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Envisioning In-Situ Sea Level Rise Adaptation for Coastal Cities

Coastal cities will experience varied levels of sea level rise, driving coastal erosion, groundwater inundation, direct marine flooding, and compound events as global climate change progresses. This research demonstrates a replicable process to utilize stakeholder input and illustrations of future physical hazards in local communities to facilitate discussions to increase adaptive capacity. This research conducted stakeholder outreach to determine locally appropriate adaptation strategies and utilized the best available science to create sea-level-rise-adjusted building design flood elevations. The most applicable adaptation strategies were integrated into newly created site-specific visual architectural renderings for two building typologies in Waikīkī, Honolulu, to inform adaptive design, planning, and policy in coastal cities.

Keywords: Sea Level Rise, Adaptation, Design Flood Elevation (DFE), Resilience, Community Outreach

Context

As coastal cities adapt to sea level rise (SLR), there is "an increasing recognition of the need for more comprehensive and proactive approaches" (Dedekorkut-Howes et al. 2020). However, there are few examples of methodological approaches for the site-specific selection of adaptation strategies. The coastal district of Waikīkī, in Honolulu, Oʻahu, is projected to experience increasing SLR-induced flooding hazards through and beyond the twenty-first century (Anderson et al. 2018). Waikīkī is responsible for approximately 34.5% of statewide visitor industry expenditures (Hawai'i DBEDT 2021). This research examines climate-resilient design options related to SLR. This multifaceted hazard includes marine inundation, storm-drain backflow, groundwater inundation (Habel et al. 2020), and compound flooding from precipitation and king tides, the year's highest tides (University of Hawai'i Sea Grant College Program 2022).

SLR responses include retreat, protection, and accommodation. Like many coastal metropolitan areas, due to Waikīkī's scale and economic importance, near-term retreat is unlikely, and strategies like seawalls cannot stop the advancement of groundwater inundation and beach loss (Summers et al. 2018; Tavares et al. 2020). Thus, the adaptation approach of accommodation is best suited to extend the district's use through the twenty-first century. Selecting accommodation strategies must principally consider the condition and density of existing buildings needing adaptation, as well as the needs and desires of the local population, availability of materials, risk tolerance, economic drivers, and a multitude of environmental priorities, the sum of which may not be appropriate for two buildings in the state, city, or even on the same block. Design, planning, and development professionals are positioned to drive wide-scale adoption of practical solutions for a site's unique conditions to address climate change's impacts rapidly (AIA 2020a).

Calls to Action: Planning for Sea Level Rise

Many plans call for the elective integration of SLR adaptation strategies into planning and design (Table 1). However, industry-standard practices rarely exceed minimum regulatory requirements. Over 25% of architects and contractors report exceeding code requirements, and over 75% of contractors and clients believe that "if a building meets code, it is resilient enough for its location" (AIA 2022).

Precedent Studies

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, the "Rebuild by Design" competition (HUD 2022) proposed and implemented in-place adaptation. An Adaptation Design and Planning Toolbox in Miami Beach addresses building and community-scale adaptation (Brooks and Scarpa 2018). China's Sponge City Program implemented guidelines for low-impact development construction to mitigate urban flooding and runoff, enhance natural hydrology, and improve aesthetics (Qi et al. 2021). Each of these initiatives responds to the question of resilience integration in situ and employs different strategies in response to the needs and challenges of a specific locality.

This study integrates place-based considerations within a nationally recognized framework for adaptation to pilot a replicable adaptation process for densely developed coastal urban areas. The Resilience Design Toolkit (AIA 2023) offers a five-step methodology for architects to introduce proactive adaptability into projects: (1) Resilience Scope, (2) Align and Plan, (3) Identify Hazards, (4) Integrate Resilience Design, and (5) Operate and Evaluate.

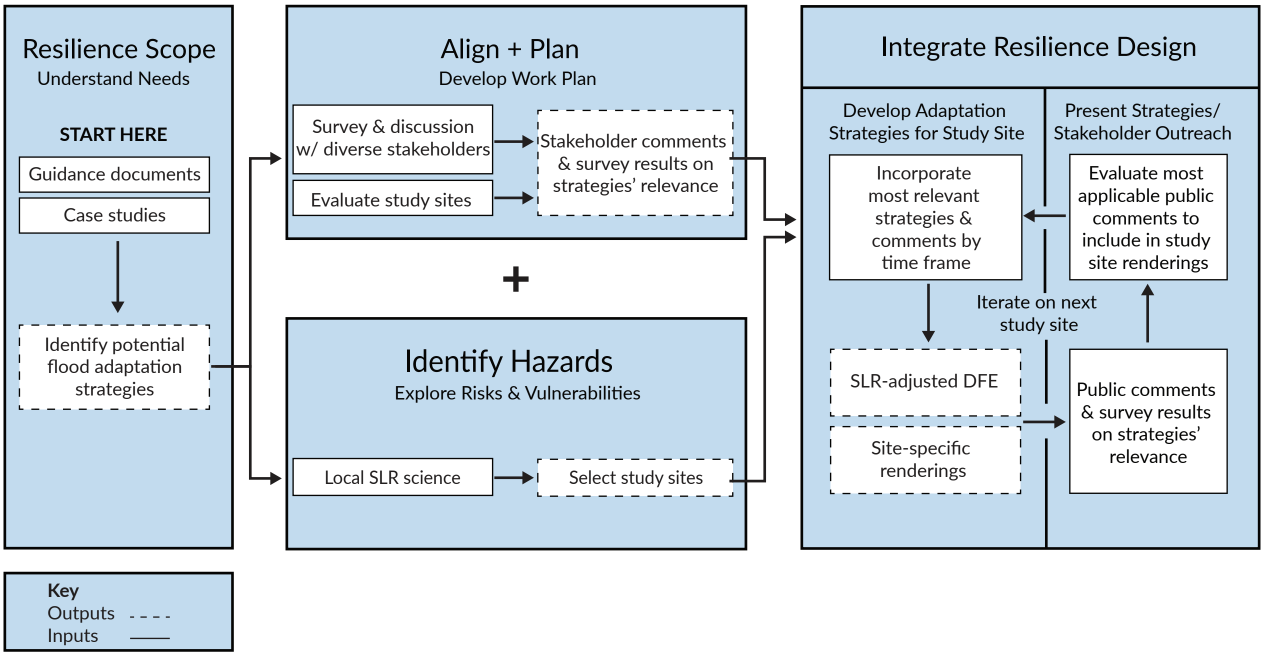
With the strategic addition of local context, the American Institute of Architects (AIA) toolkit provides a framework for integrating science, community input, and best practices into conceptualizing adaptation strategies for new construction and major renovations. An interdisciplinary team from the University of Hawai'i directed a multistakeholder process guided by principles from the AIA Resilience Design Toolkit steps 1 through 4 to identify and envision SLR adaptation strategies to inform future architectural and urban design guides and policy for a coastal urban environment. The team sought to address the research question, "How can local SLR modeling and stakeholder input shape site-specific architectural renderings of flood adaptation strategies aimed at coordinating parallel efforts and informing design and policy?"

Methodology

The research methods outlined below build upon established methods to identify effective adaptation approaches by considering SLR science, including coastal processes, local plans, vulnerability analyses, and sociocultural and economic factors (Bongarts et al. 2021). This work is reflective of the "design research" concept, a mode of knowledge characterized "not necessarily [by] the creation of something new, but rather an understanding of preferred futures and how to plan to get there.... [I]nquiry about the past and present, the preferred future, and the transition process" (Ruecker and Roberts-Smith 2018). This design research builds on an existing framework with new, localized information and the development of enhanced processes to gather, record, and incorporate stakeholder feedback. Each step outlined in Table 2 and Figure 1 represents a unique research activity, the synthesis of which enabled an iterative and stakeholder-responsive design research process.

Identification of Adaptation Strategies

To determine the design options best suited to Waikīkī's conditions, the project team collated adaptation strategies through a survey of flood resilience design guides from municipalities such as New York City (NYC 2020) and Boston (Boston Planning and Development Agency 2019), as well as national voluntary standards such as US Green Building Council (USGBC) LEED (2021). Strategies relevant to Waikīkī's dense urban fabric, flood hazards, and building types were identified and noted for stakeholder presentation.



◁ Opening Image. The prototypical study site adjacent to a canal includes a building and road threatened by flooding from sea level rise and storms. (Credit: Josephine Briones)

△ Figure 1. The diagrammatic representation distills a step-by-step replicable design process. (Credit: Josephine Briones and Wendy Meguro)

Stakeholder Outreach and Engagement

Local knowledge was acquired in five virtual workshops with 71 invited stakeholders from a cross-section of relationships to Waikīkī, including business representatives, landowners, government employees, elected officials, residents, tourists, consultants, urban planners, and design professionals. Following a summary of SLR science and potential adaptation options, participants were surveyed on the applicability of each adaptation strategy within the categories of buildings, utilities, open space, and transportation (Table 5) (Peppard 2022a). Breakout groups allowed participants to share further qualitative feedback, ideas, and concerns. The qualitative discussion introduced an element of subjectivity, and the following overarching themes emerged: policy, public buy-in, permitting/regulations, finances, timing, sequencing, and application. Stakeholders' verbal comments were transcribed grouped by theme, and short quotes were placed in the summary report.

The strategies rated most applicable by stakeholders were prioritized for depictions in the architectural and urban design adaptation renderings. Since all adaptation strategies were determined to be relevant to varying degrees, the team sought to depict as many of them in the site-specific renderings as possible while prioritizing those most highly rated. The authors qualitatively analyzed the feasibility of incorporating each adaptation using the following criteria: 1) select strategies effective in mitigating the flood hazard at a study site; 2) depict strategies that seem plausible for a study building's characteristics (e.g., the team depicted elevating the three-story building but not the 20-story building); 3) depict strategies that create a cohesive pedestrian environment; and 4) create multiple renderings to depict different approaches to addressing the same flood hazard.

This comprehensive approach was applied to analyzing quantitative (surveyed) and qualitative (discussion-based) stakeholder feedback for all adaptation strategies, which informed design decisions. In the second round of stakeholder outreach, stakeholders could respond to and discuss the resulting designs, which shared stakeholder-informed design renderings with public participants. These outcomes are discussed further in the forthcoming section, Public Outreach.

Study Site Selection

The team used local SLR maps, zoning, site observation, and property information to select prototypical buildings and land parcels on which various flood adaptation strategies could be evaluated and illustrated. The team selected sites with various older structures vulnerable to flooding, representing different uses.

Areas estimated to be flooded soonest in the 3.2 ft. (0.98 m) SLR-XA illustrated in the Hawai'i Sea Level Rise Viewer (Hawai'i CCMAC 2021). Various building program types most common to Waikīkī included high-rise and low-rise residential, commercial, retail, and hospitality, as identified on the Honolulu Land Use Ordinance map (CCH HoLIS 2020). Based on field observations, buildings with at-grade or below-grade spaces are vulnerable to flooding. Aging buildings will likely require renovation or redevelopment before the end of the century. Construction and flood zone dates were obtained from the Honolulu Real Property Information Assessment and the Flood Hazard Assessment Tool (CCH Real Property Assessment Division 2014; Hawai'i DLNR 2022).

Table 1. Selected excerpts from plans and guidance documents encourage sea level rise (SLR) adaptation.

Adaptation Statement	Document	Source	Year
"Top-down scientific assessments are not sufficient to fully assess vulnerabilities, understand uncertainties, or inform adaptation. Local knowledge and expertise are essential in this process."	Application Guide for the 2022 Sea Level Rise Technical Report	National Oceanic and Atmospheric Administration (NOAA)	2022
"Change building codes and design standards to account for sea-level rise, e.g. in building elevation and foundation design."	Responding to Rising Seas	Organization for Economic Co-operation and Development (OECD)	2019
"Support the operation and occupants of the building… during a… disruption."	The Fundamentals of Resilient & Climate Adaptive Design	American Institute of Architects (AIA)	n.d.
"Establish safer building… elevation standards… to incorporate an additional safety factor to account for rising water levels."	Resilient 305 Strategy	Miami-Dade County Office of Resilience	2020
"Select design interventions that meet the project's SLR-adjusted design flood elevation (DFE)."	New York City (NYC) Climate Resiliency Design Guidelines	NYC Mayor's Office of Resiliency	2020
"Solutions that are independently effective can also work together to provide mutual support and reduce the risk of a catastrophic failure associated with a single line of defense."	Coastal Flood Resilience Design Guidelines	Boston Planning and Development Agency	2019
"Developing guidance that integrates SLR risks into county planning frameworks is a key component for the integration of mid and long-term strategies for appropriate land use."	Hawai'i Ocean Resources Management Plan	Hawai'i Office of Planning	2020
"Conduct county-wide and community-scaled sea level rise vulnerability assessments using best-available data and identify potential adaptation strategies."	Guidance for Addressing SLR in Community Planning in Hawai'i	NOAA	2020
"Encourage voluntary adaptation measures in the sea level rise exposure area (SLR-XA) that exceed statutory requirements."	CCH Primary Urban Center Development Plan	CCH Department of Planning and Permitting (DPP)	2022

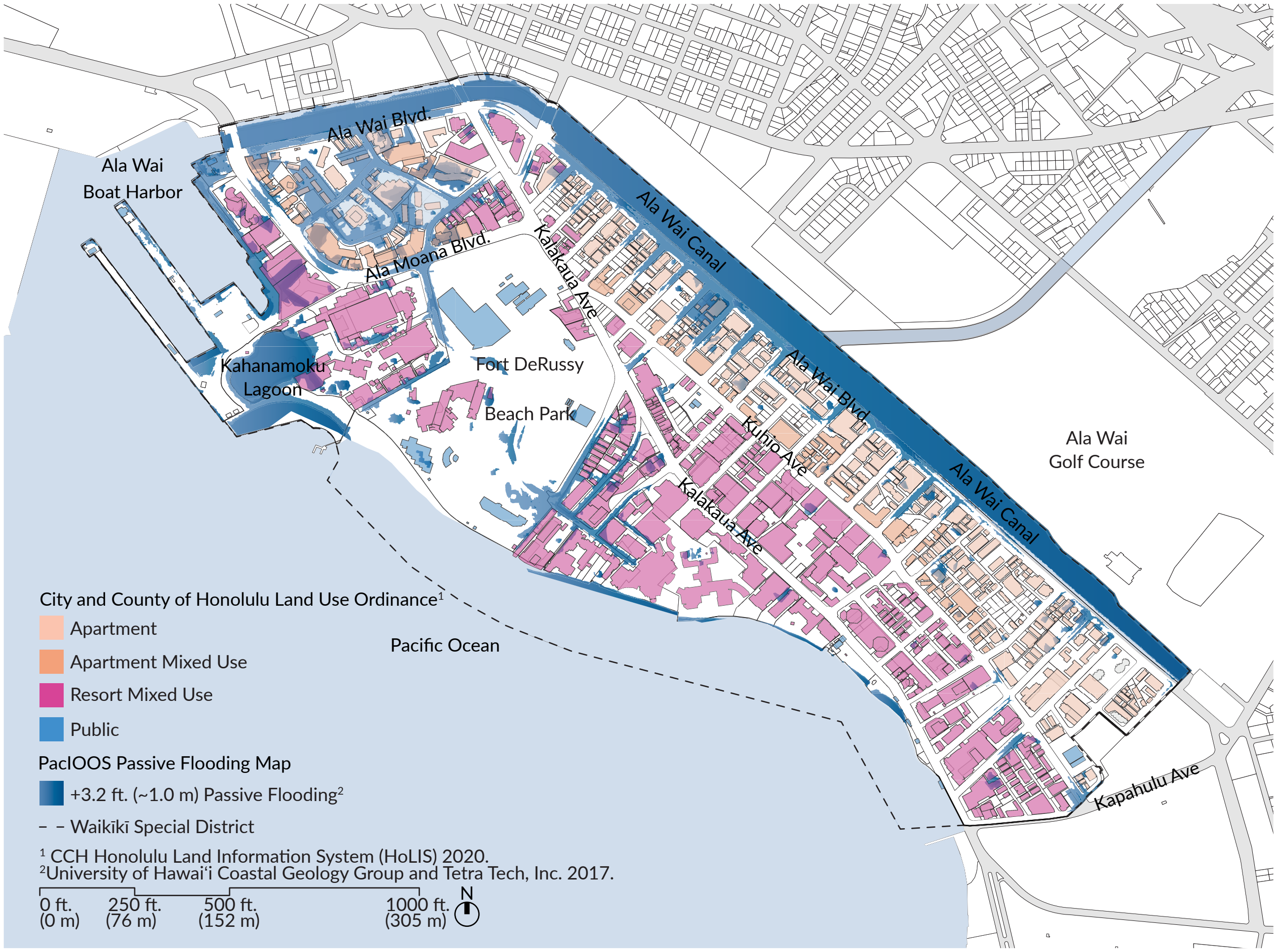
Development of SLR-Adjusted DFE for Waikīkī

The following terms are used to discuss the height of future elevated buildings.

- Base flood elevation (BFE) is the elevation of surface water resulting from a flood that has a 1% chance of equaling or exceeding that level in any given year (FEMA 2020a), based on historical flooding.
- Design flood elevation (DFE) is the elevation of the "design flood," including wave height, relative to the datum specified on the community's flood hazard map. The DFE may refer to the BFE plus freeboard (FEMA 2013).

The freeboard is the additional height between the BFE and DFE. A community may require a freeboard, which can be adjusted beyond regulatory standards at the discretion of design professionals to add a safety margin (FEMA 2020b).

Honolulu's adaptation guidance (CCH DPP 2020) and the Waikīkī Special District Design Guidelines (CCH DPP 2021c) do not provide a methodology to determine DFEs with SLR. To create an SLR-adjusted DFE, the team added future SLR, king tides, and freeboard to the BFE. The BFE is from the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FEMA 2020c). Future SLRs for 2050 and 2100 were sourced for the Honolulu Tide station from the National Oceanic and Atmospheric Administration (NOAA) report on "Global and Regional Sea Level Rise Scenarios for the United States" (Sweet et al. 2017). The king tides were estimated based on conversations with UH scientists. The intermediate-high 83% probability scenario was selected based on the low-risk tolerance of residential buildings. Revised heights for the intermediate-high SLR scenario were published later (Sweet et al. 2022) and used in future SLR planning. Freeboard requirements in the CCH's 2012 International Building Code (IBC) usually require one foot of freeboard above the current BFE within flood zones (CCH DPP 2021a). Based on the Boston Coastal Flood Resilience Design Guidelines for noncritical facilities, the team added 1' 0" (0.30 m) of freeboard for existing building retrofits and 2' 0" (0.61 m) for new construction (Boston 2019).



△ Figure 2. A suitability analysis considered sea level rise exposure and land use designations to select Site 1 (1627 Ala Wai Boulevard) and Site 2 (2085 Ala Wai Boulevard). (Credit: Josephine Briones)

Envisioning Site-Specific Flood Adaptation Strategies

Incorporating stakeholder feedback, the team iteratively designed and created conceptual urban and architectural design renderings of a habitable, attractive, economically vibrant Waikīkī. While the SLR-DFE informed building design, the shallow, rising groundwater table (estimated at a similar elevation as mean higher high water (MHHW) each year) was the main driver in determining the height to elevate streets, pedestrian, and bikeways, stormwater retention areas, and utilities.

A 3D digital model was created using the Rhinoceros (Rhino) 3D, Version 6.0 software (McNeel 2010), and rendered in 3D architectural visualization software (Lumion 2022, Enscape 2022). Shapefiles for roads, parcels, building footprints, and the Waikīkī Special District boundary line (Hawai'i Statewide GIS Program 2021), SLR-XA at 0.5' (0.17 m) to 3.2' (0.98 m) (Hawai'i CCMAC 2021), and 4' 0" (1.27 m) and 6' 0" (1.93 m) passive flooding (NOAA 2021) were imported into the GIS software ArcMap 10.7.1 (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.

Public Outreach

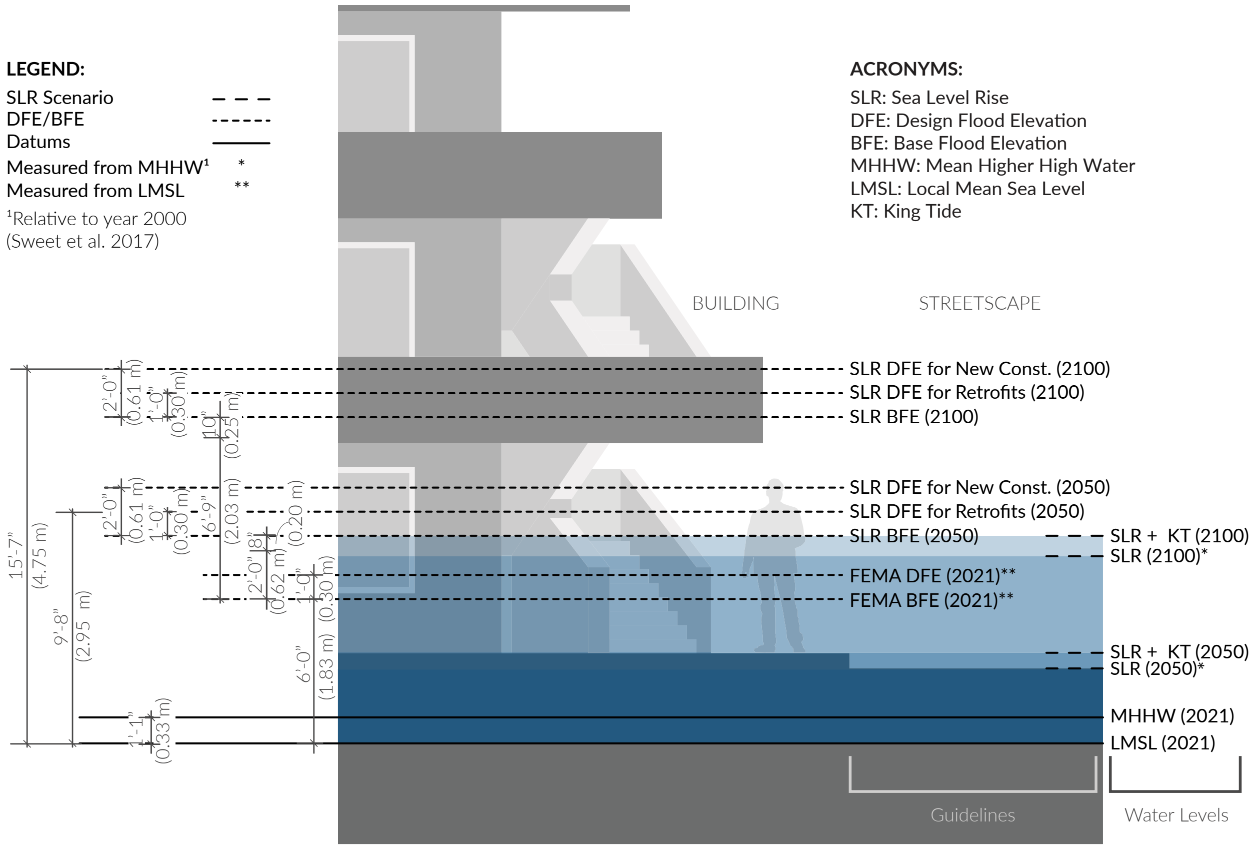
We presented the resulting conceptual architectural renderings to guest experts and an audience in a virtual public presentation with over 120 attendees. The team surveyed the audience to select the most applicable adaptation strategy for buildings, transportation, and open space in 2050 and 2100. The resulting strategy ranking, and participant comments informed the team's ongoing design and policy guidance development. The full results are available on the project website (Peppard 2022b).

Results

Study Site Selection

Our methodology yielded five potential sites. Two were selected based on their diverse representation of building size, presence of at-grade and below-grade spaces vulnerable to flooding, criticality, and potential for redevelopment (Figure 2).

Site 1 includes three 1950s low-rise residential walk-up concrete masonry unit (CMU) buildings adjacent to the Ala Wai Canal with residences at grade. This site is in the West Waikīkī



△ Figure 3. Design guidelines and water levels are illustrated for Site 1, a low-rise residential structure. (Credit: Josephine Briones and Ireland Castillo)

region, which is recommended "as a pilot area to implement [climate change] adaptation strategies" (Nakano et al. 2019). Given the building's age, renovations to extend the building's useful life to midcentury and redevelopment by the end of the century are depicted. Site 2 is a concrete residential high-rise building constructed in 1967 and adjacent to the Ala Wai Canal with parking at grade and residential floors above. We provide conceptual designs for phased renovations to extend the building's useful life to the end of the century.

Development of SLR-Adjusted DFE for Waikīkī

For each study site, SLR-adjusted DFEs were calculated for 2050 and 2100 by adding the SLR scenario, king tide, and freeboard to the present-day BFE (as explained in the methods section). *For Site 1*, Table 3 includes the SLR-adjusted DFE calculation, and Figure 3 illustrates the water levels and design guidelines. *For Site 2*, Table 4 includes the SLR-adjusted DFE calculation and illustrates the water levels and design guidelines.

Stakeholder Outreach and Engagement

During the 2021 stakeholder workshops, participants' responses to quantitative surveys showed that most were familiar with the strategies presented, and most participants thought the strategies presented were relevant to Waikīkī (Table 5). Table 5 summarizes the percentage of participants familiar with each adaptation strategy and agreement with its applicability to Waikīkī. The design team interpreted both quantitative and qualitative results in the design process. For instance, most stakeholders agreed that the elevation of streets/roads and sidewalks (85%) and resilient streetscape transition zones (74%) would apply to Waikīkī (Peppard 2021). Within discussion groups, many participants did not see a practical future for most vehicles in the area. At a minimum, a vast reduction in parking availability was anticipated to sustain Waikīkī's future. Others shared that keeping roadways at their present grade could collect and divert flood waters as other infrastructure was raised around them. Given Waikīkī's significance as a tourist destination, the necessity for SLR-adaptive transportation solutions, and the consensus among stakeholders regarding raised streets/roads, sidewalks, and resilient streetscape transition zones for Waikīkī's future, our team translated these research findings into design adaptations. This translation involved elevating specific arterial transportation thoroughfares and significantly reducing parking spaces in favor of performance-based transition zones. Features that enhanced the pedestrian experience and public safety included planter boxes with ecological water treatment, dedicated bike lanes, and expanded sidewalk areas. Longer-term visions for Waikīkī in 2100 included side streets transformed into canals.

Table 2. The table outlines the AIA Resilience Design Toolkit principles and corresponding replicable research activities.

AIA Resilience Design Toolkit Steps	Research Design Elements
AIA Resilience Design Toolkit Steps 1. Resilience Scope *Understand client/stakeholder needs*	• Survey existing guidance documents and case studies • Identify flood adaptation strategies for buildings, open spaces, transportation, and utilities with local relevance
2. Align and Plan *Develop workplan to achieve goals*	• Conduct outreach to crowdsource expertise from diverse local stakeholders • Evaluate and select study sites
3. Identify Hazards *Explore risks and vulnerabilities*	• Identify the best available SLR and king tide information downscaled for local use
4. Integrate Resilience Design *Develop design strategies*	• Develop SLR-adjusted DFE for Waikīkī • Create site-specific architectural renderings illustrating the potential application of future flood adaptation strategies • Host public discussion on the strategies presented • Document stakeholder feedback for future use
5. Operate and Evaluate* *Post-occupancy evaluation*	• *Out of Study Scope

Table 3. Site-specific SLR-adjusted design flood elevations (DFEs) were calculated for Site 1 for the years 2050 and 2100.

Year	BFE (FEMA Flood Zone AE)	Local SLR	King tide	Freeboard	SLR-DFE
2050	6’ 0” (1.83 m)	2’ 0” (0.62 m)	0’ 8” (0.19 m)	1’ 0” (0.30 m)	9’ 8” (2.95 m)
2100	6’ 0” (1.83 m)	6’ 9” (2.05 m)	0’ 10” (0.26 m)	2’ 0” (0.61 m)	15’ 7” (4.75 m)

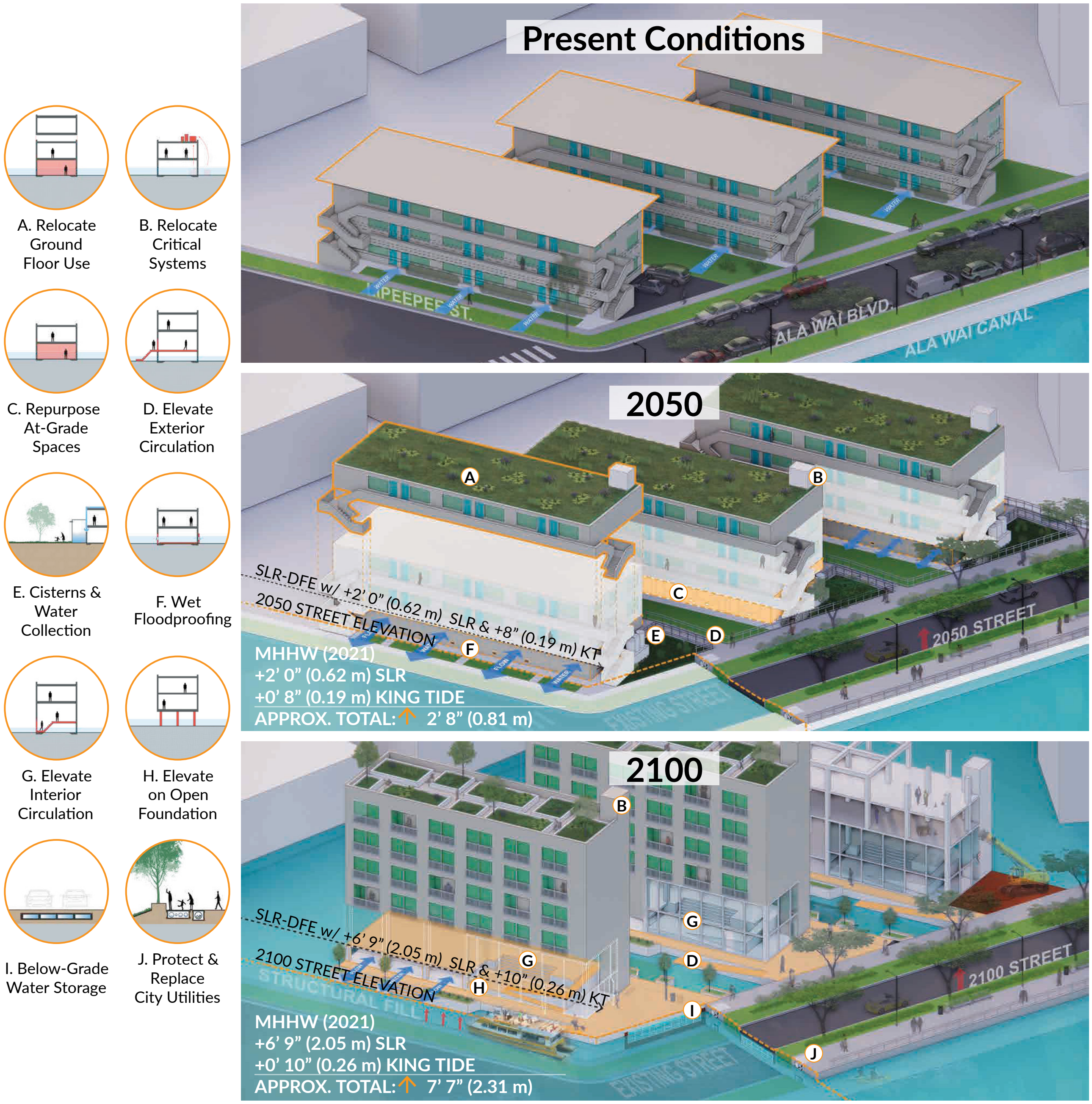
Table 4. Site-specific SLR-adjusted design flood elevations (DFEs) were calculated for Site 2 for the years 2050 and 2100.

Year	BFE (FEMA Flood Zone AO)	Local SLR	King tide	Freeboard	SLR-DFE
2050	2’ 0” (0.61 m)	2’ 0” (0.62 m)	0’ 8” (0.19 m)	1’ 0” (0.30 m)	5’ 8” (1.73 m)
2100	2’ 0” (0.61 m)	6’ 9” (2.05 m)	0’ 10” (0.26 m)	1’ 0” (0.30 m)	10’ 8” (3.25 m)

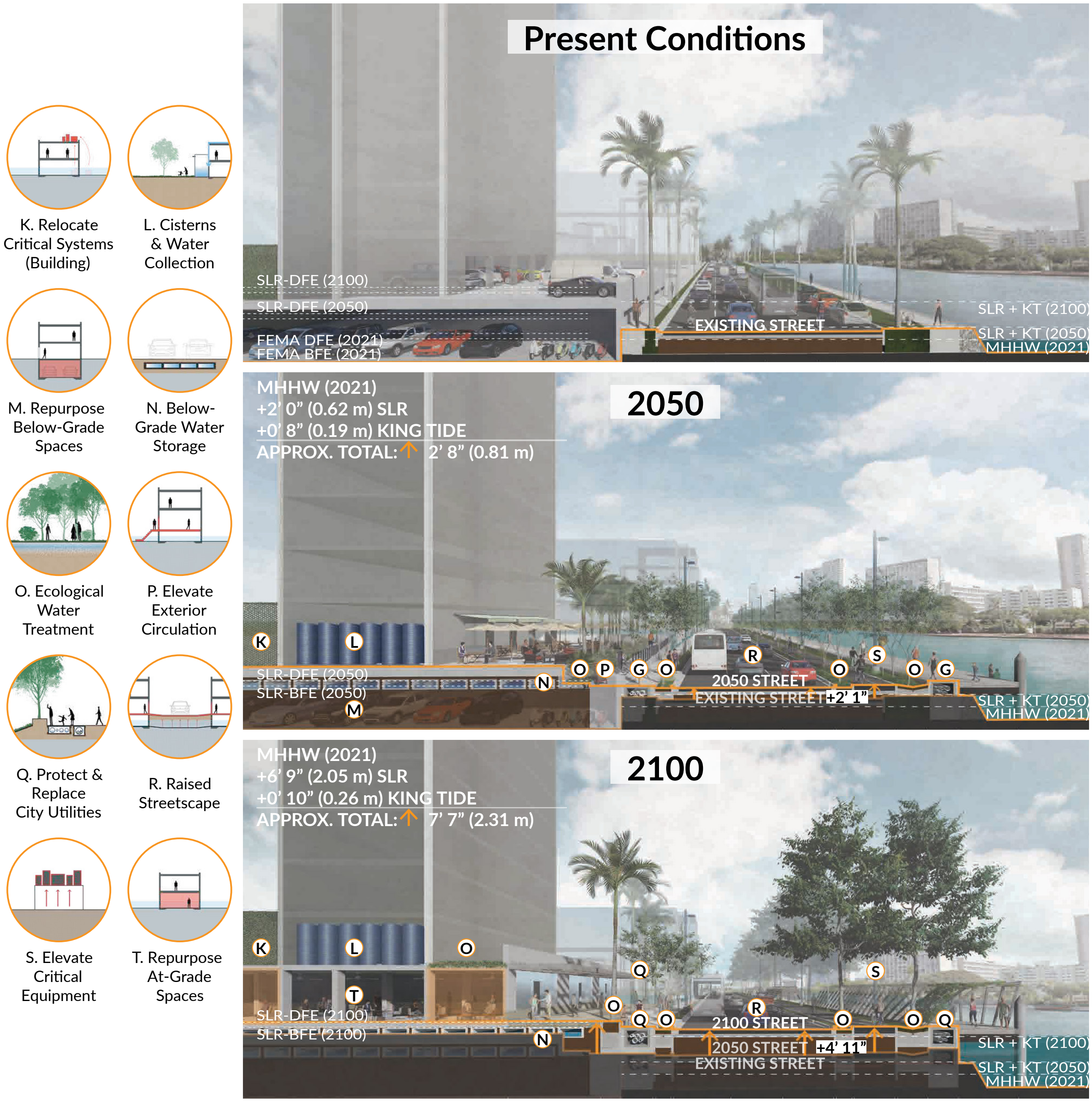
Stakeholders identified elevating utilities and relocating critical systems in buildings as most applicable and urgent. The discussions confirmed a need for coordinated building and urban-scale planning, cost estimates, and phasing. Recurring subjects included responsibility for adaptation funding, sources of fill, and the need to transition away from single occupancy vehicles (Peppard 2021). Stakeholder insights and discussion informed the research team’s integration of selected strategies into the study sites.

Proposed Adaptations

Site 1: Two retrofit options were explored for 2050 with 2’ 0” (0.62 m) of SLR with an 8” (0.19 m) king tide, a total increased water level of 2’ 8” (0.81 m). The design team incorporated the most relevant adaptation strategies to the low-rise slab on grade structure (Figure 4). Retrofits allow water to flow freely through the site, the option deemed most locally applicable by stakeholders. Existing residential spaces at grade are relocated to a new top floor with structural reinforcement to compensate for the loss of the original first floor. Space at grade is wet floodproofed and repurposed for parking, storage, or access. Wet floodproofing allows for equalizing the hydrostatic forces of flood waters on exterior walls (e.g., flood vents) (FEMA 2021). Alternatively, the ground floor could be stripped down to its load-bearing components, devoid of nonstructural walls and materials. Critical equipment is raised above the SLR-DFE, and elevated exterior stairs or ramps connect the street and building. In the future, the conveyance of stormwater runoff



△ Figure 4. Renderings of Site 1 depict present conditions, proposed retrofits for 2050, and proposed new construction for 2100. (Credit: Ireland Castillo)



△ Figure 5. Renderings of Site 2 depict present conditions, proposed retrofits for 2050, and proposed retrofits for 2100. (Credit: Josephine Briones) will be hampered by storm drain backflow, and higher groundwater tables will limit infiltration. On-site stormwater management strategies include a new green roof and a water cistern.

By 2050, streetscapes along the Ala Wai Canal will experience groundwater inundation. The illustrated road section drawing accounts for a rising water table, which is not considered in current roadway design standards. A typical roadway structure includes a top layer of asphalt and a middle base layer that is both 8” (0.19 m) thick and a subgrade layer (Knott et al. 2017). At a minimum, to avoid the weakening of road structures from SLR (Knott et al. 2017), the top asphalt and middle base layers of the roadway structure are elevated above the groundwater table, or 2’ 0” (0.61 m) above the existing street. A rainwater harvesting system could be added to the new fill below the roadway to accommodate stormwater storage. Located below the roadway surface but above the water table, it would require raising the roadway 4’ 4” (1.32 m) above the existing street level. Per stakeholder discussion, side-street parking is eliminated in favor of wide vegetated buffers and sidewalks with vaulted subsurface utilities.

In 2100, with 6’ 9” (2.05 m) of SLR plus a 10” (0.26 m) king tide, the buildings at Site 1 are likely at the end of their useful life. They may be replaced with a mixed-use development built on structural fill or an open foundation with a raised exterior circulation and critical systems above the SLR-DFE.

By 2100, significant thoroughfares like Ala Wai Boulevard must be raised 6’ 10” (2.08 m) above the existing street level to avoid SLR inundation. At this time, minor streets will likely be transformed to accommodate both flood waters and alternative modes of transportation, such as water taxis. Subgrade stormwater detention will require enclosed cisterns to keep stormwater runoff separate from the rising, brackish groundwater.

Site 2: This site is a high-rise residential structure (Figure 5). The first occupied floor of the building is located above a partially below-grade parking area and an elevated, open-air parking deck. Under the projected SLR conditions in 2050, 2’ 0” (0.62 m) of SLR with an 8” (0.19 m) king tide, the subsurface parking structure will likely become flooded and unusable. The below-grade area of the building should be filled to the nearest grade, and water cisterns should be placed within the fill to collect and retain stormwater (Boston 2019). Critical systems located in the parking area should be raised above the SLR-DFE.

As in Site 1, the proposed elevation of Ala Wai Boulevard was determined by raising the depth of subgrade and asphalt material above the estimated water table height in 2050, 2’ 1” (0.64 m) above existing conditions. Extensions of pedestrian walkways and the addition of a two-way bike lane provide safe transportation options and enhance recreational opportunities along the canal (Honolulu Complete Streets 2022). Vegetated buffers, bioswales, vaulted utilities, elevated critical equipment, and street trees would also be incorporated as a part of the streetscape.

Additional adaptations are proposed to extend the useful life of the building toward the end of the century, including filling the remaining below-grade space to the nearest adjacent grade, raising the existing ground floor to the 2100 SLR-DFE, and inserting stormwater storage in the void between the existing and new ground floor slabs. A vegetated transition zone is proposed to mitigate the height differential between the first floor and the streetscape.

By 2100, the roadway will be elevated an additional 4’ 11” (1.50 m) above the proposed 2050 street elevation, a total of 7’ 0” (2.13 m) above present conditions. Vaulted utilities will also be elevated, and critical equipment will be raised above the SLR-DFE. Due to anticipated brackish water inundation, saltwater-tolerant plants and new vegetation will be needed to provide shade, heat reduction, and stormwater mitigation.

Public Outreach

A 2022 public presentation and discussion further refined recommendations, informed the subsequent iterations of the research and were summarized in online reports (Peppard 2022b). Polling of over 120 audience members elicited quantitative stakeholder feedback, and a panel discussion provided qualitative insight into community preferences for the adaptation options depicted in the visualizations. Observations from the quantitative and qualitative stakeholder feedback report on the site-specific adaptation strategies (Peppard 2022b) follow.

Polling suggested that for Site 1, the low-rise residential building, adaptation strategies related to rethinking and relocating ground floor uses were agreeable for 2050 and nearly unanimous for 2100. Raising exterior circulation and adding water storage were significantly less popular for both time benchmarks. For Site 2, the high-rise residential building, the most highly favored design proposal was relocating critical systems above the SLR-DFE, repurposing below-grade spaces, and elevating exterior circulation. Interestingly, these top three strategies followed the same polling pattern for 2050 and 2100. Rainwater collection was deemed the least applicable to the site for 2050 and 2100. Transportation considerations followed a similar theme, with raising streetscapes valued considerably more than the other options presented for both sites and time benchmarks. Elevating critical equipment and vaulting utilities followed, with biofiltration slightly more favorable to below-grade water storage, though both were deemed the least applicable options.

These results suggest an inherent ‘phasing’ of adaptation strategies according to structural component criticality and the timing of SLR (i.e., critical systems and below-grade spaces should be addressed most urgently, followed by at-and-above-grade areas). Stormwater management solutions like cisterns, biofiltration, and below-ground water storage appear least favored, perhaps because polled participants could only select one option. These results suggest that though deemed location-appropriate in the first round of stakeholder engagement, strategies related to the continuity of building and transportation operations are valued highly compared to those oriented toward stormwater capture and treatment. These results also suggest that stakeholders may not expect nature-based solutions at the study site to mitigate the area’s flooding effectively, given the multiple sources of flooding, and more rigorous district-scale low-impact development planning and policies are needed.

Table 5. Quantitative survey responses showed stakeholders' familiarity with each adaptation strategy and its applicability to Waikīkī. (Credit: Peppard 2020a)

Category	Strategy	Stakeholders that agree or strongly agree they are familiar with this strategy (%)	Stakeholders that agree or strongly agree the strategy is applicable to Waikīkī (%)
Utilities	Elevate critical equipment	89	94
	Protect and replace city utilities	76	80
	Below-grade water storage	51	45
Open Space	Floodable open spaces	81	75
	Ecological water treatment	66	69
	Cisterns and water collection	78	64
Transportation	Elevated streets/roads and sidewalks	86	85
	Resilient streetscape transition zones	77	74
Buildings	Relocate critical systems	88	89
	Reevaluate spaces below DFE	71	76
	Flood resistant materials	53	63
	Wet floodproofing	55	61
	Elevate on open foundation	69	49
	Dry floodproofing	51	42
	Elevate on fill	60	40

Stakeholder comments also illustrated the differences in 'futures' that the populace envisions and potential next steps for research inquiry. For example, while one stakeholder said, "It would be very nice if these designs would visualize an automobile minimized Waikīkī, which would allow a much broader suite of adaptations," another commented, "Your solutions all assume reduced auto use. Is that realistic?" While most participants agreed that roadways should be raised, questions lingered about whether the island's limited supply of construction-grade fill would pose issues or if roadways elevated on columns would be more appropriate. Though out of the scope of this study, comments on the coordinated timing of adaptation strategy implementation and the structural impact of brackish flood waters were also raised.

The team transcribed, categorized, and summarized the verbal and written chat discussion for all outreach and documented it in the online reports. When incorporating qualitative feedback into the design decision-making process, the team considered a series of questions. Did multiple participants support the strategy or suggestion, and did it seem appropriate for Waikīkī, based on our background research? Would the suggested strategy better address flood hazards at the study site in 2050 or 2100? Could a suggestion be visually depicted on the current study site or inform a new study site selection? A participant's comment suggesting "empty lots for flood mitigation" influenced the site selection and floodable open space strategy depicted in a later presentation. The team found that comments on adaptation strategies could be easily incorporated into renderings. In contrast, astute comments regarding policy and finance were more challenging to illustrate and were incorporated into verbal discussions in later presentations. For example, participants noted a need to "educate the community so we can be proactive" or a desire to "align State Water Commission policies with recommendations that come out of this study" or highlight "equity issues for property owners who can't afford to... elevate or dry floodproof."

Discussion

This design research explored a unique combination of research endeavors—study site evaluation, calculation of SLR-informed DFEs, and the selection of locally appropriate adaptation strategies—and guided their translation into design. When combined with public engagement and place-based science, we demonstrated a replicable process that can inform design and planning processes in other coastal communities. This effort considered both expert input and the feedback of the broader public in a manner modeling Participatory Action Research (PAR), which is defined as "collaboration between a community with lived experience of a social issue and professional researchers... for generating knowledge-for-action and knowledge-through-action, in service of goals of specific communities" (Cornish et al. 2023).

The design research processes could be utilized to create local policy and guidance. In particular, the proposed method to establish future building DFEs, which incorporate SLR scenarios informed by buildings' risk tolerance and useful life, as well as king tides and current (2022) BFE, may be replicated or modified to create architectural or urban design guides. Until such resources are adopted, we recommend that local building professionals voluntarily exceed current regulatory standards and apply an SLR-adjusted DFE and other relevant adaptation strategies to all new construction and major renovation projects. A limitation of this research is the knowledge gap in comparative costs and benefits of adaptation strategies (Dedekorkut-Howes et al. 2020), which could be identified in a future Benefit-Cost Analysis (BCA), as suggested by the Resilience Design Toolkit (AIA 2023).

Conclusion

This research demonstrates the impact and necessity of customizing standardized architectural frameworks and methodologies by including downscaled science and soliciting input from local voices in design. This research documents an early application of the replicable methods in the AIA Resilience Design Toolkit (AIA 2023) to specific sites with public feedback that informs iterative design. The gathering of stakeholder feedback at multiple project junctures was critical to the design research's evolution, and the dimensionality of suggestions received from both qualitative and quantitative feedback was particularly invaluable to the design team because of participants' lived experiences and deep understanding of the study site areas.

Future research and policy needs include coordinated district-scale area plans and financial mechanisms to enable the adaptation and implementation of prototypes. As the regional impacts of climate change begin to affect our neighborhoods, interconnected utilities, and infrastructure widely, it will become increasingly important for site-scale adaptation strategies to be guided and informed by district-scale plans. Most coastal municipalities have yet to formalize climate change adaptation in planning efforts. With comprehensive strategies, these areas avoid maladaptation, including missed opportunities for alignment and synergy in phasing and the higher costs associated with chronic repair versus proactive adaptation measures. Incentives, testing, and monitoring of prototypes, such as those illustrated in this research, may help designers refine strategies and assist governments in updating long-range plans for coastal areas, fundamentally changing the character and function of coastal communities as we know them today.

Data Availability Statement

The data supporting this study's findings are openly available at https://seagrant.soest.hawaii.edu/meguro-adapting-waikiki/.

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