02A through partnerships between practitioners, research universities, industry, communities, compressing the distance between local, regional, and international coastal networks through innovation (figure 67).

Spatializing Innovation

The geographical dimensions of coastal adaptation and resilience efforts are enormous, spanning the globe and innumerable cultures, industries, and ecologies. Building adaptive capacity within these interconnected systems requires broad layers of society to engage in the imperative of coastal innovation. Addressing the scale and layered systems that converge in the coastal zone presents a distinct challenge for planners and governments to coordinate, therefore consolidating, or speeding up, network capacity. This is integral to effectively manage the diffusion of innovation in the sector. The long-term process of innovation in coastal systems can be effectively managed through the hybridization of two robust forms of knowledge infrastructure, the Y02A classification scheme and Geographical Information Systems (GIS). In general terms this involves the creation of technological "layers" within GIS that collate with Y02A, augmentation of Y02A classification to include specific environmental metadata to facilitate the integration with GIS and planning processes, and coordinated modeling and analysis that provides a feedback loop for spatialized innovation (figure 68).

Within the domains of planning and design the knowledge infrastructure of GIS effectively addresses issues of scale, duration, and network length, providing robust spatial data for planning urban, regional, and natural systems. GIS is a robust spatial program, database, user interface utilized by a range of design and planning professions to integrate and coordinate layered information for a range of planning activities. It seamlessly integrates layered spatial information to help comprehend the dynamic processes and systems converging at known locations on the earth's surface. Cities and regions around the world utilize GIS as a planning and decision-making tool, creating an effective mechanism for integrating technical information into planning praxis. Technical information in patent documents, patent data, and other metrics can be effectively integrated through the Y02A, linking the most robust database of adaptation technologies in existence to established spatial and environmental planning methods. In the specific case of coastal adaptation and resilience integrated Y02A & GIS has the potential to coordinate a range of environmental technologies

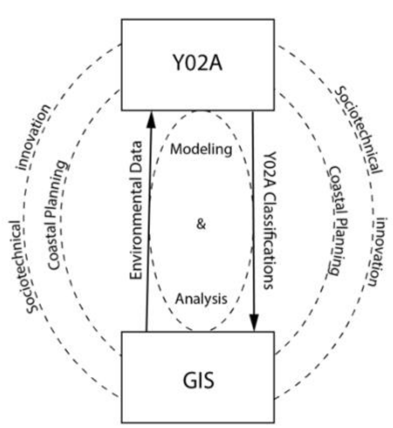

Figure 68: Diagram describing the spatialization of innovation through the integration of GIS and patent knowledge infrastructure. (by Author)

including innovative structures for the stabilization of coastlines and green infrastructure for cities.

Spatializing innovation through Integration of Y02A datasets into GIS databases consolidates information and workflow, linking two powerful forms of knowledge infrastructure. Since environmental technologies differ from hermetic "black box" technologies in that they engage the contingencies of site, natural & cultural systems, biology, duration, and process, additional metadata may be required to build effective systems that integrate technical information with GIS. As is seen through history, the patent system can be operationalized to address technical issues related to environmental management, such as is observed in the creation of the US Department of Agriculture from the early meteorological and germplasm research undertaken by the United States Patent Office in the 19th century. More recently we can look towards Japanese artificial reef innovation under the Ensei program, discussed in chapter 3, and the current Japanese patent classification system that includes biological and geographic metadata to properly classify artificial reef technology. The Japanese F-terms are used by the Japanese Patent Office (JPO) for exactly this purpose and may be adapted to a range of environmental technologies to improve their applicability and link them to GIS databases. The F-terms are JPO's original search keys that cover multiple aspects (e.g., purpose, use, structure, material, manufacturing method, processing, and operational method, and means of control) prepared for a relevant technical area ("theme"). The F-terms build upon the international patent classification (IPC) and the Cooperative Patent Classification (CPC). As mentioned in chapter 3 the F-term for artificial reefs includes theme codes that are further classified based on A) Installation configurations, B) Structures, C) Characteristics other that Structures, D) materials, E) Target Organisms. Each of these criteria is further subdivided accordingly to provide high-fidelity metadata for artificial reef planning. The result is a classification system that indicates position in a marine system, targets species, etc., creating a clearer picture of innovation in the artificial reef sector by linking innovation to biology and marine systems.

When considering the technologies of climate and coastal adaptation the F-terms offer distinct benefits as they can provide important meta data for integration of technical information into GIS layered dataset. Modeling and Analysis of existing, and proposed technologies may increase adaptive capacities and expand knowledge in the interrelated coastal sectors. This modeling and analysis are recursive, facilitating planning scenarios and discovery.

Grounding Innovation:

Linking the Y02A initiative to real-world projects is essential to operationalizing the adaptive capacities of technology, and grounding policy and funding initiatives for coastal adaptation and resilience, including the rapidly expanding national, regional, and urban level plans currently in development. Of course, coastal innovations may bypass the sequential processes of design and planning, however these professional practices provide a vital layer for coordination, review, and implementation, that are discrete to disciplinary domains. The allied professions of environmental design and planning are therefore integral to the implementation of Y02A innovation and translation of technological advancements into coastal adaptation and resilience plans. As is documented in case study chapter 2 through the search for alternative coastal stabilization technologies, patented technologies and their associated actor-networks, have the capacity to instigate change in coastal systems with the patent serving as an intermediary, circulating between actors and helping to define the relation between them. In relation to the process of grounding innovation these patent intermediaries help communicate technical information to planning disciplines and coastal managers, informing praxis and ultimately impacting real world sites as novel technologies are implemented as part of coastal development practices such as site-design and infrastructure planning.

Professional praxis provides a vital linchpin in testing, evaluation, and implementation of innovative coastal technologies into actionable projects. As is discussed comprehensively in chapter 6, the Y02A serves as an anticipatory framework for management of sequential

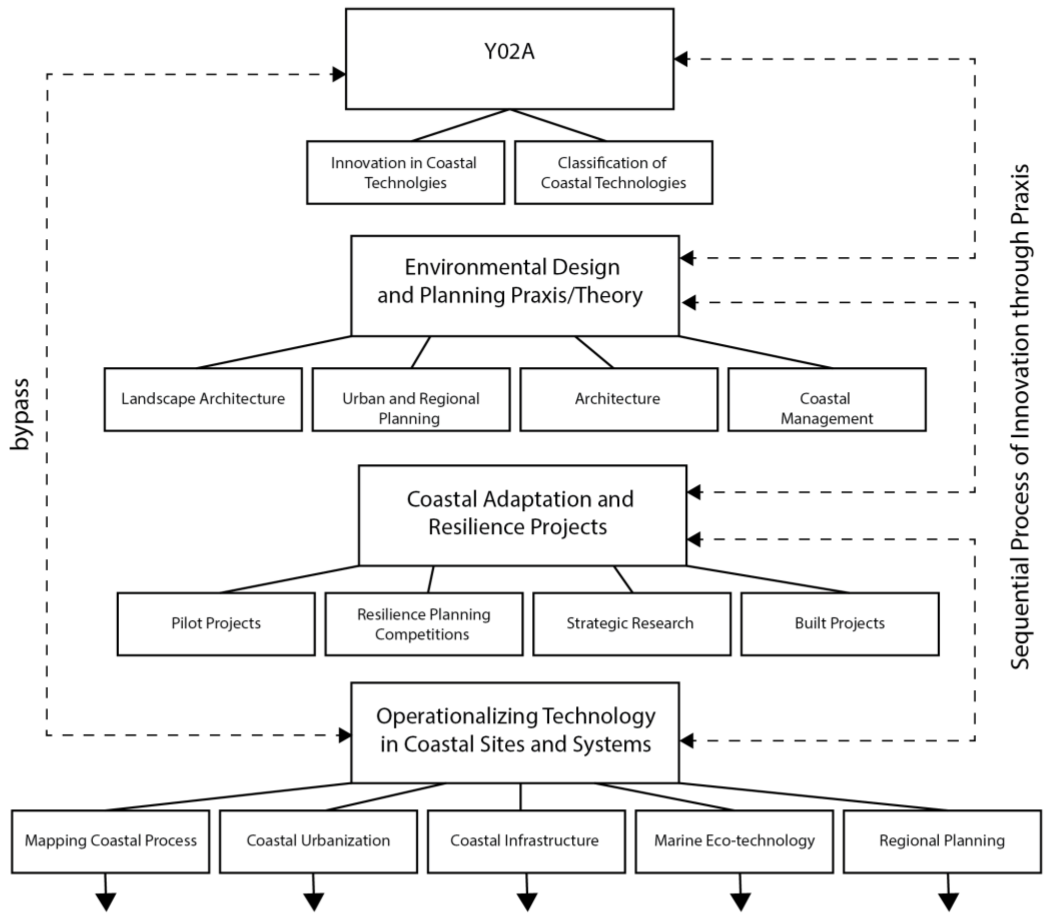

Figure 69: A schematic diagram linking the practices of design and planning to the Y02A classification scheme. (By Author)

innovation in environmental technology, informing a range of near-term and long-term planning processes. As such, integration of the Y02A with environmental planning and design praxis will inform this process across a range of interrelated planning activities, including the pragmatics of planning for probable and plausible futures as well as establish target benchmarks for pluralistic, and performative coastal futures by building the pathways to achieve these goals. The tangible benefits of this information exchange and workflow are easy to identify. For example, coastal adaptation and resilience planning competitions are an important mechanism for the diffusion of innovation. Integrating innovation studies, and innovative technologies, into the competition process through the Y02A scheme can help inform design teams, governments, and community members, of the technological pathways available and indicate areas in need of further investment. Similar opportunities exist for the integration of Y02A innovations into novel research programs that bring together innovators, researchers, and the coastal/urban planning through pilot projects. The allied fields of environmental design and planning can enable the creation of these real-world experiments, bridging between theoretical, technical, and practical domains (figure 69). Collectively the process of grounding innovation aims to site and situate global sociotechnical process of Y02A adaptation technologies within the contingencies of coastal Anthromes. Environmental design and planning praxis is uniquely situated as mediator of this process given the allied field's capacity for integrating ecological process and environmental dynamics with social, urban, infrastructural systems. Expanding this capacity to integrate and inform coastal innovation operationalizes technical pathways for adaptation and resilience works.

Projecting Innovation

The projection of coastal adaptation and resilience technology involves the refinement of core technologies and the forward-looking conceptualization of technological frontiers. These projections of technical capacity, need, and trajectory, have the potential to consolidate innovation networks by compressing the distance between local, regional, and international coastal networks through focused innovation. As is documented in chapter 2, a diverse range of actors have the potential to instigate change in coastal systems and confront entrenched power systems utilizing the distinct agency of patented technology. In the context of climate change and sea-level rise, these expanded coastal actor-networks are integral to collective problem solving. The Y02A patent scheme is central to the consolidation of the resultant network space as it gathers, collates, and communicates technical knowledge, serving as not only intermediary between partners, agents, and adaptation efforts worldwide but also as knowledge infrastructure in support of systemic change. Projections of new technological frontiers also have the potential to build new networks by establishing partnerships with industries such as Artificial

Intelligence, environmental sensing, and additive manufacturing. The Y02A creates a robust framework to organize innovation in the coastal adaptation and resilience sector, focusing the projections of novel technology as they move between localized innovation networks and strategic global initiatives.

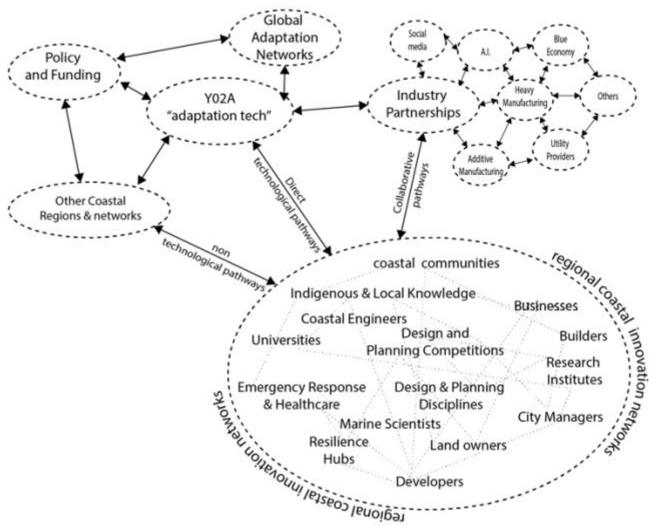

Figure 70: Diagram of the process of of projecting innovations in which actor-networks involved in coastal adaptation and resilience works invent and share novel technologies build network capacity through the Y02A. (By Author)

Establishment of distinct classes of technology for artificial reefs, green infrastructure, environmental mapping and sensing, and river restoration etc. allows for inventors, institutions, professionals, governments, and community members to clearly identify areas of technology that they may contribute to, thus facilitating discovery and hastening innovation. Of course, creating new technology requires investment in research and development, institutional partnerships, and core technologies and establishing technological frontiers in adaptation technology categories of the Y02A through partnerships between practitioners, research universities, industry, communities, and other actors in coastal networks. As is documented in case study chapter 5, these assemblages may facilitate the creation of novel forms of coastal infrastructure that are nimble, decentralized, and functionally hybrid, expanding the repertoire of coastal technology while building network capacity among partners.

Building network capacity through the projection of innovation helps identify key partners and establish future needs. Universities, professional organizations, allied environmental design and planning disciplines, coastal communities, and others in the regional adaptation and resilience networks are integral to defining the core technologies and future trends. Once these are identified, industry partners can help shape the contours of the field by contributing specific knowledge in the domains on artificial intelligence, heavy manufacturing, social media, and other industry partners. The Y02A is integral to this process, helping to manage sequential innovation, providing inventors rights, and facilitating the diffusion of innovation in emergent sectors of technology (figure 70). The newly established subclasses of the Y02A will be foundational to defining technological capacity. For example, as new mapping and sensing technology are integrated with green infrastructural systems, the linkages between storm water management, flooding, and artificial intelligence, will build likely build smarter climate adaptive cities – a sector that will only expand as climate change continues.

The Y02A is strategically situated at the juncture between climate change, risk, and technology. Empirical studies on the relationship between climate change and innovation are also bringing these trajectories into dialogue, leading to new frameworks of "risk-mitigating innovation" that document the stimulating effect of natural disasters on technology and patent submission rates.[443] Uptick in technological innovation responding to risk and climate change, and evolving range of pathways for implementing coastal adaptation and resilience efforts create a distinct opportunity for planners, designers, and engineers to integrate patent data and novel technologies into praxis. As planners, designers, and engineers, work on a diverse range of coastal projects and often integrate technology through infrastructure planning, modifications to land-use strategies, architecture, and open space systems they are logical partners in the effort to operationalize technological innovation in the coastal adaptation and resilience space. Obviously, a broader spectrum of technology converges in the coastal anthromes and must be considered in the context of coastal adaptation and resilience, including transportation, water, electricity, health, agriculture, and indirect technologies. These cross-sectoral technologies are well represented in the Y02A classification scheme and represent and expanding toolkit for coastal adaptation and resilience planning.

[443] Miao and Popp, "Necessity as the Mother of Invention: Innovative Responses to Natural Disasters."

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