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Economic Optimization of Historic Preservation in National Parks: Future Transitions for Climate Change and Cultural Resources

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Climate Adaptation Planning for Historic Buildings: A Multi-objective Optimization Approach

1. Introduction

Climate change is increasingly posing great challenges to coastal cultural resources (Adger, Arnell, & Tompkins, 2005; NPS, 2010; Seekamp & Jo, 2020). Flooding and erosions from storm events and rising sea-levels can negatively impact the condition and historic integrity of tangible cultural resources in the coastal areas (Peek et al., 2017; Reeder-Myers & McCoy, 2019; Rockman, Morgan, Ziaja, Hambrecht, & Meadow, 2016). Tangible cultural resources are the physical record of human experiences, and the Sustainable Development Goals (SDGs) and Paris Agreement give unprecedented recognition of the fundamental role of cultural resources in transitions to climate-resilient development pathways (ICOMOS, 2019). Anthropogenic climate change accelerates the ongoing deteriorative effects on historical and cultural resources in national parks (Hambrecht & Rockman, 2017), highlighting the need for national- and international-level preservation of cultural resources to tackle threats of climate change and climate extremes (Seekamp & Jo, 2020). This urgency for developing transformative frameworks and practices for cultural heritage preservation under climate change is recognized by the International Council on Monuments and Site (ICOMOS, 2019).

At a national level, the US National Park Service (NPS) has served as the leading agency to steward these important cultural resources and has recognized the impacts of climate change as the greatest threat to the integrity of cultural resources in national parks (NPS, 2010, 2014; Rockman et al., 2016). Although international, national, and local conservation agencies have implemented initial adaptation planning efforts to preserve the cultural resources on the coastal parks (Barnett et al., 2014; Borrelli & Beavers, 2008; Hambrecht & Rockman, 2017; Rockman & Hritz, 2020), limited guidance and policies exist to inform adaptation decision making under climate change, challenging the sustainability of coastal heritage (Rockman & Hritz, 2020). These challenges have highlighted the importance of developing decision frameworks that integrate climate change projections and support managers in identifying appropriate adaptation actions under uncertain future conditions (Fatorić & Seekamp, 2017b; Khakzad, 2017; Perez-Alvaro, 2016).

Substantive efforts on climate change and adaptation planning research have been focused on natural resources and biodiversity (Keith et al., 2008; Thomas et al., 2004; Wintle et al., 2011). These efforts involve reinforcing the multiplicity of systematic adaptation frameworks by integrating ecological and economic factors to optimize climate adaptation actions (Wintle et al., 2011). Interfacial convergence between the environment and cultural resource integrity necessitates a generalized integration of the culture-nature adaptation approach on a global scale to respond to climate change (Brown & Murtha, 2019; DeCrappeo, Bisbal, & Meadow, 2018; ICOMOS, 2019). Yet, little specific advice or precedent exists in the literature to systematically guide climate adaptation planning for cultural resources (Fatorić & Seekamp, 2017a; Rockman & Hritz, 2020).

A few short-term, prescriptive, and qualitative approaches for cultural resource adaptation planning have been developed to date (Anderson et al., 2017; Casey & Becker, 2019; Johnson & Germano, 2020). For instance, the NPS has developed a four-pillar approach highlighting science, mitigation, adaptation, and conceptual communication framework for climate-change response strategies for cultural resources (Hambrecht & Rockman, 2017; Rockman et al., 2016). Moreover, Carmichael (2016) developed a conceptual framework to assess the impacts of climate change on Australia's cultural heritage sites that integrate the community-based assessment of climate-related risks on cultural heritage sites to a bottom-up planning methodology (Carmichael, 2016). These studies conceptualize frameworks and prescriptive approaches for climate adaptation planning for cultural resources and highlight the importance of scientific knowledge in the historic preservation processes (Fatorić & Seekamp, 2017a; Hambrecht & Rockman, 2017). However, very few analytic approaches exist to guide decision-makers to prioritize climate adaptation planning for cultural resources by considering the risks of climate uncertainty (Fatorić & Seekamp, 2017c), the likelihood of use potential, and condition loss (Fatorić & Seekamp, 2018), and financial feasibility of adaptation actions (Xiao et al., 2019). Integrating these factors into a culture-nature adaptation framework aligns with SDGs to advance long-term cultural sustainability and integrity by optimizing the preservation outcomes (ICOMOS, 2019).

The traditional prescriptive decision support tools for historic preservation are subjected to the limitations of defining the objectives, quantifying the values, and evaluating the trade-offs among alternative actions (Xiao et al., 2019). Moreover, historic preservation is highly conditional on the cost of adaptation actions (NPS, 2010). The cultural resources stewarded by the NPS are increasingly facing the challenges of insufficient funding for deferred maintenance; as such, integrating the costs of adaptation actions to historic buildings can improve the transparency and transferability of the cultural resource adaptation planning decision-support framework (Seekamp et al., 2019). However, very few studies have documented the costs of adaptation actions and assessed the financial feasibility of climate adaptation actions in the literature. Bridging these gaps in historic preservation through transformative, transparent, and transferable adaptation decision support tools has been highly recommended in response to climate change in global, national, and local climate-related policies and guidelines (Rockman & Hritz, 2020).

Informed by the normative decision theory (Howard, 1988; Parnell, Terry Bresnick, Tani, & Johnson, 2013), researchers are beginning to utilize qualitative and quantitative analytic approaches to support climate adaptation planning and prioritization of cultural resources (Fatorić & Seekamp, 2018; Xiao et al., 2019). By structuring a series of alternative decisions under uncertainty, evaluating the trade-offs among decisions, and restructuring the crucial components of decisions, idealized adaptation options can be identified (Howard, 1988). Xiao et al. (2019) developed an optimized model as a decision support tool that integrates costs of historic preservation and climate adaptation actions, as well as realistic economic constraints, in an effort to maximize the accumulated resource value of a set of historic buildings during a 30-year planning horizon. The study serves as the first attempt to quantify cultural resource values and financial feasibility of historic preservation under climate change. The approach integrates metrics for historical value, use potential, and vulnerability of historic buildings to support complex choices between historic preservation and adaptation actions under mid-term projected impacts from climate change.

Despite the contributions of Xiao et al.'s (2019) foundational study, its singular objective focus (maximizing resource value) is a key limitation. Similar to natural resources and biodiversity conservations (Holzkämper, Klein, Seppelt, & Fuhrer, 2015; Klein, Holzkämper, Calanca, Seppelt, & Fuhrer, 2013), historic preservation decisions in parks and protected areas are often multi-dimensional and involve trade-offs among management objectives (Fatorić & Seekamp, 2017b; Klein et al., 2013; Seekamp, Fatorić, & McCreary, 2020). For instance, when funding allocations for management and adaptation are limited, managers must apply complex decision-processes to consider the extent to which actions should focus on preserving historic buildings, adapting historic buildings, or both, and which historic buildings should be prioritized. The NPS's current fragmented approach to managing and preserving climate-related historical resources has limited its capacity to integrate the financial costs and multi-dimensional management objectives into an adaptation planning framework. These constraints underscore the urgent need to advance the generalizability of the optimal preservation decision support tool. Moreover, the diverse associations' stakeholders have to specific buildings, and their connections to the landscape, necessitate transparency in decision making (Seekamp et al., 2020). Yet, to our knowledge, there is a gap in the literature on research that integrates multi-dimensional management objectives in climate adaptation planning for cultural resources.

In this study, we aim to advance the Optimal Preservation (OptiPres) Model developed by Xiao et al. (2019) by integrating multiple management objectives. Specifically, we identify the optimal adaptation plans for historic buildings under three objectives: (a) maximize historical value (significance and use potential), (b) maximize cost-efficiencies, and (c) minimize vulnerability. Additionally, we compare the trade-offs of adaptation actions between the multiple management objectives (a-c) among different budget scenarios.

2. Materials and methods

2.1 Study site

Cape Lookout National Seashore (CALO), located in a 56-mile chain of the barrier island off the North Carolina coast, is managed by the NPS. Managers are tasked with stewarding diverse natural and cultural resources within the barrier island landscape. In this study, we selected 17 historic buildings located in two historic districts listed on the National Register: Portsmouth Village (PV) and Cape Lookout Village (CLV). The buildings were strategically selected to represent diverse conditions, historical values, current and potential uses, and vulnerability (exposure and sensitivity) to climate change impacts (Seekamp et al., 2019). When considered together, these attributes represent a building's "resource value" and when each building's resource value is combined, it represent the "accumulated resource value" of the 17 buildings.

2.2 OptiPres preservation model and budget scenarios

The optimized preservation model expanded the model developed by Xiao et al. (2019) that includes all sub-attributes of historical significance, use potential and vulnerability to a designated objective, which maximizes the number of historical buildings that received climate-focused preservation actions (i.e., minimize vulnerability) across a 30-year planning horizon.

The proposed budget scenarios were adapted from Xiao et al. (2019), including budget scenarios: (a) a low budget scenario of historic preservation where the annual budget allocation is \$50,000; (b) an industry-standard budget scenario of historic preservation where the annual allocation is \$222,000; and (c) a high budget scenario of historic preservation where the annual allocation is \$500,000. The process, data needs, and research effort for OptiPres Model was described in Figure 1.

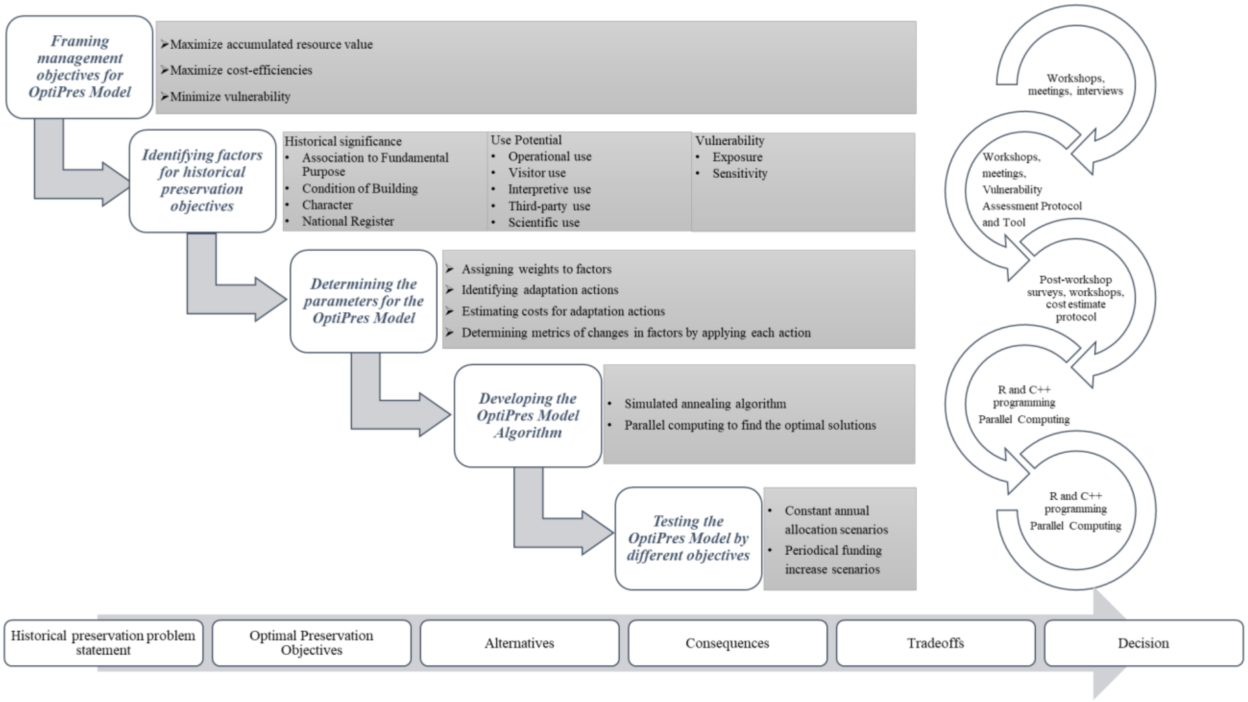

Fig. 1. The OptiPres Model structuring and development processes, including data and expertise needs

3. Results

3.1 Dynamics of different management objectives under varying annual budget allocation

The dynamics of resource values of historic buildings under $0 to $500,000 annual allocated budget are displayed in Figure 2, with the red dash line (a) indicating the original accumulated resource value of the 17 historic buildings without the disruptive interference from climate impacts and (b) demonstrating the gains and loses associated with the different budget allocations at the end of the 30-year planning horizon. The accumulated resource value (objective 1) varies in different stages of budgetary allocations, with increases in the annual allocated budget resulting in cumulative growth in accumulated resource value accordingly (for more details about the dynamics of objective 1, see Xiao et al., 2019). At an annual budget allocation of $200,000, gains in accumulated resource value begin to be actualized (objective 1).

The results also highlight the fluctuations of cost-efficiency (objective 2) under different annual allocated budget (Figure 2a), with the curve of cost-efficiency overlayed on each $50,000 interval (black dash line). The cost-efficiency curve indicates a steep gradient, linear growth pattern for the starting stage; that is, as the annual allocated budget from $0 to $50,000, the increase in cost-efficiency grew exponentially. This initial allocation of an annual budget leads to a drastic growth of cost-efficiencies because (a) the allocated budget was fully utilized and (b) the relatively low cost of actions selected (i.e., annual maintenance and core & shell preservation). Notably, once the allocated budget crosses beyond the calculated threshold of about $50,000, the cost-efficiency undergoes an exponential decay between $50,000 and $150,000, gradually flattening the gradient of the cost-efficiency (black dash line) with the increase of allocated budget over $200,000. The actions applied with an annual budget over $200,000 involve a proportionate rise in receiving annual maintenance and relocation/elevation or relocation actions, while annual budget allocations between $350,000 to $450,000 function identically with indistinguiable shifts of resource value and cost-efficiency. The curve of cost-efficiency also indicates that, under objective 1 (maximize accumulated resource value), the cost-efficiency of the industry standard budget scenario ($222,000) is expected to be nearly identical with the cost-efficiency of the high budget ($500,000). These results highlight the fact that an increase in the annual allocated budget can lead to an increase in resource value of historic buildings, but does not necessarily yield an increase in cost-efficiency in most tested budget scenarios.

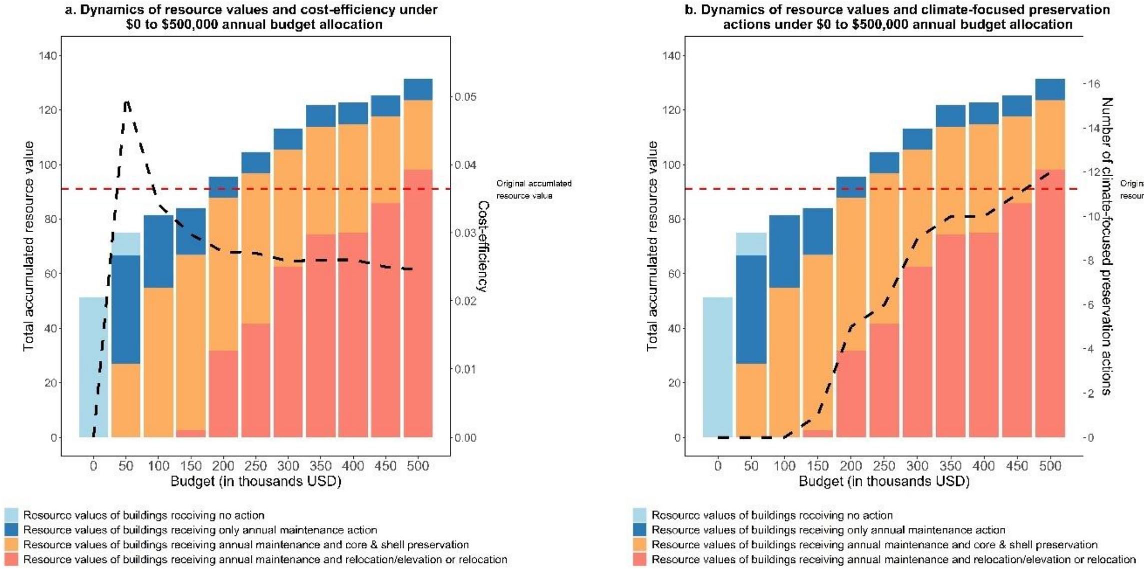

Fig. 2. The expected accumulated resource value (a & b), cost-efficiency (a), and the number of buildings receiving climate-focused preservation actions (b) under $0 to $500,000 annual budget allocation with $50,000 intervals.

The dynamics of objective 1 and objective 3 (number of buildings receiving climate-focused preservation) actions under $0 to $500,000 annual allocated budget scenarios are depicted in Figure 2b. Although the resource value of historic buildings increased nearly 60% from $0 annual allocation budget scenario to $100,000 annual allocation budget scenario, no climate-focused preservation action was applied to any historic buildings under the optimization objective of maximizing resource value. The slope of the curve for objective 3 (black dash line in Fig. 2b) raises sharply from $150,000 to $200,000 and $250,000 to $300,000 annual allocation budget scenarios, indicating increases in the number of buildings receiving climate-focused preservation actions (from 1 to 5 and 6 to 9, respectively). The curve for objective 3 remains steadily or risen slowly and between $350,000 to $500,000 annual allocation budget scenarios. Under $500,000 annual allocation budget scenario, 12 buildings are expected to receive climate-focused preservation actions by the optimization objective of maximizing resource value. Although reducing the vulnerability of 12 buildings is desirable, nearly 30% of historic buildings can not receive climate-focused preservation actions due to the unavoidable trade-offs between improving historic resource values and reducing the vulnerability of historic buildings under the maximum budget constraint.

3.2 Trade-offs of historic preservation by different optimization objectives

To evaluate the trade-offs of historic preservations among three management objectives, three specific budget scenarios were tested by the OptiPres Model. The proposed actions applied to the buildings varied greatly among three optimization objectives under various budgetary allocation scenarios (Figure 3). These trade-offs were evaluated by complicated iterative processes that involve multiple factors (e.g., historical values, building conditions, use potential, vulnerability, adaptation costs, and cost-benefit value by different preservation actions), which were prioritized differently to achieve the three management objectives.

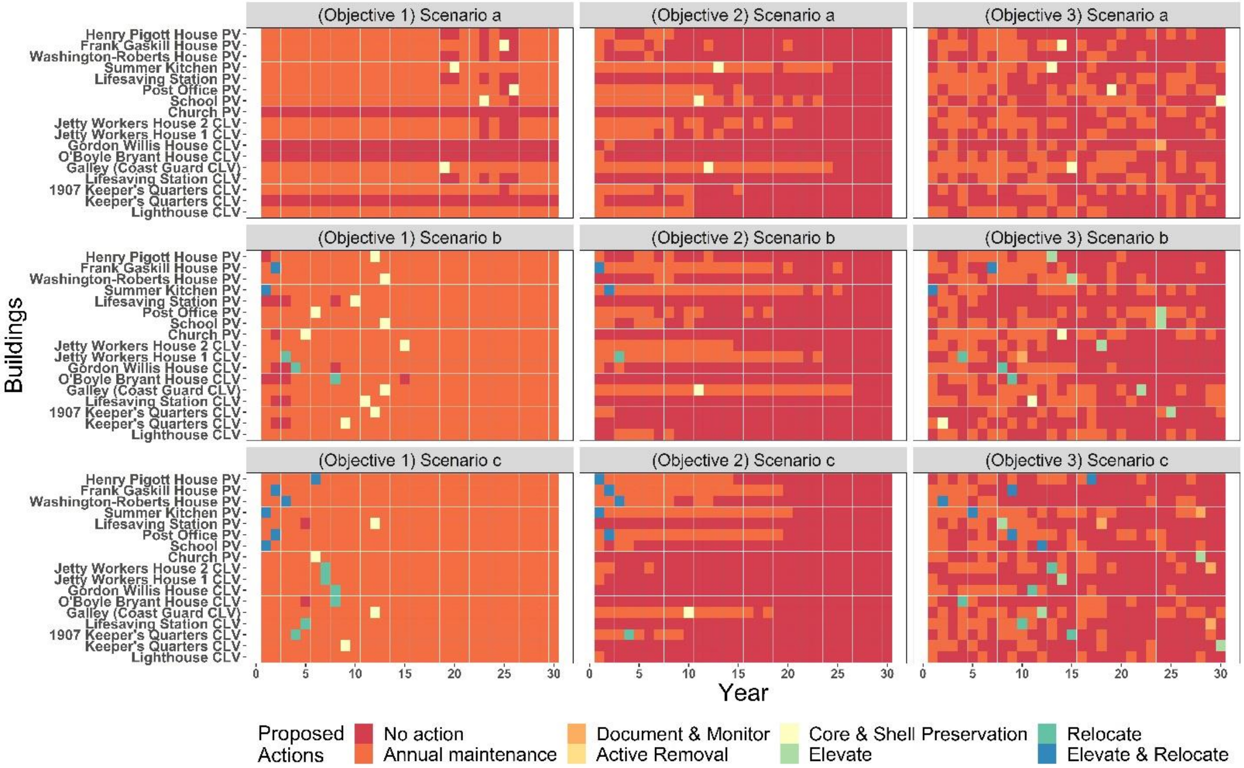

Fig. 3. Proposed adaptation plans for three management objectives (1: maximize accumulated resource value; 2: maximize cost-efficiency; 3: maximize number of buildings receiving adapation) under scenarios a ($50,000), b ($222,000), and c ($500,000)

Under objective 1 of maximizing accumulated resource value, annual maintenance is expected to be applied across the planning horizon to decelerate the decay rates, except in years when a one-time large preservation action is applied to a specific building and some of those costs are “borrowed” by applying no action to other building(s). For instance, given a relatively low budget allocation in scenario a ($50,000 annual allocation), the annual maintenance was dominantly proposed for three-quarters of the building set but still has discretional alternatives (i.e., core & shell preservation) for a small portion of the historic buildings. Once the annual budget allocation is sufficient to enable climate-specific adaptation actions (i.e., relocation, and elevation and relocation), the trade-off involves more instances of not implementing annual maintenance to other buildings.

Notably, core and shell preservation and adaptation actions can only be utilized one-time for each building throughout the 30-year planning horizon based on the guidance and practices of historic preservation determined by earlier focus group discussions, meetings, and workshops by NPS managers and stakeholders (Xiao et al., 2019). Hence, implementing core and shell preservation and adaptation actions to buildings without interfering with other buildings’ eligibilities for annual maintenance is the priority for optimally allocating the budget in management objective 1. Also, the proposed adaptation actions for the constant budget allocation scenarios (scenarios a, b, and c) under objective 1 indicate that the increased funding allocation can enhance the resource value of the building set by three primary approaches: 1) upgrading the conditions of more buildings through core & shell preservation; 2) reducing the vulnerability of more buildings through climate-focused preservation actions; and 3) minimizing the trade-offs of leaving other buildings unmanaged when a large preservation action was applied to a particular historic building.

Under the objective of maximizing the cost-efficiency of historic preservation (objective 2), the proposed actions were significantly different from objective 1 for all three budget scenarios. Cost-efficiency specifies the ratio of resource value improvement to total adaptation cost; that is, instead of maximizing the total resource value of the building set using allocated funding as much as possible, objective 2 aims to maximize the improvement of resource value per unit of cost spent on historic preservation. Rather than applying annual maintenance across the 30-year planning horizon as for objective 1, the OptiPres Model proposes annual maintenance for objective 2 across the early and middle phases of the planning horizon and leaves most buildings unmanaged for the last 10-year planning horizon to optimize the cost-efficiency. Under scenario b and c for objective 2, where the allocated budget is affordable for core & shell preservation and adaptation actions, the model applies climate-focused adaptation actions as the optimal cost-efficient preservation actions. Although the climate-focused adaptation actions were more costly than core and shell preservation, applying specific adaptation actions (e.g., relocation and elevation and relocation) could yield two to three times more improvement in resource values than core and shell preservation.

An intriguing finding from objective 2 is that buildings generally do not obtain any maintenance actions after the 25th year under each of the three tested budget scenarios. The primary reason for this trend is that the conditions of most buildings have decayed to either fair or poor class, which makes the annual maintenance less efficient in yielding the improvement of resource value in this time-period, as the decay rates of building conditions are higher when buildings are in fair (10%) or poor class (15%) than in good class (6%). In addition, under objective 2, about one-third of the buildings receive no action across the 30-year planning horizon in each of the three tested scenarios. The proposed "unmanaged" buildings are the ones that either have relatively low historical values or have relatively high costs of annual maintenance, making them less cost-efficient to be managed than other buildings.

Objective 3, which maximizes the number of buildings receiving climate-focused adaptation actions, focuses on prioritizing treatments that relocate, elevate, or relocate and elevate buildings with the highest risks of unanticipated climatic impacts to less vulnerable locations[1]. Under the industry standard scenario (scenario b), 70% of the historic buildings were expected to receive climate-focused adaptation actions. Specifically, the findings demonstrate the optimal plan is to relocate (and elevate) the buildings to the relocation zones if the funding is sufficient to minimize the buildings' exposure and sensitivity to climate risks; applying elevation action to the buildings is next priority, as elevation only reduces building's sensitivity to climate risks. Additionally, the findings demonstrate that for all scenarios except scenario d, the document and monitor adaptation action is selected for at least one and at most four buildings. This type of active, management-induced transformation of the historic landscape occurs as early as year 7, but typically isn't considered optimal until the last quarter of the 30-year planning horizon. Document and monitor encompass a small set of historic buildings whose conditions have deteriorated to the "poor" class. Simultaneously, this preservation action can document new conditions for the "poor" class buildings extensively. The refinement of document and monitor on these historic buildings

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[1] Since the allocated funding in scenario a is not sufficient for any building to receive climate-focused adaptation actions, the objective 3 was adjusted to maximizing number of buildings receiving high cost adaptation actions.

serves as an alternative action rather than applying annual maintenance when the objective is not maximizing the accumulated resource value, which involves compromises of degraded visitor use, third-party use, operational use .

When more funding is available in objective 3, such as scenario c and scenario e, more buildings are eligible for climate-focused adaptation actions. Specifically, more than 70% of the historic buildings are expected to be relocated (and elevated) under these two scenarios, minimizing the vulnerability to climate risks for the majority of the building set. Notably, annual maintenance is not the dominant action under objective 3; instead, the OptiPres Model saves the cost from "no action" to allocate funding to apply climate-focused adaptation actions to more buildings. These trade-offs of applying costly adaptation actions but making more buildings ineligible to receive annual maintenance were manifested in scenarios b and c.

3.3 The effectiveness of budget allocation on different management objectives of historic preservation

The effectiveness of allocated funds under various budgetary scenarios was measured by the ratio of used to allocated budget for each of three management objectives of historic preservation at CALO (Figure 4). Objective 1 intends to maximize the accumulated resource value; thereby, allocating funds is proportionally delegated to recurring annual maintenance and adaptation actions optimally to maximize the accumulated resource value at the end of the 30-year planning horizon. In scenario a, $50,000 is insufficient to apply annual maintenance to all of the buildings; instead, the allocated budget filled accordingly with scattered annual maintenance actions, with about 98% of the budget allocated. In scenario b and c, the curve of adaptation costs levels off, indicating an equilibrium state of annual maintenance after more costly actions are implemented to buildings; this ongoing annual maintenance on buildings supports the maximization of accumulated resource value. However, the amount of funding used was less than 50% of allocated budget in scenario b, and even lower in scenario c.

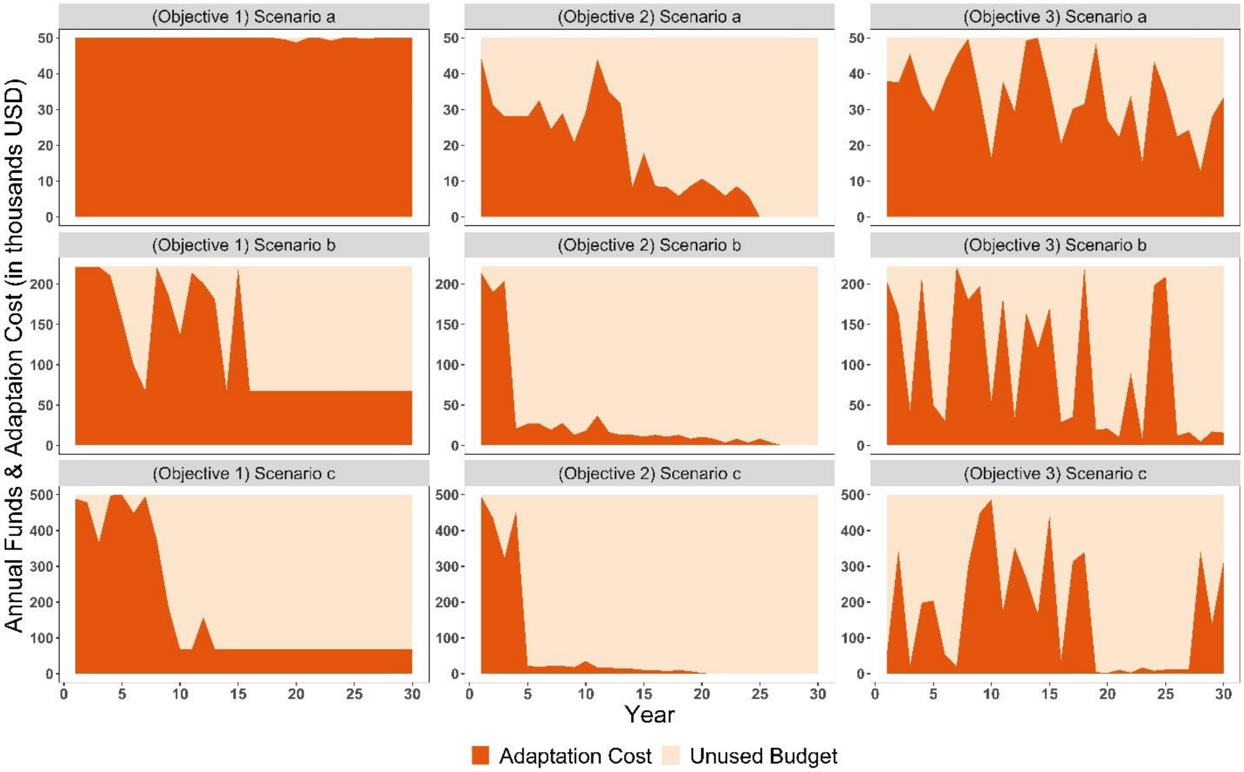

Fig. 4. Total adaptation cost and allocated budget by three management objectives (1: maximize accumulated resource value; 2: maximize cost-efficiency; 3: maximize number of buildings receiving adapation) under scearios a ($50,000), b ($222,000), and c ($500,000)

Objective 2 prioritizes cost-efficiency as its primary consideration. Therefore, the optimized algorithm intentionally saves unnecessary expenses to improve the performance of cost-efficiency. Under scenario a, preservation actions (annual maintenance or core & shell preservation) are implemented in the early phase of the 30-year planning horizon, but less than half of the allocated funding was used. The percentage of used funding was even lower in scenario b & c, approximately 20% of allocated budgets.

Objective 3 intends to maximize adaptation of buildings that are vulnerable to the impacts of climate change. With the threat of climatic impacts, optimal actions reduce the risks of damage (i.e., minimize vulnerability). Hence, relocate actions are the prioritized action when balancing trade-offs under limited budget scenarios. The keen-edged peaks of used funding under the three tested budget scenarios display the preferred adaptation of relocate or elevate and relocation, which are comparatively costly. Although the accumulative effectiveness of budget allocations by objective 3 and objective 1 are somewhat identical, the temporal patterns of funding usage for preservation actions were different between these two objectives, especially under scenarios b & c. The peaks of used funding scattered across the planning horizon in objective 3 were driven by maximizing the number of climate-focused adaptation actions applied to the historic buildings, whereas the peaks of used funding concentrated in the early or middle planning phases in objective 1 were driven by maximizing the accumulative resource value of the historic buildings.

4. Discussion

This study addresses a fundamental gap in addressing historic preservation under climate change by integrating multiple management objectives to the OptiPres Model. Climate adaptation planning for cultural resources involves complex dynamics to quantify and evaluate the trade-offs of preservation decisions under different management objectives. By extending the OptiPres Model from the CALO pilot study (Xiao et al., 2019), the present study demonstrates that the OptiPres Model can serve as a decision support framework to explore different management goals for historic preservation. These management objectives included: maximizing the accumulated resource value after assessing the trade-offs between improving historical value, improving building condition, improving use potential, and reducing vulnerability to climate risks (objective 1); maximizing the cost-efficiencies among different budget scenarios to better inform realistic scenarios of funding shortages (objective 2); and maximizing the application of climate-focused adaptation actions to minimize the vulnerability of buildings with high risks of exposure and sensitivity to storm-related flooding and erosion, as well as longer-term inundation from sea level rise (objective 3). These advancements to the current OptiPres Model provide important insights for managers seeking to apply optimal adaptation treatments under budgetary constraints that meet diverse management goals during mid-range climate adaptation planning efforts. Specifically, this multi-objective, historical-economic optimization study enhances the transparency of climate adaptation planning for cultural resources by evaluating the spatial and temporal patterns of alternative plans.

Our study results indicate that a traditional, single-objective approach for historic preservation may yield inefficient investments in adaptation actions as well as insufficient mitigation of climate risks to historic buildings at CALO. Driven by the objective of maximizing the accumulated resource value across the 30-planning horizon (objective 1), the OptiPres Model proposes the strategic adaptation actions while maximizes the implementation of annual maintenance. Yet, this objective does not necessarily consider the cost-benefit for resource value or the overall vulnerability of the buildings to climatic impacts across the planning horizon. These compromises are manifested by the uncertain budget scenarios ranging from $0 to $500,000 annual allocations, where the resource value increases with each additional annual allocated budget but the cost-efficiency peaks at $50,000 annual allocation and declines or remains steadily with increases in funding allocations. Consequently, developing a historical-economic optimization analytic approach that integrates multiple management objectives can enhance managers' ability to (a) integrate adaptive efforts with historic preservation stewardship and (b) set the broad objective of climate change-cultural resource integration outlined in Goal 3 of the NPS's Cultural Resources Climate Change Strategy (Rockman et al., 2016).

By comparing the optimal historic preservation plans among nine scenarios (three specific budget scenarios among three management objectives), our results indicate that, generally, each optimal historic preservation plan has a trade-off with, at the minimum, one of the other considerations. To be specific, maximizing the accumulated resource value (objective 1) involves trade-offs that could apply costly adaptation actions with relatively low marginal gains in buildings' resource values but reduce their vulnerability to potential climatic impacts. As climate uncertainties, such as stochastic storm events, fluctuate during the planning horizon, the buildings in CALO's historic districts are likely more at risk to destruction or deterioration than accounted for in this study, making costly adaptation actions potentially more imperative than captured when singularly considering maximizing historic preservation as the management objective.

Alternatively, the objective of prioritizing cost-efficiencies (objective 2) by expending the least costs with augmented quantification of marginal gain in preservation outcomes involves different types of trade-offs. Annual maintenance is predominantly implemented prior to the last 10-year planning phase due to the fact that most buildings' conditions have decayed to such an extent (fair or poor class) that annual maintenance becomes less efficient in yielding the improvement of resource value. When allocated budgets make climate-focused adaptation actions (elevate, relocate, relocate and elevate) affordable, they are promptly proposed as priorities early in the 30-year planning horizon, enabling the one-time marginal gain in a building's condition while downgrading the risk index of exposure, sensitivity, or both.

As many of CALO's historic buildings are exceptionally vulnerable to climate impacts, scenarios in which only the annual maintenance and core and shell preservation actions are applied could be interpreted as making budgetary allocations in vain. Objective 3 addresses this concern by maximizing the number of historic buildings receiving climate-focused adaptation actions. By relocating lower cost buildings to less vulnerable zones in the early phase of the planning cycle and elevating costly buildings in the middle or later planning horizon, this objective minimizes the risks to climate uncertainties and "best" prepares the districts for stochastic storm events. Moreover, different than the results in original singular objective application OptiPres Model efforts (Xiao et al., 2019), the objective to minimize vulnerability results in document and monitor being occasionally selected as an adaptation action for a small set of historical buildings that deteriorated to poor conditions in the middle and late planning horizon rather than applying annual maintenance consecutively. This type of adaptive planning approach provides extensive documentation of historic buildings and reduces the potentials for human injury due to deteriorated conditions of historic buildings via fencing. Importantly, this action demonstrates that preparing for loss (Barnett, Tschakert, Head, & Adger, 2016; Seekamp & Jo, 2020) can be an optimal adaptation strategy.

Our study results also suggest that the OptiPres Model can be adapted to include a range of desired management objectives, such as the mid-range preservation goals, the status of the historic resources, and the allocated funds of a specific park. This flexibility demonstrates the transferability of the OptiPres Model to other coastal settings stewarding historic buildings. Rather than setting a single historic preservation management objective (objective 1), the multi-objective OptiPres Model integrates rational and practical considerations to prioritize historic buildings vulnerable to climatic impacts by setting appropriate constraints, which can be tailored to the realistic circumstances found at diverse coastal settings.

Similarly, the objective of maximizing the number of historic buildings receiving climate-focused adaptation actions (objective 3) was also defined by the nature of the high vulnerability of the tested building set at CALO, with the same prerequisite of resource value with objective 2. The modified objective minimizes the climate risks while maintaining the resource value to an acceptable level, rather than randomly proposing climate-focused adaptation actions without considering their impacts on historical integrity loss. These prerequisites and thresholds can be modified based on the preservation needs of other coastal settings, ideally using processes that institute manager and stakeholder collaboration. By developing this historical-economic optimization approach, the OptiPres Model can provide desirable, realistic, and operational management information to assist with the efforts to implement NPS's policy on stewardship of cultural resources Memorandum 14-02, which states that "management decisions should be directed toward resources that are 'both significant and most at risk" (NPS, 2014).

5. Conclusion

The historical-economic optimization updates of the OptiPres Model integrate multiple management objectives, evaluate the trade-offs of adaptation actions by historical, economic, and climate-related factors systematically, and suggest desirable actions that satisfy the practical and realistic preservation needs of coastal parks by quantitative metrics. The OptiPres Model provides insight to prioritize adaptation plans that enhance the historical significance and use potential, invest the limited funds to achieve the highest efficiency of cost-benefit for resource value by appropriate adaptation actions, and minimize the risks to climate extremes and uncertainties for historic buildings. These optimal adaptation plans can inform decision makers and heritage managers about climate adaptation actions that meet different heritage preservation goals regarding the specific historic resources, funding constraints, and vulnerabilities of coastal settings. The historical-economic optimization approach of climate adaption planning developed in this study demonstrates the OptiPres Model can be transferred to other coastal settings by modifying optimization objectives. Additionally, this paper documents the framing process, data needs, and research efforts of the OptiPres Model, demonstrating its flexibity in informing historic preservation and adaptation planning at site-specific, regional, national, and global scales. Yet, more research is needed to incorporate stochastic storm events and integrate a multi-stage adaptive optimization approach to enhance the robustness of modeling efforts and better guide climate adaptation planning of cultural resources in coastal parks and protected areas.

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