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Unveiling Climate-Adaptive World Heritage Management Strategies: The Netherlands as a Case Study

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Abstract: The Netherlands has established climate-adaptive strategies shaped by its long history of water-related climate events, such as the floods in 1421 and 1953. UNESCO World Heritage (WH) properties in The Netherlands reflect centuries of human intervention and natural processes to adapt and mitigate climate challenges, including spatial design and hydraulic engineering. The Dutch Climate Research Initiative also highlights cultural heritage as an integral component in preparing for the 2026 National Climate Adaptation Strategy. This article aims to unveil climate-adaptive World Heritage management strategies (CAWHMSs), using WH properties in The Netherlands as a case study. It collects textual data from Statements of Outstanding Universal Value, State of Conservation Reports by the State Parties and management plans. Through qualitative coding and keywords aggregation of the documents, the visualised results of a Sankey diagram and two semantic networks confirmed two CAWHMSs: conservation and developing WH properties as collaborative knowledge hubs. Conservation supports regulating urban climate and sustainable water management. As collaborative knowledge hubs, multidisciplinary sectors explore opportunities to align WH properties with broader sustainable development initiatives. They also deepen younger generations' awareness of cultural and natural significance relevant to mitigating climate threats. The results emphasise WH as a contributor to climate adaptation. Cross-sectoral stakeholders can advance holistic climate adaptation efforts using CAWHMSs.

Keywords: world heritage; climate adaptation; management strategies; The Netherlands

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1. Introduction

Climate change intensifies socio-environmental challenges worldwide, highlighting the need for multidisciplinary actions to support holistic climate adaptation efforts [1–3]. In countries with past experience in tackling climate events, World Heritage (WH) properties can reflect cultural and natural capabilities to manage socio-environmental challenges [2,3]. The Netherlands has a long history in tackling water-related crises, such as the Saint Elizabeth's flood in 1421 and the 1953 North Sea Flood [4]. Subsequently, it has established climate-adaptive strategies, including spatial design and hydraulic engineering, to improve flood resilience capacity [4]. For example, the WH properties Beemster Polder and Schokland and Surroundings exemplify how water management and land reclamation considered water as a landscape design principle [5,6]. The interventions by preceding inhabitants shaped these cultural landscapes, demonstrating strategic adaptation to water-related challenges [3]. The safeguarding of WH properties also ensures the continuity of knowledge-building, where traditional knowledge embedded in human–environment interaction continues to inform contemporary water management and spatial planning in The Netherlands [4,7].

However, The Netherlands is experiencing worsening climate effects. Between 1901 and 2020, it experienced an average surface temperature increase of 2.3 °C [8]. The 2018 and 2019 drought in northwestern Europe caused freshwater shortages in southeastern parts of The Netherlands [9]. There was also a 21% rise in annual precipitation between 1906 and 2020 [8]. Intensified winter rainfalls in 2023 and 2024 thus led to excessive water levels, surpassing municipal discharge capacities [10]. With climate challenges intensifying, national initiatives emphasise the integration of cultural and natural heritage to support climate adaptation efforts. The National Delta Programme highlights authorities' commitment to safeguarding the UNESCO WH property, the Wadden Sea, to develop a climate-robust and dynamic environment for communities [10]. Furthermore, as part of the upcoming 2026 National Climate Adaptation Strategy (NAS), the Dutch Climate Research Initiative (KIN) developed the 'Make-atons' approach to explore multidisciplinary measures for climate adaptation [11]. Measures are being developed for five subjects: cultural heritage, flooding, health, waterways and infrastructure [11]. The 'Make-atons' approach promotes synergy between sectors and integrates cultural heritage into the 2026 NAS [11,12]. On an international scale, this heightens the relevance of cultural heritage for building climate-robust living environments [13,14].

The Netherlands has made significant progress in correlating heritage with climate adaptation efforts. Whilst this recognition is a crucial step forward, there remains fragmented information available online and limited structured insights on how the heritage sector supports climate adaptation in a real-world context. Earlier theoretical concepts by Fatorić and Egberts revealed heritage benefits which support climate adaptation efforts, such as providing traditional knowledge and contributing to a sustainable economy [7]. Furthermore, Fatorić and Daly proposed a 'climate-smart cultural heritage' approach to reduce heritage susceptibility to climate impacts, while optimising heritage benefits to improve societal adaptive capacity against climate threats [15]. Expanding upon these concepts, this article aims to identify climate-adaptive World Heritage management strategies (CAWHMSs), using WH properties in The Netherlands as a case study. They uphold cultural and natural significance recognised under the operational guidelines of the 1972 UNESCO World Heritage Convention, offering insights into how human intervention and natural processes tackled past climate effects worldwide [16,17]. Fundamentally, cultural and natural landscapes demonstrate how human intervention and natural processes contribute to addressing climate challenges [2,3]. Ultimately, this article provides a structured perspective on how WH properties support climate adaptation efforts. It thus advocates for further integration of WH properties as valuable contributors, benefiting the development of climate-robust living environments [14,17].

2. Materials and Methods

This article selected 12 out of the 13 WH properties in The Netherlands as a case study (see Figure 1). It excluded the Historic Area of Willemstad, Inner City and Harbour, Curaçao located in the Caribbean Sea, due to differing climate and subsequent management strategies compared to those in The Netherlands.

Figure 1. Location of 12 WH properties in The Netherlands. Map adapted from Erfgoedatlas by the Cultural Heritage Agency of The Netherlands (RCE). Copyright: CC BY 4.0. Available online: https://rce.webgis.nl/nl/map/erfgoedatlas?snapshot=01893981-1bb2-480e-8e6b-927aceea7334 (accessed on 28 March 2025). Modifications include the addition of a legend and the sequential numbering of WH properties, organised chronologically based on their year of inscription.

Figure 2 illustrates the research workflow. It encompasses data collection, data preparation, textual data coding, thematic coding and categorisation, quantification, visualisation and data analysis.

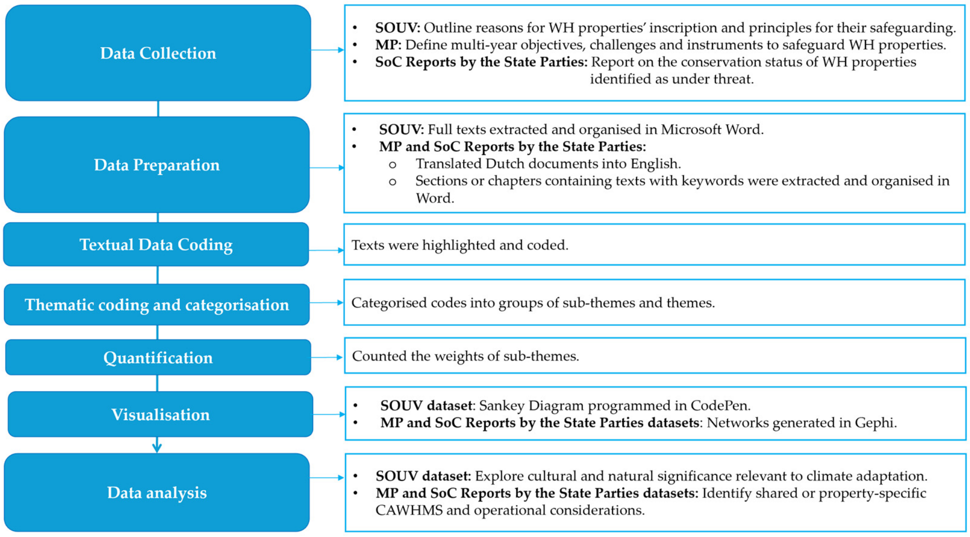

Figure 2. Research methodology flowchart.

2.1. Data Collection

The textual data were collected from three sets of official documents publicly available on the UNESCO World Heritage Convention website for The Netherlands [18]. They are, respectively, as follows: (1) the Statement of Outstanding Universal Value (SOUV), (2) management plans (MPs) and (3) State of Conservation (SoC) Reports by the State Parties. First, the SOUVs outline the justifications for the WH properties' inscriptions and cultural and natural significance of outstanding universal value (OUV) [19,20]. They are the baseline for State Parties to develop MP, conduct Reactive Monitoring and prepare SoC reports [19,20]. Secondly, the MPs establish multi-year objectives. They address challenges and detail resource allocation and management instruments to safeguard the OUV, authenticity and integrity of WH properties [20]. Thirdly, the SoC Reports by the State Parties stem from the Reactive Monitoring process [21]. This process involves reporting to the World Heritage Committee on the conservation status of WH properties under threat [22]. This is different from Periodic Reporting, which is a self-reporting system by the State Party every six years [23]. Therefore, not all WH properties have SoC reports. Reactive Monitoring only considers the following WH properties [22]:

- WH properties on the List of World Heritage in Danger;
- WH properties that require conservation reports or monitoring tasks requested by the World Heritage Committee in previous sessions;
- WH properties under threat since the previous World Heritage Committee session and requiring immediate actions beyond consultations;
- WH properties for which the World Heritage Committee requested follow-up after being inscribed on the World Heritage List.

This research first reviewed the documentation on 12 WH properties' SOUVs to explore natural and cultural significance potentially relevant to climate change and adaptation (see Appendix A for the document set). It then reviewed the MPs and SoC Reports by the State Parties to identify relevant CAWHMSs (see Appendices B and C for document sets). The MP for D.F. Wouda Steam Pumping Station was excluded from the data analysis because it was not publicly accessible, and a new MP is currently being developed [24].

2.2. Data Preparation and Processing

Texts from the three document sets were extracted and organised in Microsoft Word for textual data coding. This research used inductive coding and did not generate predefined code schemes for the document sets [25]. This data-driven method followed the principle of grounded theory, conceptualising findings based on coded texts [26]. For this research, the method supported identifying shared and property-specific CAWHMSs among WH properties, which emerged from the data coding [25,26].

No keywords were prepared in advance when reviewing the 12 SOUVs. This supported identifying and inducing human interventions and natural processes relevant to mitigating environmental challenges that emerged during the coding.

For the MPs and SoC Reports by the State Parties, the original documents in Dutch were translated into English using Google Translate or Microsoft Translator between December 2024 and February 2025 before coding. A list of keywords relevant to climate change and adaptation was prepared as the coding guideline, since climate was not the sole subject in the two document sets (see Table 1 for keywords). When a keyword was identified in the documents, the corresponding sections or chapters were extracted for coding. This article reviewed all five SoC Reports by the State Parties, while only the Wadden Sea and Dutch Water Defence Lines fell under its scope.

Table 1. Keywords and their implications for extracting texts from MPs and SoC Reports by the State Parties.

Keyword	Implication	Source
Act; Decree; Legislation; Legislative	Legal provisions at provincial, national and international levels about climate change, environmental and spatial planning, nature protection, sustainable development and/or heritage protection.	[20]
Climate; Climate change	Climate and environmental changes may impose risks on the conservation status of WH properties.	[27]
Conservation	Efforts to safeguard WH properties from climate-driven and environmental threats.	[20]
Dry; Drought	A climate impact that leads to water scarcity.	[10]
Environment; Environmental	Environmental resilience affected due to climate impacts and/or human activities. For example, biodiversity loss is a result of rising temperatures.	[28]
Flood; Flooding; High water level	A climate impact that leads to water management challenges.	[10]
Framework	Provincial, national and transnational plans for climate adaptation and sustainable development.	[10]
Heat; Heat stress	A type of climate impact due to high temperatures.	[10]
Human activities	Anthropogenic factors that worsen climate impacts such as emitting greenhouse gas (GHG).	[29]
Research; Review; Assess; Monitor	Studies, assessments and monitoring efforts to identify climatic challenges and suggest measures for WH properties.	[29]
Restoration	To repair or recover damages caused by climate and environmental impacts on WH properties.	[14]
Sustainability; Sustainable development	Environmental sustainability and inclusive socio-economic development contribute to climate adaptation and building sustainable living environments. Within this context, texts may suggest integrating WH properties and their OUV into these efforts.	[14]

After the texts were organised in Microsoft Word, they were highlighted and coded. The codes and reference texts from each document set were then exported to Microsoft

Excel as document-specific datasets for qualitative clustering analysis, categorising the codes into groups of subthemes. The occurrence frequency of the finalised subthemes was counted, allowing the later visualisation of their numerical patterns.

2.3. Visualisation

The SOUV dataset was programmed in CodePen (CodePen is an online platform to create front-end code. The website available at https://codepen.io/ (accessed on 13 April 2025)) was used to generate a Sankey diagram to illustrate its hierarchical relationships [30]. The diagram organised codes, subthemes and themes as nodes distributed across columns [30]. The nodes were assigned colours corresponding to the flows they were connected to [30]. The flows were represented by proportional band widths in terms of the nodes' frequency of mentioning [30]. This enabled a comparison of the predominant and least mentioned nodes across the 12 WH properties.

Gephi is an open-source network visualisation and analysis software system. The website available at https://gephi.org/ (accessed on 13 April 2025) was used to generate two separate networks for the MP and SoC Reports by the State Parties datasets. The datasets were imported into Gephi as semantic networks with nodes and edges [31]. Each source node signified a WH property. The target nodes represented the themes and subthemes and their codes. The weighted edges represented the strengths of the connections between the source and target nodes. These connections reflected the occurrence frequencies of the themes or subthemes associated with a WH property, based on its referenced MP or SoC report. The edges were transformed into undirected edges to illustrate the co-occurrence and mutual links of the themes shared among the WH properties. The visualisation combined graph layout algorithms and manual adjustments to achieve optimal readability. The Fruchterman–Reingold algorithm was used to position the nodes, followed by automatic and manual refinements to avoid overlapping. The Fruchterman–Reingold algorithm distributes nodes evenly, which is ideal for producing clear layouts for preliminary-stage visualisation [32]. Subsequently, the source and target nodes were adjusted manually based on their node colour and weight [31]. Target nodes with heavier weights and higher frequencies of mentioning were positioned towards the centre of the networks.

3. Results

3.1. Hierarchical Codes for SOUVs, MPs and SoC Reports by State Parties

3.1.1. Codes Developed from the SOUV Dataset

A total of 18 codes were generated from the SOUV dataset. Their implications were rooted in coded reference texts (see Figure 3). The code structure provided an overview of the cultural and natural significance of the 12 WH properties. It also encompassed a structured exploration of the connection between the WH properties and climate challenges. The codes were categorised into four subthemes: 'Built structures', 'Cultural landscapes', 'Resilience factors' and 'Environmental components'. These subthemes were grouped into three main themes: 'Cultural terms', 'Climate terms' and 'Natural terms'. In particular, five codes under 'Environmental components' belonged to both 'Natural terms' and 'Climate terms'. Their implications suggest upholding ecological stability to regulate climate effects. Moreover, all the main themes are directly and/or indirectly connected to 'Resilience factors', illustrated by dashed and solid lines. They imply that human mechanisms and natural processes facilitate 'Adaptation' and sustain 'Persistence' in response to societal and environmental challenges, such as 'Climate threats'. This relationship also supports the continued recognition, transfer and application of cultural and natural practices across generations and regions, thereby strengthening resilience over time.

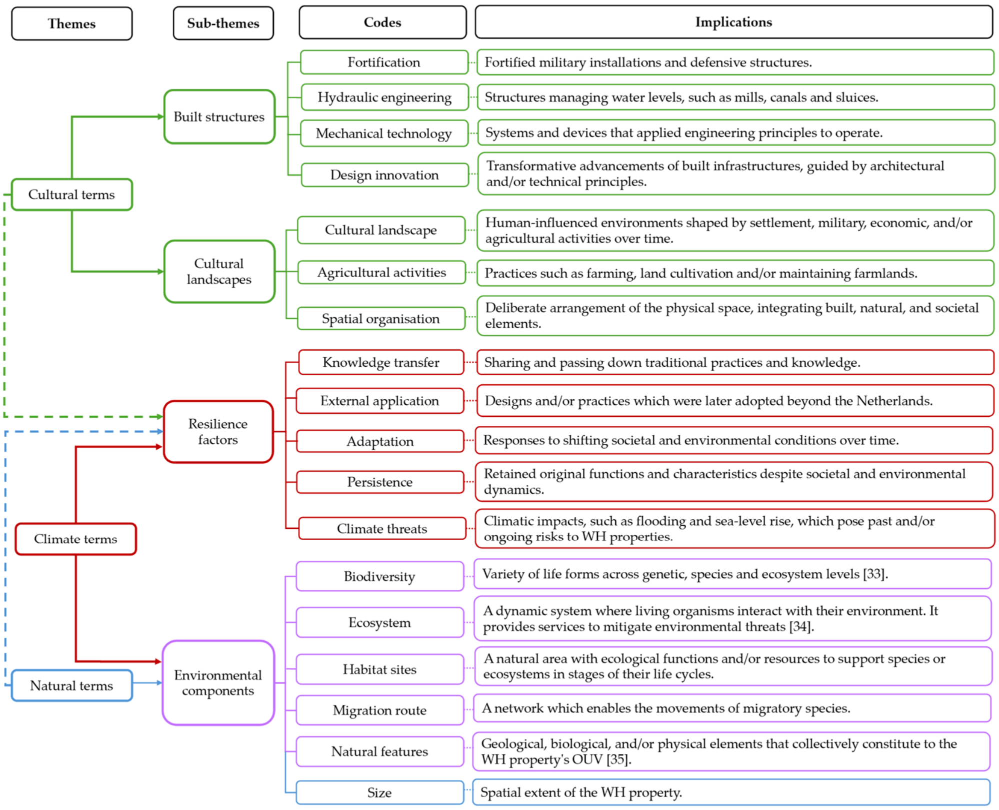

Figure 3. Codes developed from the SOUV dataset. Among the codes, three 'Environmental components' codes drew their implications from the official glossary provided by the UNESCO World Heritage Convention [33–35]. The remaining 15 codes' implications were generated based on the contents of reference texts.

3.1.2. Codes Developed from the MPs and SoC Reports by the State Parties

The datasets of the MPs and SoC Reports by the State Parties shared a similar coding process. Both datasets have two overarching themes: 'Strategies' and 'Operational considerations'. In the MP dataset, the theme 'Strategies' was subdivided into 'Past', 'Present' and 'Future' (see Figure 4). The subdivision captured the essence of MPs' multi-year objectives. 'Past' refers to foundational management strategies that continue to inform and shape contemporary management practices. 'Present' implies ongoing measures to mitigate identified climate-related challenges. Furthermore, 'Future' proposes possible practices to ensure a WH property's adaptability to emerging climate threats. On the other hand, SoC Reports by the State Parties only contained the subtheme 'Present' under 'Strategies' because the dataset focused on addressing immediate threats and reporting on subsequent actions and plans by stakeholders (see Figure 5).

The theme 'Operational considerations' was divided into 'Challenge' and 'Management consideration' for both datasets. A 'Challenge' could have influential consequences if not strategically monitored or addressed. 'Management consideration' refers to aspects of management actions that need further attention, serving as alerts or reminders to stakeholders. 'Operational considerations' concern external factors, such as 'Climate change' and 'Soil subsidence'. They also suggest internal factors within the heritage sector, such as 'Research gap', which implies underexplored aspects relevant to climate and environmental sustainability and requires further investigation. Some 'Operational considerations' encompass both external and internal factors. For example, 'Limited heritage inclusion' as a 'Challenge' implies a lack of heritage-inclusive decision-making in climate adaptation plans.

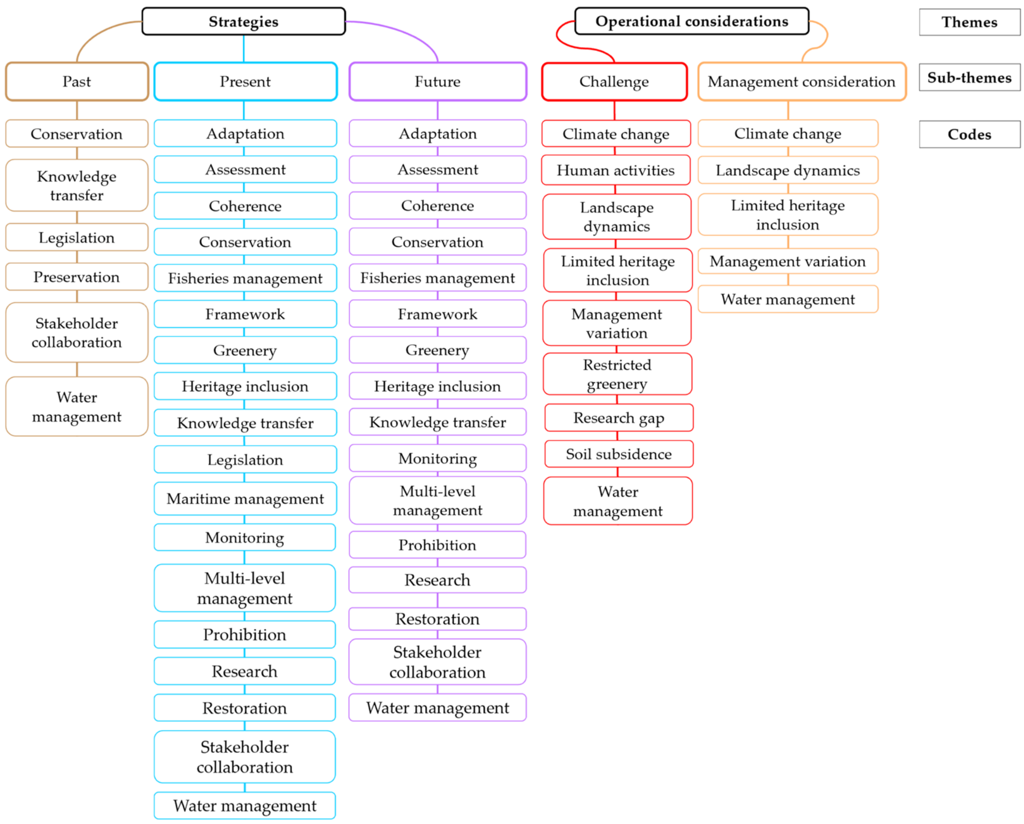

Figure 4. Codes developed from the MP dataset.

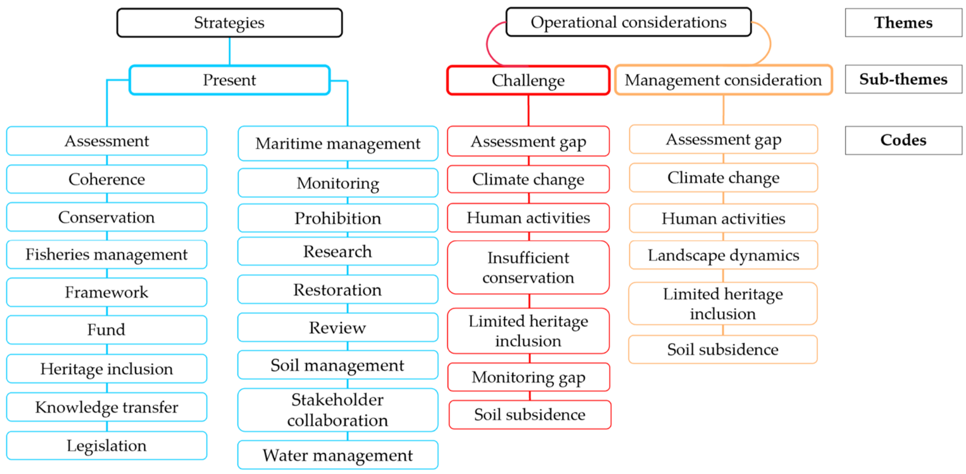

Figure 5. Codes developed from the SoC Reports by State Parties dataset.

3.2. WH Properties and Their Relevance to Climate Adaptation in SOUV Dataset

The SOUV dataset outlines the cultural and natural significance of WH properties, which can relate to climate adaptation (see Figure 6). 'Cultural terms' is predominant and only applies to cultural WH properties (n = 203). In particular, 'Cultural landscapes' (n = 109) underscores the consideration of landscape elements, such as water, in 'Spatial organisation' (n = 54) by preceding inhabitants. Furthermore, 'Hydraulic engineering' (n = 27) is a key traditional practice in constructing 'Built structures' (n = 94) for water level control. Collectively, deliberate spatial layout and water management represent human interaction with their environment, shaping the cultural landscapes of WH properties, such as Beemster Polder, the 17th-century Canal Ring Area of Amsterdam within the

Singelgracht, Mill Network at Kinderdijk-Elshout and D.F. Wouda Steam Pumping Station (see Table 2).

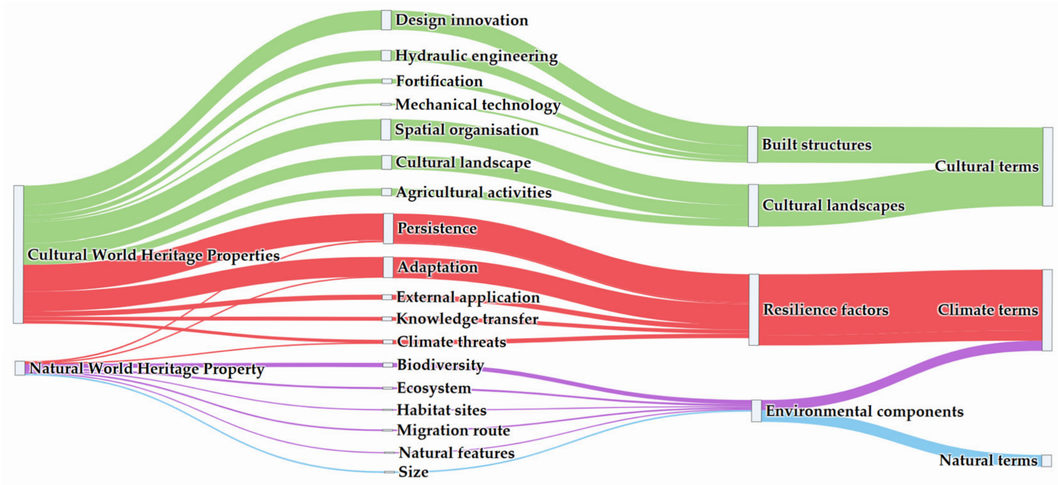

Figure 6. Sankey diagram showing the distribution of SOUV codes, subthemes and themes.

Table 2. Extracted quotes from the SOUV dataset under 'Cultural terms'.

Code	Reference Text	WH Property
Spatial organisation	*These include the pattern of waterways and roads with avenues of trees, a ring dyke and a ring canal, the historical structure and location of the villages, and the ribbon development of farms along the roads*	Beemster Polder [5]
Spatial organisation	*The network of canals in concentric arcs of a circle that forms the basis of the urban layout*	17th-century Canal Ring Area of Amsterdam within the Singelgracht [36]
Hydraulic engineering	*. . .polders, high and low-lying drainage and transport channels for superfluous polder water, embankments and dikes, 19 drainage mills, 3 pumping stations, 2 discharge sluices*	Mill Network at Kinderdijk-Elshout [37]
Hydraulic engineering	*The Wouda Pumping Station represents the apogee of Dutch hydraulic engineering*	D.F. Wouda Steam Pumping Station [38]

The Wadden Sea is the only natural WH property in The Netherlands. Hence, 'Natural terms' is the least dominant theme and only applies to it (n = 30). Most 'Environmental components' belong to both 'Natural terms' and 'Climate terms' because they require a stable climate to support the environmental integrity of the Wadden Sea (see Table 3) [39]. This includes 'Biodiversity' (n = 11), 'Ecosystem' (n = 5) and 'Migration route' (n = 4).

Table 3. Extracted quotes from Wadden Sea's SOUV under 'Natural terms' and 'Climate terms'.

Code	Reference Text	WH Property
Biodiversity	*Biodiversity on a worldwide scale is reliant on the Wadden Sea.*	Wadden Sea [40]
Ecosystem	*The Wadden Sea includes some of the last remaining natural large-scale intertidal ecosystems.*	Wadden Sea [40]
Migration route	*The property is the essential stopover that enables the functioning of the East Atlantic and African-Eurasian migratory flyways.*	Wadden Sea [40]

The second most common theme, 'Climate terms', is the only theme that applies to both cultural and natural WH properties (n = 183) (see Table 4). The Dutch expertise in water and landscape management was influential, some of which are in combating 'Climate threats' (n = 9), including Schokland and Surroundings and D.F. Wouda Steam Pumping Station. Notably, D.F. Wouda Steam Pumping Station reflects the Dutch expertise in hydraulic engineering and has contributed to global standards for centuries, as highlighted by 'External application' (n = 13). In addition, most WH properties underwent 'Adaptation' (n = 52) to incorporate changing socio-environmental conditions. Their 'Persistence' (n = 73) thus reflects their capacity to uphold their defining cultural and natural significance over time.

Table 4. Extracted quotes from the SOUV dataset under 'Climate terms'.

Code	Reference Text	WH Property
External application	*. . .provided the models and set the standards for the whole world for centuries*	D.F. Wouda Steam Pumping Station [39]
Climate threats	*The area provides exceptional evidence of a cultural tradition of island-dwellers threatened by the water and ultimately evacuated*	Schokland and Surroundings [6]
Adaptation	*. . .the innovative responses of Roman military engineers to the challenges posed by the dynamic landscape of a lowland river, as witnessed by the positioning and design of the military installations and by water management works.*	Frontiers of the Roman Empire—The Lower German Limes [41]
Adaptation	*. . .provide an invaluable record of the ongoing dynamic adaptation of coastal environments to global change*	Wadden Sea [40]
Persistence	*. . .survives in its entirety, with its old embankments and historic facade alignments*	17th-century Canal Ring Area of Amsterdam within the Singelgracht [37]

3.3. Climate-Adaptive WH Management Strategies in MPs

Through visualising the MP dataset, a network of both shared and property-specific 'Strategies' and 'Operational considerations' among the WH properties was identified (see Figure 7). It reveals that 'Climate change' has been identified as a 'Challenge' in most MPs, except for Van Nellefabriek and Schokland and Surroundings. Furthermore, the theme 'Strategies' accounts for 64.04% of all the nodes, with 'Present' strategies dominating (20.22%), followed by 'Future' strategies (17.98%). The Wadden Sea displays a series of distinct 'Strategies' and 'Operational considerations' seldom mentioned in cultural WH properties, including 'Fisheries management' and 'Maritime management'.

Several 'Strategies' appear across 'Past', 'Present' and 'Future', indicating their recurrence and relevance throughout different timeframes. Hence, some 'Present' strategies are not standalone concepts. Instead, they stem from 'Past' strategies (6.74%) and continue to be implemented as 'Future' strategies. These include 'Conservation', 'Water management' and 'Knowledge transfer'. For example, the Wadden Sea revealed enduring efforts supporting 'Knowledge transfer' (see Table 5). In the past, this helped to build a network of scientists to safeguard the Wadden Sea collectively. It progressed to support multidisciplinary collaboration on sharing climate adaptation practices. This suggests that some 'Present' strategies are anchored in 'Past' strategies. Their enduring effectiveness remains relevant for future applications as 'Future' strategies.

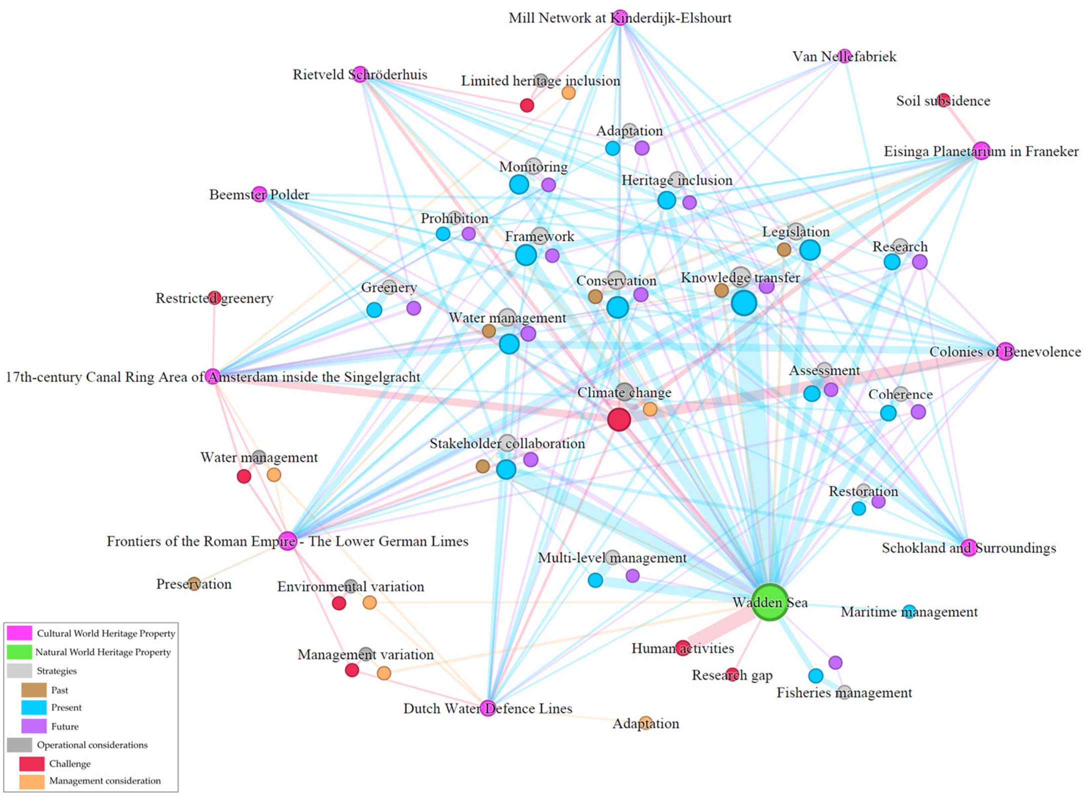

Figure 7. The MP network illustrates shared and property-specific 'Strategies' and 'Operational considerations' among WH properties.

Table 5. Extracted quotes from the *Wadden Sea*'s MP on 'Knowledge transfer' as 'Strategies'.

Code	Reference Text	WH Property
Knowledge transfer (Past strategy)	*A milestone to collect and make this knowledge available started with the Wadden Sea network of engaged scientists in the 1960s.*	Wadden Sea [42] (p. 33)
Knowledge transfer (Present strategy)	*Stimulate and maintain trilateral knowledge exchange and interdisciplinary discussions about, among others best practices for adapting to climate change.*	Wadden Sea [42] (p. 25)
Knowledge transfer (Future strategy)	*Putting the Wadden Sea on the global scene also offers new pathways for international cooperation, mutual learning, and developing solutions for the preservation of the Wadden Sea in a rapidly changing world.*	Wadden Sea [42] (p. 36)

'Conservation' suggests safeguarding the cultural and natural significance of the WH properties to support building climate-robust living environments (see Table 6). For instance, 'keur' gardens (*keurtuinen*) in canal houses and the preliminary layout of trees on the canals of the 17th-century Canal Ring Area of Amsterdam within the Singelgracht are safeguarded. This helps maintain the vegetation cover of the WH property. Furthermore, conserving hydraulic systems sustains their 'Water management' functionality in the Colonies of Benevolence and Dutch Water Defence Lines. This approach advocates the integration of past hydraulic engineering with contemporary water management, instead of constructing new hydraulic systems. Moreover, WH properties act as knowledge hubs. In Noordoostpolder's primary schools, students learn about the cultural significance of Schokland and Surroundings, such as its history in mitigating water challenges. Through education, awareness is heightened across generations about the WH property's cultural significance in relation to climate adaptation. Similarly, the Trilateral Wadden Sea Cooperation (TWSC) engages with relevant stakeholders to advocate balancing human activities with sustainable development to minimise carbon footprints, such as eco-friendly shipping, thereby fostering cross-sectoral collaboration and advancing heritage-inclusive climate adaptation efforts at the Wadden Sea.

Table 6. Extracted quotes from the MP dataset on 'Conservation', 'Water management' and 'Knowledge transfer' as 'Strategies'.

Code	Reference Text	WH Property
Conservation (Present strategy)	*For the canal ring area, proper maintenance and reinforcement of the tree structure along the canals and the 'keur gardens' behind the canal houses are part of the values to be protected.*	17th-century Canal Ring Area of Amsterdam within the Singelgracht [43] (p. 57)
Conservation (Present strategy)	*This means that preventive measures will be taken in the water system and in spatial planning. Here, too, the world heritage and the maintenance of the existing ditch pattern are the starting point and precondition.*	Beemster Polder [44] (p. 30)
Water management (Present strategy)	*. . .rehabilitation of the Westerbeeksloot barge canal includes measures to improve the period of water retention in the barge canal, so as to increase resistance against dehydration for a longer period of time.*	Colonies of Benevolence [45] (p. 189)
Water management (Future strategy)	*With the right designs, this spatial planning challenge could contribute to making the Dutch Water Defence Lines easier to understand and recognise, by converting former inundation fields into areas for water retention.*	Dutch Water Defence Lines [46] (p. 168)
Knowledge transfer (Present strategy)	*At all primary schools in Noordoostpolder, the Schokland World Heritage site forms a permanent part of cultural education, so every child in primary education knows about Schokland.*	Schokland and Surroundings [47] (p. 31)
Knowledge transfer (Present strategy)	*The TWSC together with the Wadden Sea Forum, relevant authorities, environmental NGOs, and other partners, to facilitate trilateral dialogue regarding climate- and nature-friendly shipping in the trilateral Wadden Sea.*	Wadden Sea [42] (p. 29)

Figure 7 revealed 'Limited heritage inclusion' in environmental sustainability topics in Rietveld Schröderhuis and the 17th-century Canal Ring Area of Amsterdam inside the Singelgracht. The Mill Network at Kinderdijk-Elshout also pointed out this limitation but indicated that cultural heritage properties have been progressively integrated into environmental sustainability discussions (see Table 7). On the other hand, stakeholders at Van Nellefabriek researched opportunities to adapt its building to reduce gas consumption, thereby reducing greenhouse gas (GHG) emissions and improving energy efficiency. This also aligns with the earlier indication that WH properties serve as knowledge hubs. In this context, Van Nellefabriek is the focus of research on optimising energy consumption, thereby contributing to climate adaptation efforts. In addition, Eisinga Planetarium in Franeker highlighted that OUV preservation is incorporated into the national Environmental and Planning Act. Overall, the inconsistency and 'Limited heritage inclusion' in the environmental sustainability topics hampers WH properties from collaborating with external sectors to support building climate-robust living environments.

Table 7. Extracted quotes from the MP dataset related to the inclusion of WH properties in environmental sustainability topics.

Code	Reference Text	WH Property
Limited heritage inclusion (Challenge)	*The provincial environmental vision does not specifically address the Rietveld Schröder House.*	Rietveld Schröderhuis [48] (p. 11)
Limited heritage inclusion (Management consideration)	*It is recommended that in future attention for heritage will be included as an eighth theme, or to explicitly include heritage in the living environment and materials themes.*	17th-century Canal Ring Area of Amsterdam inside the Singelgracht [43] (p. 57)
Heritage inclusion (Future strategy)	*World Heritage can provide a platform for this by developing and testing new approaches that assess the relevance of heritage for establishing sustainable development.*	Mill Network at Kinderdijk-Elshout [49] (p. 19)
Heritage inclusion (Present strategy)	*. . .the Outstanding Universal Value is considered in the design phase of the dyke-strengthening, for example around the Honswijk-Everdingen fort complexes.*	Dutch Water Defence Lines [46] (p. 168)
Research (Present strategy)	*An initial study showed that this can reduce the gas consumption of the complex by approximately 80% and the power consumption of the data centre by approximately 30%.*	Van Nellefabriek [50] (p. 14)
Heritage inclusion (Present strategy)	*The latter article is especially imperative. It literally states that in the environmental plan the importance of the preservation of the Outstanding Universal Value of World Heritage should be taken into account.*	Eisinga Planetarium in Franeker [51] (p. 73)

3.4. Climate-Adaptive WH Management Strategies in SoC Reports by State Parties

The network for SoC Reports by the State Parties dataset revealed shared 'Present' strategies between the Dutch Water Defence Lines and the Wadden Sea and property-specific 'Operational considerations' (see Figure 8).

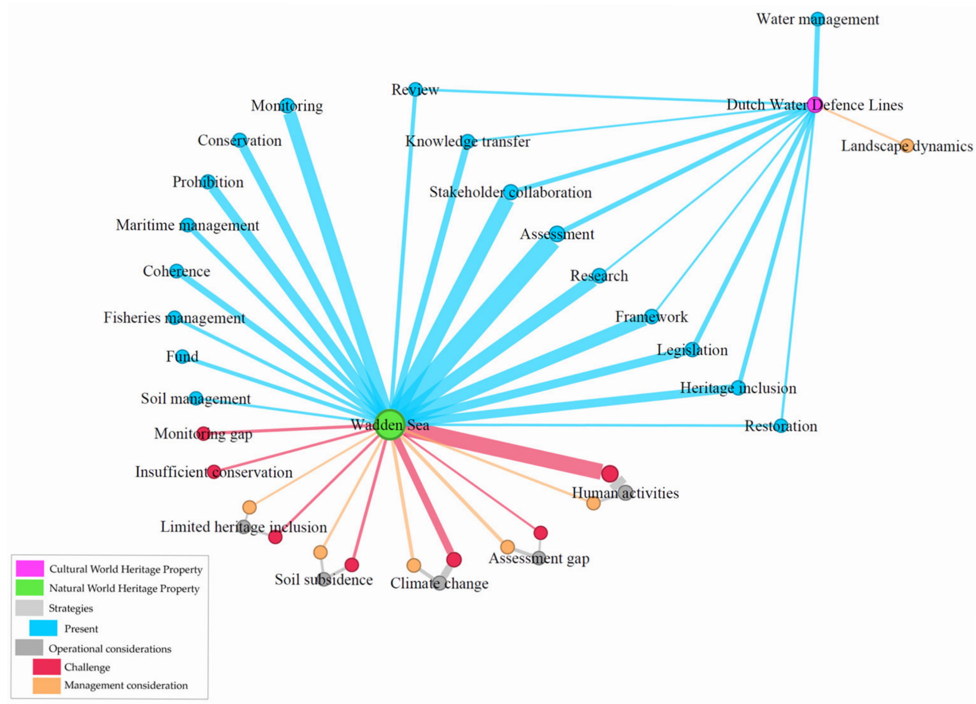

Figure 8. SoC Reports by the State Parties network. It shows shared 'Present' strategies between the Dutch Water Defence Lines and Wadden Sea and property-specific 'Operational considerations'.

The network revealed 'Strategies' again as the dominant theme (47.37%). Both the WH properties shared 'Present' strategies, such as 'Restoration' and 'Knowledge transfer' (see Table 8). Stakeholders managing the Dutch Water Defence Lines aim to restore inundation sluices for sustainable water management. This maintains the functionality of past hydraulic structures in contemporary water level regulation. Furthermore, stakeholders target restoring natural connections between the Wadden Sea and its surroundings to strengthen networks in water and land environments. The two WH properties also function as collaborative platforms for 'Knowledge transfer', a strategy that has also been emphasised in the MP dataset. The hydraulic structures at the Dutch Water Defence Lines were restored to share their history in water management with the public. In addition, the TWSC of the Wadden Sea invited students to participate in the Trilateral Youth Conference in 2022. They proposed insights and ideas, which were later formally presented to policymakers, ensuring youth perspectives played a role in collectively safeguarding the Wadden Sea.

Table 8. Extracted quotes from the SoC Reports by State Parties on shared 'Present' strategies.

Code	Reference Text	WH Property
Restoration (Present strategy)	*At Fort Vuren, the eastern inundation sluice will be restored and will become a functioning part of the water management system.*	Dutch Water Defence Lines [52] (p. 11)
Restoration (Present strategy)	*Lauwersmeer-Vierhuizergat, dyke improvement to restore the connection between the Wadden Sea and the hinterland, soften the hard edges of the mudflats, build gradual fresh-salt transitions, and develop salt marshes.*	Wadden Sea [53] (p. 44)
Knowledge transfer (Present strategy)	*. . . former battery of the Dalems sluice and the former dike warden's hut 'Hercules' are now visible and their stories can be told.*	Dutch Water Defence Lines [52] (p. 11)
Knowledge transfer (Present strategy)	*In September 2022 a first Trilateral Youth Conference was organised. Young people already engaged in the Wadden Sea came together to exchange, discuss challenges, and collect ideas that were transferred to the trilateral ministers during the 14th Trilateral Governmental Conference in 2022.*	Wadden Sea [53] (p. 41)
Assessment (Present strategy)	*To define the core qualities in further detail, the site holder has commissioned sixteen area analyses to provide greater insight into where and how the core qualities emerge. This will facilitate sustainable conservation efforts and allow the core qualities to be used as a building block for development.*	Dutch Water Defence Lines [52] (p. 2)
Research (Present strategy)	*Explore and emphasise the potential of typical Wadden Sea habitats as "blue carbon" ecosystems to contribute to natural CO_2 sequestration (e.g., saltmarshes, sediments).*	Wadden Sea [53] (p. 10)

Both WH properties share preventative measures, including 'Assessment' and 'Research' (see Table 8). They support investigating socio-environmental and climate impacts on WH properties to strengthen their adaptive capacity. They also support research efforts to leverage WH properties for climate adaptation and sustainable development initiatives. For example, stakeholders from the Wadden Sea are researching the use of salt marshes for carbon dioxide sequestration. In addition, assessment helped evaluate strengths and vulnerabilities at the Dutch Water Defence Lines to facilitate sustainable development, balancing its protection and meeting socio-environmental development needs. Ultimately, the finding reinforces the earlier indication that WH properties serve as knowledge hubs, where the topic of climate adaptation is addressed through research and assessment.

4. Discussion

4.1. The Documents and Their Relevance to Climate Adaptation

This article has confirmed the high relevance of WH properties in The Netherlands to climate adaptation. This is evident in the datasets derived from all three types of documents.

The SOUV dataset provided an overview of cultural and natural significance, some of which are fundamental in addressing climate and socio-environmental challenges. Under 'Cultural terms', 'Hydraulic engineering' and 'Spatial organisation' are traditional water and landscape management practices that characterised the cultural landscapes of several cultural WH properties. They are thus fundamental to alleviating environmental challenges whilst supporting agricultural and settlement activities. The Wadden Sea is directly relevant to climate and environmental concerns. For instance, rising temperatures can alter its species distribution, affecting its integrity [54]. Safeguarding ecological balance is thus key to strengthening ecological resilience to changing climate effects [54]. Hence, most of the Wadden Sea's SOUV codes fell under 'Climate terms' and 'Natural terms' to reflect their complementary relationship. Interestingly, the SOUV dataset revealed that the investigated cultural and natural WH properties do not share 'Cultural terms' or 'Natural terms'. They only share codes under the subtheme 'Resilience factors'. This suggests a distinction in the OUV between the WH properties, while demonstrating their shared relevance in addressing societal and environmental challenges.

The MP dataset unveiled the highest volume of information among the three datasets. All the MPs are accessible online, aside from D.F. Wouda Steam Pumping Station. The visualisation illustrated a highly interlaced network, revealing a dominant focus on 'Present' strategies adopted by the WH properties' stakeholders. It also displayed a series of 'Strategies' recurring as 'Past', 'Present' and 'Future' strategies, such as 'Conservation', 'Water management' and 'Knowledge transfer'. Moreover, most WH properties have identified 'Climate change' as a 'Challenge'. The interconnections among WH properties suggest a similar application of CAWHMSs and concerns raised by relevant stakeholders, despite the differing contexts of the WH properties.

The SoC Reports by the State Parties dataset revealed the least amount of information, given that only the Wadden Sea and Dutch Water Defence Lines have keywords that fall under this article's scope. Despite this, it exhibited a series of 'Present' strategies shared between the two WH properties, including 'Knowledge transfer, 'Assessment, 'Research' and 'Restoration'. These are also key instruments for preparing the Reactive Monitoring process, facilitating the evaluation and reporting of contemporary and anticipated conservation statuses to the World Heritage Committee [22].

Furthermore, there remains a gap in how 'Climate' is addressed and perceived in MPs and the SoC Reports by the State Parties. The majority of MPs have identified 'Climate' as a 'Challenge' in The Netherlands, but there are only two SoC Reports by the State Parties that addressed climate and broader sustainability topics. In the face of worsening climate conditions in The Netherlands, this raises concerns about whether climate threats are being perceived and acted upon as immediate risks, despite their prolonged and potentially irreversible effects on OUV [55]. The imbalance in the number of available SoC reports and MP documents has created a gap in strategic alignment. Given that a large number of interconnections and similarities are evident in the MPs, more links are expected to be found in the SoC reports, reflecting responses under climate challenges.

4.2. Conservation for Climate-Robust Living Environments

The concept of cultural heritage conservation has evolved to contribute to creating sustainable living environments [56]. Conservation is recognised as a heritage management strategy to balance urban development and quality of life under the 2011 UNESCO

Recommendation on the Historic Urban Landscape (HUL) [57]. In the 17th-century Canal Ring Area of Amsterdam inside the Singelgracht, 'keur' gardens (keurtuinen) and trees along canals are conserved, supporting urban climate regulation. Since the 17th century, the city council replaced linden with elm trees because they were more resilient to urban environments and helped to stabilise quays using their roots [43]. Hence, adaptation efforts reflect early consideration by the city council to balance urban development with natural elements. Whilst urban cities are prone to Urban Heat Island effects due to higher population and building density, the conservation of trees and 'keur' gardens highlights the enduring relevance of the 17th century landscape design principles in creating a climate-robust urban environment. It is thus a CAWHMS to alleviate heat stress, improve air quality and support carbon sequestration [57–59].

Several WH properties conserve hydraulic structures to maintain their functionality for contemporary water management. The Colonies of Benevolence have developed initiatives to recover the Westerbeeksloot barge canal for water retention to mitigate water shortages at Component A, in response to the 2018–2019 dry summers [45]. In addition, D.F. Wouda Steam Pumping Station is conserved by the Friesland Water Board for flood prevention in the province [39]. Hence, conserving hydraulic structures in WH properties sustains and strengthens their functionalities to alleviate contemporary climate challenges. It promotes the integration of past hydraulic structures for sustainable water management. Overall, vegetation and hydraulic structures characterised the cultural landscapes of the WH properties, reflecting past human interventions that addressed urban expansion and water management to establish climate-robust living environments. By conserving vegetation and hydraulic structures, this approach sustains their inherent role and continues to support urban climate regulation and water management. Ultimately, this CAWHMS aligns with UNESCO's HUL Recommendation to integrate heritage conservation into the broader objectives of climate change and urban development [57].

4.3. Heritage as a Collaborative Knowledge Hub

WH properties are collaborative knowledge hubs to advance cross-disciplinary approaches in climate adaptation efforts. The Wadden Sea is the world's biggest and uninterrupted system of intertidal sand and mud flats [40]. Given its size, the fragmented safeguarding measures between The Netherlands, Denmark and Germany have posed difficulties in coherently managing the WH property, making it challenging to assess future climate conditions [60,61]. Subsequently, the Wadden Sea's MP and SoC report consistently emphasised multidisciplinary actions to safeguard its OUV [42,53]. For instance, it advocates eco-friendly shipping activities to reduce environmental impacts, balance human activities and strengthen the resilience of ecosystems [42]. Meanwhile, Van Nellefabriek revealed research efforts to align the WH property with energy transition ambition, thereby reducing GHG emissions and achieving energy efficiency [7,50]. The examples suggest WH properties as collaborative knowledge platforms, facilitating interdisciplinary and transdisciplinary research to advance transformative heritage management [7]. This ensures the inherited OUV of WH properties is respected, whilst supporting human activities and energy transition ambitions [2,7].

Developing WH properties as collaborative knowledge hubs also connects with younger generations to stimulate their awareness about the reciprocal relationship between WH properties and climate adaptation. In 2022, young people from The Netherlands, Germany and Denmark participated in the Trilateral Youth Conference, engaging in open-ended discussions that brought together multidisciplinary perspectives, such as heritage protection, ecology and environmental history, fundamental to the holistic safeguarding of the Wadden Sea [4,53]. Another example includes Schokland and Surroundings, in which Noordoostpolder's primary school students learn about its history in tackling water-related challenges [6,47]. Through incorporating the WH property as an educational resource, younger generations deepen their awareness and broaden their understanding of cultural resilience and traditional water management practices as responses to alleviate environmental challenges [4,13].

4.4. Inconsistency in Heritage-Inclusive Sustainable Development and Environmental Management

The MP dataset revealed that WH properties have not yet been systematically incorporated into sustainable development and environmental management plans. Rietveld Schröderhuis and the 17th-century Canal Ring Area of Amsterdam inside the Singelgracht are not fully incorporated in environmental management topics [43,48]. The MP of Mill Network at Kinderdijk-Elshout also stated that cultural heritage properties were previously not integrated into sustainable development topics [49].

However, more sustainable development topics now position cultural heritage as an individual theme [49]. The inconsistency implies untapped CAWHMSs that are yet to be investigated. The lack of systematic exploration and validation makes it challenging for climate adaptation frameworks to confidently incorporate CAWHMSs. To address this limitation, stakeholders of WH properties can focus on identifying CAWHMSs, using OUV as a guiding principle. They can also leverage mechanisms such as monitoring and research, similar to those used in preparing SoC Reports by the State Parties. Meanwhile, external sectors, including water management, spatial planning and nature conservation, should reinforce cross-sectoral collaboration with the heritage sector in sustainable development and environmental management plans [55]. Once these efforts are consistent, they can holistically contribute to advancing national climate objectives.

4.5. Limitations and Recommendations

This article focuses on official documents accessible on the UNESCO World Heritage Convention website. This may overlook local and alternative CAWHMSs advocated by non-governmental organisations (NGOs) and private organisations, possibly developed out of the heritage sector. Future research could explore bottom-up perspectives on CAWHMSs for climate adaptation. This could be achieved by conducting qualitative interviews with local stakeholders involved in heritage, environmental protection, climate adaptation and landscape architecture projects. International and national climate adaptation policies can also be processed under the same framework to retrieve CAWHMSs information for heritage under climate change.

While this article prioritises synthesising CAWHMSs through qualitative coding and keyword aggregation, this structured approach may have overlooked certain climate-related perspectives within datasets. The MP and SoC Reports by the State Parties datasets rely greatly on extracting texts from official documents based on a list of keywords prepared beforehand. Consequently, the implications discussed in this article are limited to the subjective selection of texts. This may also impose constraints on presenting a comprehensive analysis of climate-related perspectives from the two datasets. Future studies may co-develop and expand on the set of keywords to bring in underrepresented climate-related perspectives that have not been captured thoroughly in this article, such as 'Renewable energy' and 'Nature-based solution'.

Moreover, this article identifies and elaborates on how CAWHMSs support climate adaptation. It does not discuss the role of legislation and frameworks in shaping heritage–climate management in WH properties. However, policymaking plays a fundamental role in bridging heritage management with sustainable development [13,55]. Future research could investigate how legal instruments strengthen or weaken the connection between heritage and climate adaptation, such as the national Environment and Planning Act, which took effect on 1 January 2024 [62].

Furthermore, this article mainly used qualitative coding to identify climate-related themes and CAWHMSs in The Netherlands. Future studies could discover the use of Artificial Intelligence and Large Language Models to scale up the analysis process and reproduce the analytical framework globally across different countries.

5. Conclusions

This article identified two sets of climate-adaptive World Heritage management strategies (CAWHMSs) that support climate adaptation efforts in The Netherlands: the conservation and development of WH properties as collaborative knowledge hubs. Vegetation conservation helps regulate urban climates and mitigate Urban Heat Island effects. In addition, conserving past hydraulic structures maintains their functionality and integrates them into sustainable water management. Collectively, the conservation of vegetation and hydraulic structures as cultural landscape elements sustains their role and continues to support climate adaptation efforts. Furthermore, WH properties serve as collaborative knowledge hubs, where the topic of climate adaptation is explored across age groups and sectors. WH properties bring together heritage stakeholders and cross-disciplinary sectors to integrate WH properties with broader sustainable development needs, including energy transition, thereby advancing heritage-inclusive climate adaptation efforts. In addition, WH properties are educational resources for younger generations to engage in and deepen their understanding of the defining cultural and natural significance fundamental to past and contemporary climate risk mitigation.

However, WH properties have not been systematically integrated into climate adaptation and broader environmental management initiatives. This inconsistency calls for stronger collaboration with external sectors, such as water management, spatial planning and nature conservation, to implement CAWHMSs for holistic and dynamic climate adaptation initiatives. This ensures that all the relevant sectors are aligned to strengthen national and international climate adaptation efforts.

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Abbreviations

The following abbreviations are used in this manuscript (in alphabetic order):

CAWHMS	Climate-Adaptive World Heritage Management Strategy
GHG	Greenhouse gas
HUL	Historic Urban Landscape
KIN	Dutch Climate Research Initiative (Klimaatonderzoek Initiatief Nederland)

MP	Management plan
NAS	National Climate Adaptation Strategy
NGO	Non-governmental organisation
OUV	Outstanding Universal Value
SOUV	Statement of Outstanding Universal Value
SoC	State of Conservation
TWSC	Trilateral Wadden Sea Cooperation
WH	World Heritage

Appendix A

Table A1. SOUV documents and their source.

WH Property	Document Link
Schokland and Surroundings	https://whc.unesco.org/en/list/739 (accessed on 27 March 2025)
Dutch Water Defence Lines	https://whc.unesco.org/en/list/759 (accessed on 27 March 2025)
Mill Network at Kinderdijk-Elshout	https://whc.unesco.org/en/list/818 (accessed on 27 March 2025)
D.F. Wouda Steam Pumping Station	https://whc.unesco.org/en/list/867 (accessed on 27 March 2025)
Beemster Polder	https://whc.unesco.org/en/list/899 (accessed on 27 March 2025)
Rietveld Schröder House	https://whc.unesco.org/en/list/965 (accessed on 27 March 2025)
Wadden Sea	https://whc.unesco.org/en/list/1314 (accessed on 27 March 2025)
Seventeenth-Century Canal Ring Area of Amsterdam inside the Singelgracht	https://whc.unesco.org/en/list/1349 (accessed on 27 March 2025)
Van Nellefabriek	https://whc.unesco.org/en/list/1441 (accessed on 27 March 2025)
Colonies of Benevolence	https://whc.unesco.org/en/list/1555 (accessed on 27 March 2025)
Frontiers of the Roman Empire—The Lower German Limes	https://whc.unesco.org/en/list/1631 (accessed on 27 March 2025)
Eisinga Planetarium in Franeker	https://whc.unesco.org/en/list/1683 (accessed on 27 March 2025)

Appendix B

Table A2. MP documents and relevant page numbers linked to keywords in Table 1.

WH Property	Document Link	Page Numbers Relevant to Keywords in Table 1
Schokland and Surroundings	https://whc.unesco.org/document/207277 (accessed on 27 March 2025)	pp. 5–35
Dutch Water Defence Lines	https://whc.unesco.org/document/177896 (accessed on 27 March 2025)	p. 49; pp. 102–104; pp. 163–170
Mill Network at Kinderdijk-Elshout	https://whc.unesco.org/document/193466 (accessed on 27 March 2025)	pp. 14–24; pp. 29–30

Table A2. *Cont.*

WH Property	Document Link	Page Numbers Relevant to Keywords in Table 1
Beemster Polder	https://whc.unesco.org/document/218353 (accessed on 27 March 2025)	p. 11; pp. 17–22; pp. 28–33; pp. 37–38
Rietveld Schröder House	https://whc.unesco.org/document/219693 (accessed on 27 March 2025)	pp. 10–13; pp. 19–22
Wadden Sea	https://whc.unesco.org/document/208611 (accessed on 27 March 2025)	pp. 11–13; p. 15; pp. 17–37
Seventeenth-Century Canal Ring Area of Amsterdam inside the Singelgracht	https://whc.unesco.org/document/206323 (accessed on 27 March 2025)	pp. 8–12; p. 20; pp. 38–39; pp. 57–65; pp. 76–77
Van Nellefabriek	https://whc.unesco.org/document/187731 (accessed on 27 March 2025)	pp. 8–14; p. 18
Colonies of Benevolence	https://whc.unesco.org/document/180470 (accessed on 27 March 2025)	pp. 57–62; pp. 73–75; pp. 118–126; pp. 189–190; pp. 227–228; p. 269
Frontiers of the Roman Empire—The Lower German Limes	https://whc.unesco.org/document/184624 (accessed on 27 March 2025)	pp. 17–43; pp. 47–49
Eisinga Planetarium in Franeker	https://whc.unesco.org/document/195151 (accessed on 27 March 2025)	pp. 25–31; pp. 52–66; pp. 72–74; pp. 77–85; pp. 90–94; pp. 111–112; pp. 140–143

Appendix C

Table A3. SoC Reports by State Parties documents and relevant page numbers linked to keywords in Table 1.

WH Property	Document Link	Page Numbers Relevant to Keywords in Table 1
Dutch Water Defence Lines	https://whc.unesco.org/document/218129 (accessed on 27 March 2025)	pp. 1–11
Wadden Sea	https://whc.unesco.org/document/205413 (accessed on 27 March 2025)	pp. 6–44

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