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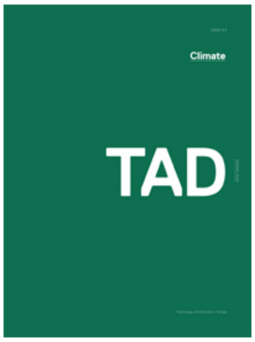

Technology|Architecture + Design

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/utad20

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To cite this article: Wendy Meguro (2024) Co-Innovating for Integrated Research, Teaching, and Outreach in Sea Level Rise Adaptation, Technology|Architecture + Design, 8:1, 97-105, DOI: 10.1080/24751448.2024.2322918

To link to this article: https://doi.org/10.1080/24751448.2024.2322918

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Published online: 24 May 2024.

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Co-Innovating for Integrated Research, Teaching, and Outreach in Sea Level Rise Adaptation

Approximately 680 million people live in low-lying coastal regions susceptible to flooding (IPCC 2019), and architects are positioned to drive wide-scale adoption of practical design solutions to address climate change impacts (AIA 2020). This paper describes innovative pedagogical approaches to integrate climate change into the architectural curricula in conjunction with funded applied research and community outreach to inform future climate change adaptation. The community-engaged scholarship, Envisioning Sea Level Rise Adaptation in Waikīkī, Hawaiʻi and its parallel graduate architecture courses resulted in locally tailored architectural renderings, policy guidance, and visions that may inform future design and policy. The replicable research methods describe the processes, individuals, partnerships, and products for knowledge-sharing and coordinating climate change adaptation and resilience through interdisciplinary cocreation within academia and coordinated community input.

Keywords: Architecture, Pedagogy, Climate Change, Resilience, Community

Context

The "Hawai'i Sea Level Rise Vulnerability and Adaptation Report" predicts a 19 billion USD loss of land and structures due to sea level rise (SLR) impacts (HCCMAC 2017). Waikīkī is the economic hub of Hawai'i's tourism industry. NOAA's (2020) modeling indicates that high tide flooding will grow exponentially until it becomes a chronic disruptive issue by or before mid-century. High tide flooding, high wave events, and rain cause storm drain backflow, groundwater inundation, overflow of the Ala Wai canal, and marine waters flowing over the beach into buildings, landscapes, and roadways. Increasing groundwater inundation is especially problematic because it can evade coastal barriers (Rotzoll and Fletcher 2013). This flooding will increase in severity with additional SLR, which is accelerating (Nerem et al. 2018). Protective strategies like seawalls cannot stop the advancement of groundwater inundation and are a principal driver of beach loss in Hawai'i (Summers et al. 2018; Tavares et al. 2020). Existing regulations, including shoreline setbacks and point-of-sale disclosures, are intended to protect coastal development from flooding but do not offer guidance on adaptation to SLR (HRS §205-A, HRS §508D-15). Honolulu's existing Climate Adaptation Design Principles do not yet address direct marine and groundwater inundation, critical drivers of flooding in Waikīkī (CCH Transit Oriented Development (TOD) 2020).

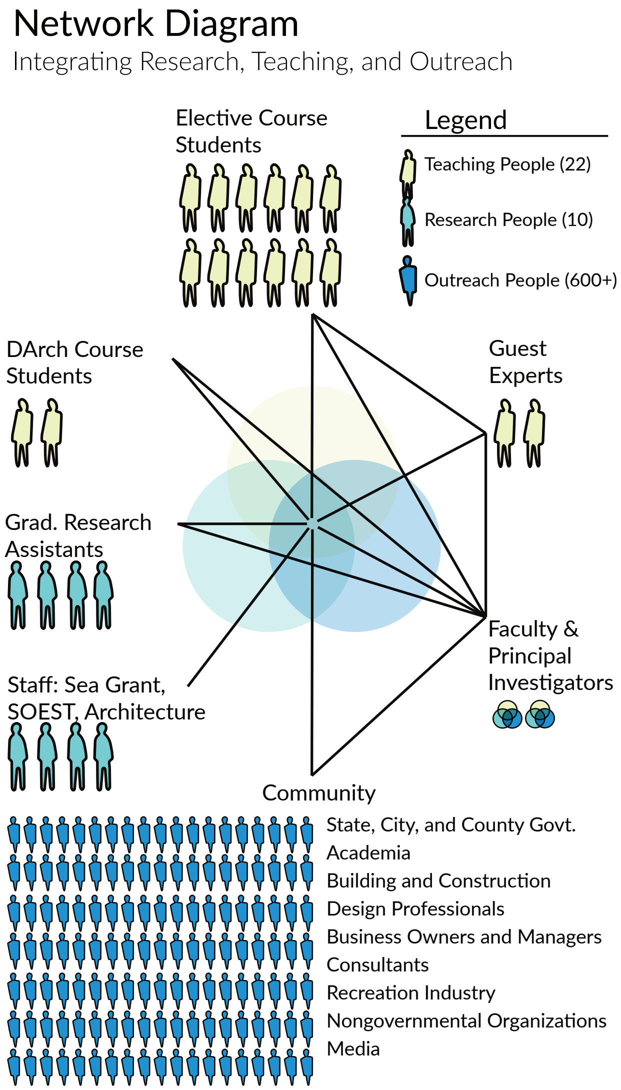
This design research utilizes the Honolulu Climate Change Commission guidance on planning and policy benchmarks for sea level rise in 2100 (HCCC 2022): currently 1.16m (3.8') for all planning, which would cause flooding mainly in coastal edges of Waikīkī , and about 1.78m (5.8') for public infrastructure and low-risk tolerance projects, which would cause widespread flooding in Waikīkī . Design research aims to understand possible futures and determine how to get there (Simon 1969). This project prompts inquiry about the preferred future to help people determine desirable goals (Ruecker 2018). The population, infrastructure, and investment commitment in Waikīkī make near-term retreat undesirable. One option is to develop an "in-place" adaptation strategy to accommodate SLR and extend the useful life of these coastal urban areas, which, to date, has not been proposed in detail. Many municipalities are applying recent research on the anticipated impacts of SLR to create actionable guidance, and there is an opportunity for academic research to inform the coordinated, interdisciplinary development of coastal policy and design guidance for Honolulu. This research explores in-situ accommodation of flooding, and the renderings illustrate the marked difference between the potential moderate adaptations with 3' (0.91m) of SLR versus drastic adaptations with 6' (1.8m) of SLR. These renderings and community feedback reports provide knowledge to designers (and policymakers) to improve decision-making during the design (and policymaking) process (Ruecker 2018), which should include a comprehensive analysis of accommodation and managed retreat. A separate future analysis should consist of local redistribution of risks and benefits, nonmonetary targets (e.g., ecological quality and individual well-being), and long-term pathways shaped by near-term

◁ Opening Figure. Collaboration between academia, government, and the community accelerates adaptation to flooding in coastal communities such as Waikīkī. (Credit: Shellie Habel)

△ Figure 1. The Venn diagram depicts overlapping products and goals for research, teaching, and outreach. (Credit: Eric Teeples, Wendy Meguro)

decisions to avoid potential negative lock-ins (Mach and Siders 2021; Hurk et al. 2022). It should consider the thresholds at which SLR-induced impacts compromise the functionality of the built environment. For example, effects from direct marine inundation and rising coastal groundwater will likely damage coastal roads, building foundations, potable water mains, stormwater conveyance, and sanitary sewers. These challenges may be partially addressed through groundwater level monitoring and simulation, elevated roadbeds, frequent structural assessment, anticorrosion strategies, timely pipe replacement, stormwater check valves, pumps, and storage, fixing pipe defects, and wastewater salinity monitoring (Habel et al. 2023). Evaluating multiple climate-related transformations, including managed retreats, helps a community understand core values, the costs they are able or willing to endure, and the opportunities they can forego (Mach and Siders 2021).

Many calls for local SLR adaptation guidance and policy are not initiated due to a lack of funding, coordination of the many parties affected, and leadership. Several of Hawai'i's city, county, and state-level plans, reports, and strategies call for integrating SLR adaptation into planning and design frameworks but lack the place-based guidance and specificity needed to translate plans into action. The Honolulu Climate Adaptation Design Principles recognize that "regional or neighborhood scale adaptation strategies will need to continue to be developed through community, special district, and functional plans" (C&C 2020). The City and County of Honolulu (CCH) Primary Urban Center Development Plan anticipates the need for "more specific and stringent policies and standards for all development in the Sea Level Rise Exposure Area (SLR-XA), including the review of the



△ Figure 2. The integrated research, teaching, and outreach required collaboration between interdisciplinary students, faculty, and community. (Credit: Eric Teeples, Wendy Meguro)

proposed site and building adaptation measures." It proposes the creation of "tools for increased adaptation requirements and design standards over time." It also encourages voluntary adaptation measures that exceed statutory requirements (CCH Department of Planning and Permitting (DPP) 2022).

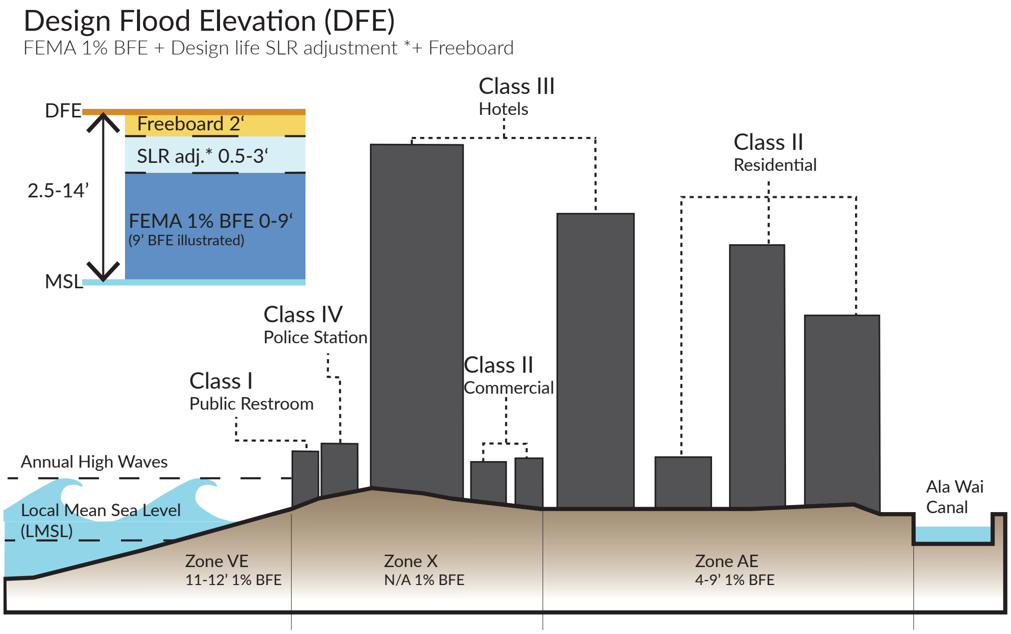
Other flood-prone coastal cities utilize design competitions, academic research, and government initiatives to bridge the gap between calls for adaptation and real-world implementation. In New York City (NYC), the *Rising Currents* exhibition (Museum of Modern Art (MOMA) 2022) and the Rebuild by Design competition (US Dept. of Housing and Urban Development (HUD) 2022) resulted in in-place adaptation. It informed the Lower Manhattan Resilience Study, a precursor to the NYC "Climate Resiliency Design Guidelines" (New York Mayor's Office of Recovery and Resiliency 2019 and 2020). An interdisciplinary team from the redacted saw the opportunity for academia to address these high-priority needs and knowledge gaps. It directed a multistakeholder process integrating new coursework, research, and outreach to identify and envision locally applicable SLR adaptation strategies. Intentional coordination of teaching and funded research resulted in more rapid progress, products, and student education than a typical research model conducted by a few student hires and faculty principal investigators.

This article examines how innovative pedagogical approaches to integrate climate change into architectural curricula in conjunction with funded applied research and community outreach may inform future climate change adaptation design guides and policy. Generating visionary and quantitative details for site-specific SLR adaptation strategies will compel coordinated conversation and action. It demonstrates a model for interdisciplinary research, led by architects and universities, which integrates coursework, research, and outreach to address previously overlooked community needs and fill gaps in workforce training. Previous research laid the groundwork for integrating students into adaptation decisions in the urban context (Gamez 2020) and demonstrating integrative thinking models for SLR adaptation (Huber 2020). Both stress the importance of interdisciplinary collaboration within and beyond the university setting. Previous studies' pedagogical frameworks emphasized integrating diverse perspectives, indicating higher project quality (Borrego and Newswander 2008). Although architecture inherently includes various disciplines, addressing SLR impacts requires additional input from sea level rise scientists, coastal engineers, hydrologists, ecologists, and social scientists.

Methodology

The mode of this research is community-driven, "design practice" that is "a solution to a problem generating new or improved knowledge in the process" with "research and scholarship opportunities" that need to be "framed and captured" and "disseminated and validated" (ACSA 2019). Site-specific research is valued for its local impact and transferability of methods. For example, University of Washington faculty, civic leaders, city staff, and community stakeholders are designing and advocating site-specific transit planning policies for equitable, resilient neighborhoods (Mohler 2023). University-led publications, community engagement, and design studios cultivate a vision to support the analysis of the proposed policies (Mohler 2023). Similarly, this research generates new knowledge and illustrations of potential site-specific SLR adaptations and DFEs for engagement with community stakeholders.

The replicable processes and results are captured and disseminated in public presentations, discussions, and reports. Methodologies include speculative conceptual design, qualitative interviews, and quantitative surveys. This multiyear research effort established an innovative approach to SLR adaptation that integrates teaching, research, and outreach. New coursework and research positions address a need for workforce training in SLR adaptation and resilience through interdisciplinary cocreation within academia. Outreach workshops solicited and documented input from the community, which informed the ongoing research (Figures 1 and 2). The



◁ Figure 3. The diagrammatic section-perspective drawing of Waikīkī illustrates a method to determine future sea-level-rise-adjusted design flood elevations based on a building's useful life and class. (Credit: Keola Annino and Kammie-Dominique Tavares in a course taught by Wendy Meguro)

teaching structure promoted learning by doing. Students/researchers developed adaptations based on precedents and site-specific knowledge; instructors developed new curricula informed by emerging guidelines, and community partners told the architectural renderings. These were incorporated into research outcomes, resulting in an integrated research and pedagogical approach beyond departmental and university boundaries. In addition to curated readings, all students and researchers completed the American Institute of Architects (AIA) Resilience and Adaptation Certificate Program. This research was recognized with regional and local design awards from the AIA and American Planning Association (APA).

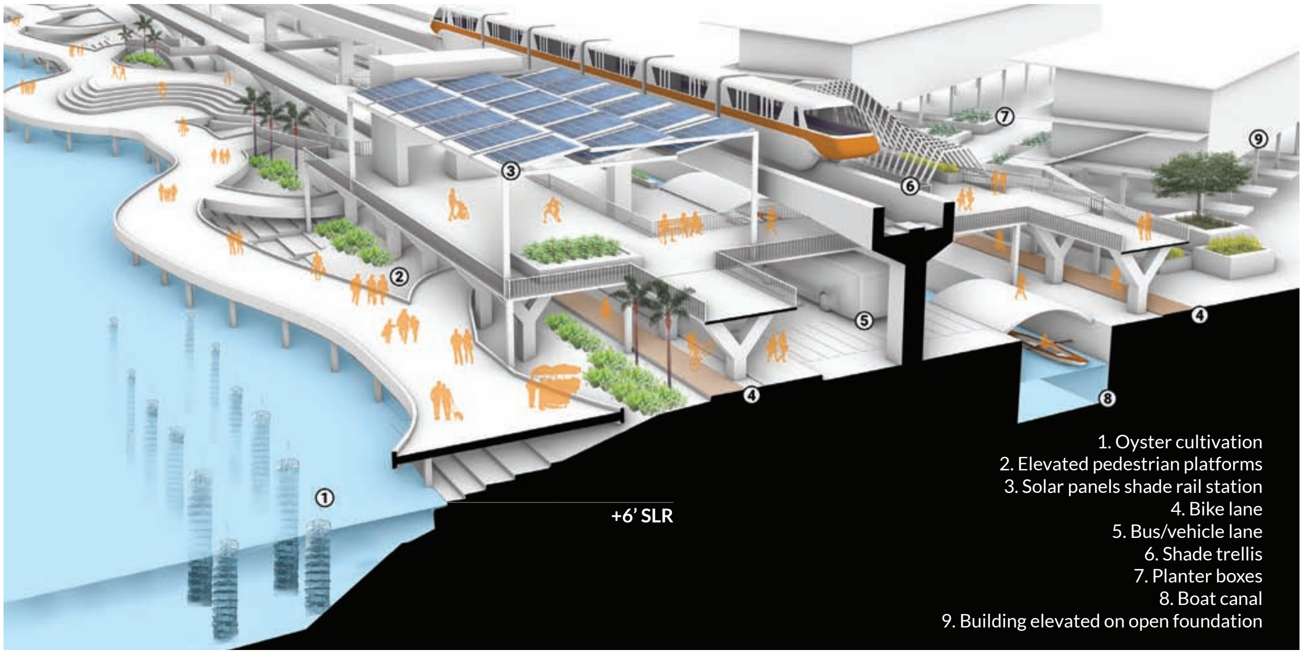
Teaching Mode

The novel integration of teaching and funded research, combined with the time necessary to build relationships outside academia, resulted in design research that spanned six semesters (and is ongoing). The typical design process stages employed in a one-semester architecture studio course—exploration, information gathering and analysis, interpretation, and schematic design (Solimon 2016)—were carefully divided and products defined in detail to iteratively share work between students in coursework and the funded research team. New pedagogical materials were compiled to rapidly brief students and researchers on sea level rise adaptation.

The spring 2020 and 2021, the newly developed architecture graduate elective course Urban Adaptation to Coastal Flooding attracted students from architecture, structural engineering, civil engineering, planning, and landscape architecture with multidisciplinary faculty mentorship and guest reviews. The elective course students and research team informed each other; students engaged with subject-matter experts and new curricula were developed based on emerging research. In the spring 2020 elective course, students compiled background research into a design brief and case studies, which informed the research team's selection of mitigation strategies. The students identified, mapped, and illustrated the SLR-related flood hazards for Waikīkī, which include direct marine flooding, stormwater runoff, storm drain backflow, and groundwater inundation. Students reviewed the AIA Resilience and Adaptation series (AIA n.d.), New York City "Climate Resiliency Design Guidelines" (2020), Boston "Coastal Flood Resilience Design Guidelines" (2019), Miami-Dade County Sea Level Rise Strategy (Miami-Dade County n.d.), Miami Beach Rising Above (Miami Beach n.d.), USGBC LEED Resilient Design Pilot Credits (USGBC 2021a, 2021b), and the (now retired) RELi (USGBC n.d.) adaptation credits. They compared (i) flood hazards, (ii) SLR planning timeframes, (iii) adaptation strategies, and (iv) design flood elevations. Students also researched acceptable durations for loss in service and future transportation options. The 2020 elective course outcome, the design brief, prompted student teams of various disciplines to determine and combine their complementary skill sets.

While students from all disciplines looked at primary sources, the architecture students voluntarily initiated new graphics to inform future design teams. For example, planning and architecture students created urban scale 3D graphics to depict the history of Waikīkī , zoning, and potential future design flood elevations; an engineering student contributed programmatic and building material requirements for resilience; and a landscape student proposed transportation resilience and prioritization and possible open space for stormwater storage. The case studies report summarized examples of flood resilience design proposals and visual communication methods, bolstering student learning and providing a resource for future designers.

In the spring 2021 elective course, students utilized the design brief and case studies developed the previous year and created preliminary conceptual architectural and urban renderings of site-specific flood adaptation strategies. The renderings were informed by interdisciplinary interactions between



△ Figure 4. Potential flood adaptation strategies with six feet of sea level rise are integrated into the existing urban area of Waikīkī at the Ala Wai Canal. (Credit: Kendal Leonard in a course taught by Wendy Meguro)

students, faculty, and guest experts. For example, lectures and design critiques by groundwater researchers illuminated the rising groundwater table and limited stormwater infiltration capacity, which informed the design proposals for insulated planters (Figure 4) and enclosed below-grade cisterns (Figure 5). The renderings were honed through critiques with guest experts from coastal geology, planning, and Waikīkī management and informed the renderings that the research team initiated in parallel.

Research Mode

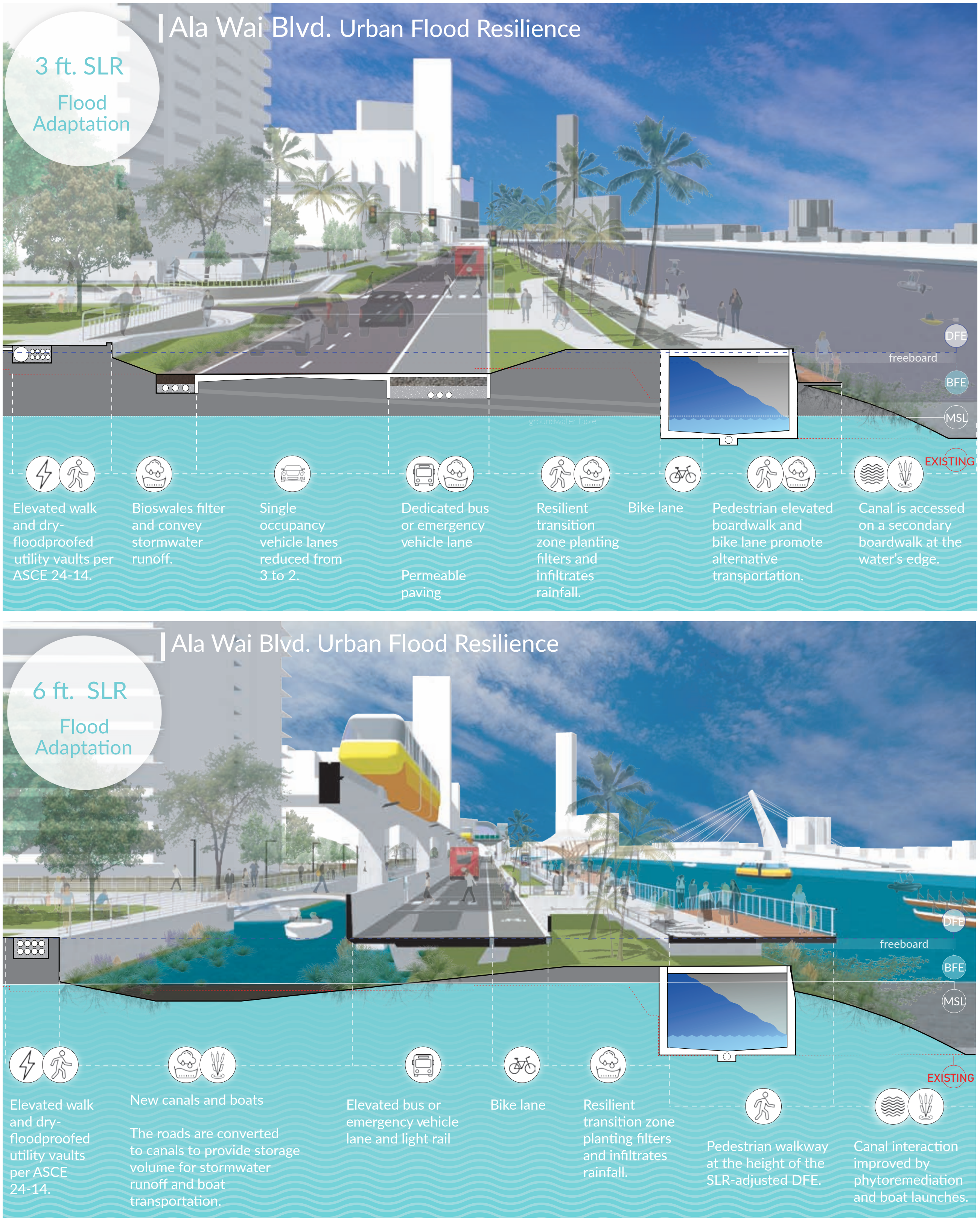
From the summer of 2020 to the present, interdisciplinary faculty, Hawai'i Sea Grant Fellows, and graduate research assistants identified flood adaptation strategies, surveyed stakeholders, developed renderings, and solicited and documented public input. Building upon the design brief and case studies, the team identified the physical flood adaptation strategies with conceptual relevance for Waikīkī and solicited stakeholder feedback on their applicability and feasibility. The survey feedback and comments on each scenario were compiled into a publicly available report and informed the strategies selected for the site-specific renderings.

From 2021 to 2022, the students in coursework and student researchers created site-specific urban and architectural renderings illustrating an application of the flood adaptation strategies with future SLR over time with twice-weekly guidance from the principal investigators and periodic guidance from guest experts. A 3D digital model was created in the Rhinoceros (Rhino) 3D Version 6.0 software (McNeel 2010) and rendered in 3D architectural visualization software (Lumion 2022). Shapefiles for roads, parcels, building footprints, and Waikīkī's special district boundary line (Hawai'i Statewide GIS Program 2021), 2'-0" to 6'-0" (0.60 m to 1.82 m) passive flooding (NOAA 2021) were imported into the GIS software ArcMap 10.7.1 (Environmental Systems Research Institute (ESRI) 2011), georeferenced to the coordinate system "NAD_1983_HARN_UTM_Zone_4N," exported as .dwg files, and imported into Rhino 3D. A 3D topography mesh was modeled using the SLR-XA and passive flooding layers.

Outreach Mode

Public presentations, survey polls, and formal workshops resulted in crowdsourced preferences and ideas from participants and were documented in publicly available reports and videos. After identifying the flood adaptation strategies most relevant to Waikīkī, in 2021, the research team conducted virtual presentations, surveys, and breakout group conversations to gather preferences and comments. Over 70 stakeholders participated, representing diverse interests in Waikīkī, including building and business owners, government policymakers, residents, tourists, and design professionals. Each strategy was described and illustrated, and the participants stated whether they were familiar with the strategy, if they thought it applied to Waikīkī, and their ideas and concerns. Mentimeter (Mentimeter 2022) or Zoom (Zoom 2022) were used for polling, and breakout group comments were recorded, transcribed, categorized, and summarized.

The most highly preferred strategies were incorporated into site-specific renderings. In 2022, the renderings were publicly presented and discussed with guest experts and an audience of over 120 people and are available online. Surveys captured the audiences' most favored adaptation strategies and comments, compiled into publicly available reports (Peppard 2022) for use by future design teams and policymakers.



△ Figure 5. Potential sea level rise adaptation strategies with 3' (top) or 6' (bottom) of sea level rise are illustrated for Waikīkī at the Ala Wai Canal. (Credit: Kaimana Tuazon, Wendy Meguro)

Additional dissemination included invited presentations to about 40 policymakers at a conference, an annual meeting of about 300 individuals in the business and tourism sector, and a presentation to 15 government officials in planning, sustainability, and resilience. This research received an honorable mention from the AIA Northwest and Pacific Design Awards and was an AIA Honolulu distinguished entrant.

Results

The integrated teaching, research, and outreach resulted in the coproduction of site-specific design guidance, renderings of SLR adaptation over time, and community feedback reports. The products from coursework, research, and outreach informed each other, and the multiyear schedule allowed for creation, sharing, reflection, and integration. Teaching and research products include a design brief, case studies, proposed new SLR-adjusted design flood elevations, and renderings of potential flood adaptations. The students illustrated likely new SLR-adapted design flood elevations for a cross-section of Waikīkī that could inform future policy or design teams (Figure 3). Based on New York City's guidance (NYC 2022), 2' (60.96 cm) of freeboard is suggested for critical and noncritical-facilities-and-useful life SLR adjustments are 6" (15 cm) through year 2039, 16" (41 cm) through year 2069, 28" (71 cm) through year 2080, and 36" (91 cm) through year 2100.

The near-term site-specific renderings with 3' of SLR include elevated pedestrian, bicycle, and vehicular transportation, vegetated bioswales, and vaulted utilities in the near term (Figure 4). Looking ahead to the end of the century, with 6' (1.82 m) of SLR, roadways are converted to waterways for water taxis; elevated rail emphasizes mass transportation and pedestrian and bicycle pathways are elevated. Large below-grade cisterns temporarily store stormwater runoff for reuse or delayed discharge (Figures 4 and 5). The research team created additional detailed renderings and explanations of each adaptation strategy and surveyed hundreds of presentation participants on their applicability, benefits, and concerns. Their feedback is captured in a series of reports intended to be utilized by policymakers as they create practical guidance for designers or new area development plans.

The feedback from guest experts and the public presentations and discussions advanced all participants' knowledge and were reported for future use. "Sharing local experience with developing solution strategies and collaboration networks can help formulate new methods and transparent societal objectives. This can provide the effective scientific support required by the major societal transformations ahead of us" (Hurk et al. 2022).

In public presentations of other adaptation strategies and renderings, most of the audience members agreed that all the adaptation strategies presented applied to Waikīkī, and elevating critical equipment was indicated as the highest priority. For each strategy, the community outreach reports include the survey results on relevance and quote valuable insight on issues requiring attention. For example, moving an existing backup generator from the basement to an upper floor seemed like a "no-brainer" for many stakeholders. Still, a structural engineer explained that most upper floors are not designed for additional structural load and fuel delivery (Peppard 2021).

The public outreach advanced the conversation from speculating appropriate adaptation strategies to recording suggestions and questions on the feasibility, policy, funding, and sequencing for implementation. For example, stakeholder feedback (Peppard 2021) noted that government agencies must collaborate on infrastructure and codes in close communication with landowners and community members. The discussion highlighted the need for cost estimates and potential funding sources to assess the feasibility and phasing of the accommodation strategies, alongside comparison to managed retreat options. For example, the pedestrian experience is a high priority, and elevating buildings on an open foundation or fill may discourage people from entering shops, a significant concern for Kalakaua Avenue, one of the country's strongest streets for sales. Stakeholders noted the huge volume of fill needed to elevate streets and buildings while acknowledging that the dense development, concentration of capital, and bounded footprint make Waikīkī a relevant location for further cost/benefit evaluation.

Stakeholder comments directly indicated a desire for this research to inform policy. The local professional organization is working on building codes for SLR and seeking guidance on setting finish floor elevations to meet architects' standard of care, given buildings' long service life. This research initiates conversation with a proposed methodology for calculating an SLR-adjusted DFE. In addition, a state entity indicated a desire to implement recommendations from this research on shifts in water use permits, brackish water use, greywater, and stormwater. This research visualizes and calculates the on-site rainwater storage required to detain a 95th percentile rain event, initiating the conversation on feasibility and potential policies. Almost all attendees reported the discussions increased their knowledge of SLR impacts and adaptation strategies and felt their insights were heard and captured.

Discussion

The university-led research fills a gap in local policy with potential methods to determine design flood elevations and a need in coastal urban resilience planning by envisioning possible adaptation strategies to address novel problems. The renderings and design guides generated are research outcomes that demonstrably improve what is understood by people with expertise in the field and demonstrably yield new insight into the knowledge base of a field (Ruecker and Roberts-Smith 2018). The combined research, community engagement, and design practice (ACSA 2019) approach provides designers, residents, and policymakers with new information on community preferences. It generates knowledge on site-specific adaptation strategies and issues with replicable processes. The productive partnerships between faculty and students across disciplines directly address the university's strategic plan to "develop innovative interdisciplinary programs responsive to emerging industries, the needs of the state, and the careers of tomorrow" (University of Hawaiʻi at Manoa 2015) and the ACSA's Strategic Plan's goal to "demonstrate the value of architectural research to practice and society" (ACSA 2016). As the team strives to "build long-term community trust" (ACSA 2019), the local district association is utilizing this research to consider the development of DFEs, which is a first step toward the desired outcome of "contributing to public policy" (ACSA 2019). Interdisciplinary relationships lead to new architectural services, such as design thinking applied to public policy, and new disciplines, such as public-interest design (Fisher 2017).

More robust knowledge loops are needed in architecture in which practitioners and researchers share challenges, investigate issues, and communicate findings in ways that can be put into practice (Fisher 2017). This research addresses multiple steps to strengthen the knowledge loop by connecting academics and practitioners: 1) bringing the academy into practice settings through presentations and feedback, and 2) utilizing public presentation and practitioner panel discussion to connect the generalizable knowledge created in this academic research to practitioners who may apply the information to projects.

Further research is needed to evaluate appropriate district-scale flood adaptation strategies and coordinate their phased implementation with complementary district-scale efforts such as renewable energy generation, water reuse, and extreme heat resilience. Efforts to create strong and equitable partnerships with diverse stakeholders should continue (Kūlana Noiʻi Working Group 2021).

Integrating interdisciplinary faculty and students through teaching, research, and outreach on SLR adaptation in Waikīkī resulted in background research, conceptual policy, and community-informed renderings. These publicly available products are resources for local policymakers, design teams, and stakeholders. The process provides a model for developing new curricula and funded research in parallel, creating conceptual designs, and surveying and recording public insights. The renderings of site-specific adaptation strategies provided a common understanding for professionals and the community discussion about the coordination, phasing, funding, and policy implications. The renderings prompted discussion of the need for coordinated action by public and private parties on urban-scale planning and phasing of adaptation strategies. The public outreach confirmed the need for a forum for the many public and private parties to coordinate in-place adaptation planning (or retreat), assign a convener, and develop an adaptation plan updated over time. Insightful public outreach comments indicated a desire for near-term, incentivized adaptation pilot projects to allow time for multiple iterations and monitoring to inform coastal development policy.

Acknowledgements

Thank you to the students in the elective courses, community experts and stakeholders, and the research team: Charles Fletcher, Josephine Briones, Ireland Castillo, Eric Teeples, Gerry Failano, Georgina Casey, Desiree Joy Malabed, Eileen Peppard, Dolan Eversole, Chris Lomboy, Andrew Tang, Aiko Tells, Melanie Lander (first draft conference abstract). We are grateful for funding from the Hawaiʻi Sea Grant, National Sea Grant, and the Office of Naval Research, and in-kind support from the UH School of Architecture and Sea Grant.

Data Availability Statement

The data supporting this study's findings are available from the corresponding author, W. M. upon reasonable request.

Supplemental Online Material

https://seagrant.soest.hawaii.edu/meguro-adapting-waikiki/

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