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Coastal Heritage Conservation Methods, a Visual-Based Pathological Assessment for Historic Masonry; A case study of Fort Williams

Cephas Teyie, Han Weicheng*

College of Architecture and Art, Taiyuan University of Technology, Taiyuan, China
No. 79 West Yingze Street, Wanbailin District, Taiyuan, Shanxi Province, China
*Corresponding Author

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***Keywords*— Architectural heritage conservation, coastal masonry deterioration, Fort Williams, ICOMOS standards, visual-based assessment, Ghanaian forts.**

***Abstract*—*Ghana's coastal forts and castles, including Fort Williams, suffer from severe decay due to marine exposure, rising damp, salt crystallization, biological growth, and past improper repairs. Systematic, low-cost diagnostic methods are needed for resource-limited heritage contexts. To diagnose the principal deterioration mechanisms of Fort Williams using a non-invasive visual assessment aligned with ICOMOS standards, and to propose a phased, evidence-based conservation framework. A four-phase visual protocol was applied: (1) systematic photographic survey, (2) pathology taxonomy and causal analysis, (3) intervention design guided by conservation ethics, and (4) monitoring plan. Deterioration types were recorded across all architectural spaces. The key mechanism is a self-reinforcing cycle: capillary rise, rain, and sea spray introduce moisture that dissolves salts; evaporation causes sub-florescence, generating crystallization pressure that cracks bricks and mortars, allowing more moisture ingress. Persistent dampness also supports algae, fungi, and moss, which retain further moisture. The most severe decay occurs at wall bases and in areas with poor ventilation or roof leaks. Interrupting moisture sources is the only way to break the deterioration loop. A phased intervention is proposed: (1) source control and monitoring (0–12 months), (2) desalination and biological cleaning (12–24 months), (3) lime mortar reinstatement and brick replacement (24–48 months), and (4) perpetual maintenance. Systematic visual assessment alone can produce robust conservation decisions, offering a replicable model for other coastal forts in Ghana and similar tropical environments. Future work must include laboratory salt analysis, long-term monitoring, and socio-economic integration.*

I. INTRODUCTION

Ghana's coastal forts and castles, built between the 15th and 19th centuries, are UNESCO World Heritage sites of immense historical, architectural, and cultural significance. Among them, Fort William (originally Fort Anomabo, built 1753) is notable for its well-preserved layout and its later use as a state prison and community library. However, centuries of exposure to a harsh marine environment, combined with deferred maintenance and inappropriate past repairs, have led to severe material decay.

Most previous studies on Ghanaian coastal heritage have focused on historical narrative, tourism, or adaptive reuse potential, but systematic, building-pathology-based conservation diagnostics remain rare. This gap is critical because interventions that do not address root causes such as rising damp and salt transport can accelerate damage.

This study therefore aims to diagnose the principal deterioration mechanisms affecting the masonry of Fort Williams using a non-invasive, ICOMOS-aligned visual assessment; classify and map the spatial distribution of pathologies; then propose a phased, material-compatible conservation framework that prioritizes moisture source control.

The significance of this study can therefore be identified in threefold. (1) Culturally preserving a key symbol of Ghana's colonial and post-colonial history. (2) Scientifically advancing an evidence-based, engineering-informed approach for coastal heritage in tropical climates. And (3) practically providing a low-cost, replicable diagnostic protocol for heritage professionals and policymakers in resource-limited settings.

II. THEORETICAL AND ETHICAL FOUNDATIONS.

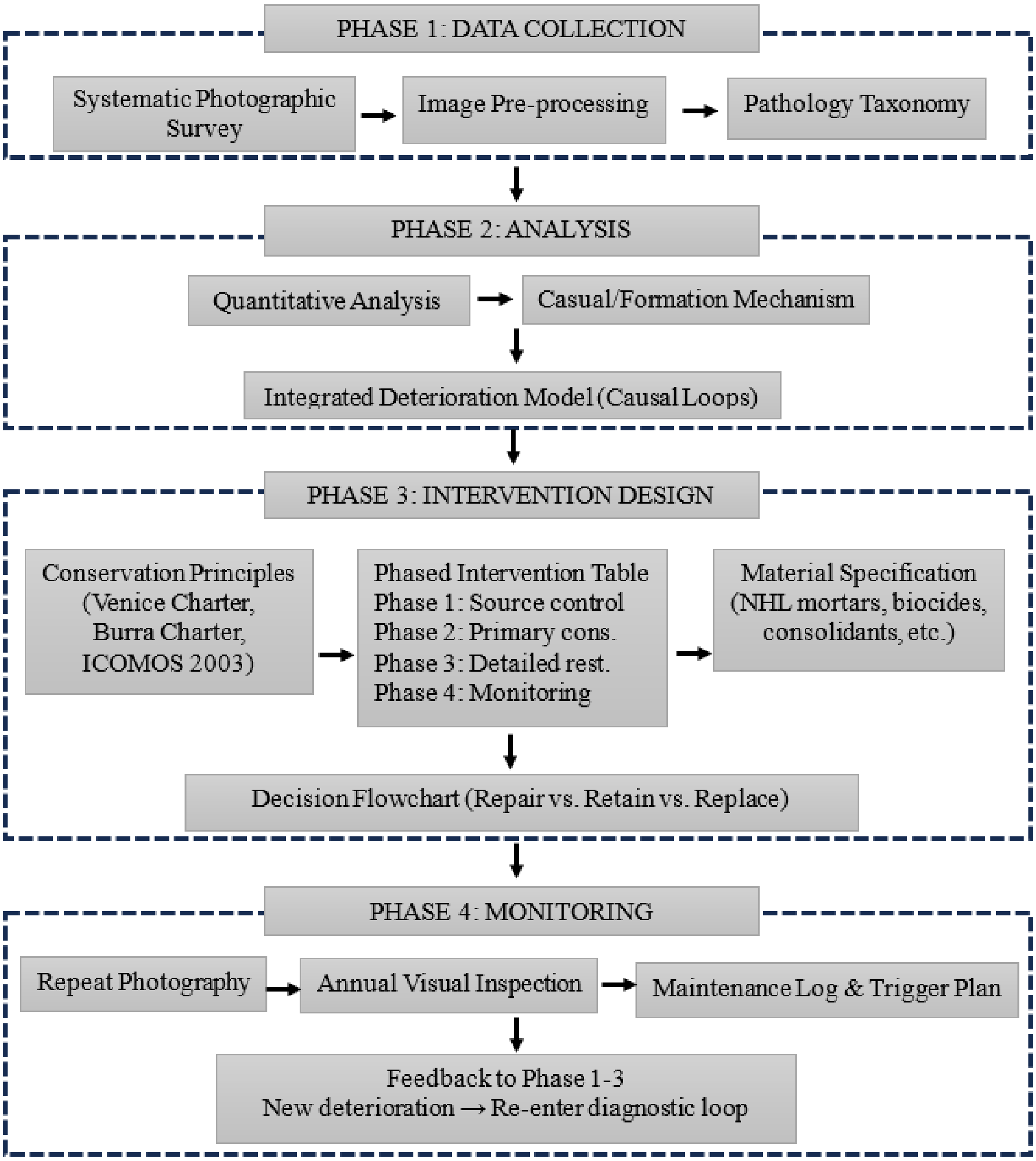


Fig.1. Conceptual Framework

This study is grounded in four interconnected bodies of knowledge:

1. ***Heritage Values Theory (Mason, 2002):*** Recognizes historical, aesthetic, informational, communal, and economic values. Any intervention must enhance rather than diminish these values.
2. ***Conservation Doctrine - Venice Charter (1964), Burra Charter (2013), ICOMOS Structural Restoration Charter (2003)***: Principles of minimal intervention, reversibility, authenticity, material compatibility, and root-cause treatment.
3. ***Building Pathology***: Focuses on understanding the physical, chemical, and biological mechanisms of deterioration (e.g., salt crystallization, capillary rise, biofilm formation).
4. ***Structural Assessment Theory***: Provides systematic inspection and documentation methods (visual, non-destructive).

These theories are operationalized through the conceptual framework as shown in Figure 1.

Table 1 summarizes the international standards aligned with the study.

Table 1. Summary of International Standards Aligning with the Study.

Standard	**Year**	**Key principles aligned with the study**
Venice Charter	1964	Authenticity, Minimal Intervention, Documentation.
ICOMOS Structural Restoration Charter	2003	Medical Approach, Root Cause Treatment, Material Compatibility, Reversibility.
Burra Charter	1979/2013	Cultural Significance, Retention of Fabric, Conservative Reconstruction
ICOMOS Timber Structures Principles	1999	Monitoring, Maintenance, Material Matching, Discreet Marking
Nara Document	1994	Culturally Relative Authenticity, Intangible Values
UNESCO World Heritage Operational Guidelines	Various	Reconstruction only with Documentation, No Conjecture
ICOMOS-ISCS Glossary	2008	Standardized Pathology Terminology

III. METHODOLOGY

3.1 Research Approach

The research adopted a visual-based, non-invasive diagnostic survey aligned with the ICOMOS medical model for structural restoration (ICOMOS, 2003). This model emphasizes systematic diagnosis of root causes before intervention, rather than ad hoc treatment of symptoms. No samples were taken from site, all assessments were based on systematic observation, photography, and mapping. The methodology was structured into four phases, as illustrated in the conceptual framework (Figure 1).

3.2 Case Study Area: Fort Williams, Anomabo

Fort William is located in Anomabo, Central Region, Ghana (5°10′N, 1°08′W). Built by the British in 1753 on the site of earlier Dutch and English forts, it was renamed in the 1830s after King William IV. Constructed almost entirely with local materials (stone, brick, lime mortar), it was inscribed as a UNESCO World Heritage site in 1979. After the abolition of the slave trade, it served as a state prison until 2001, then briefly as a community library. The fort's architectural form (see Figures 2–5) includes a courtyard, governor's chamber, dungeons, and defensive walls.

Architectural Form of Fort Williams.

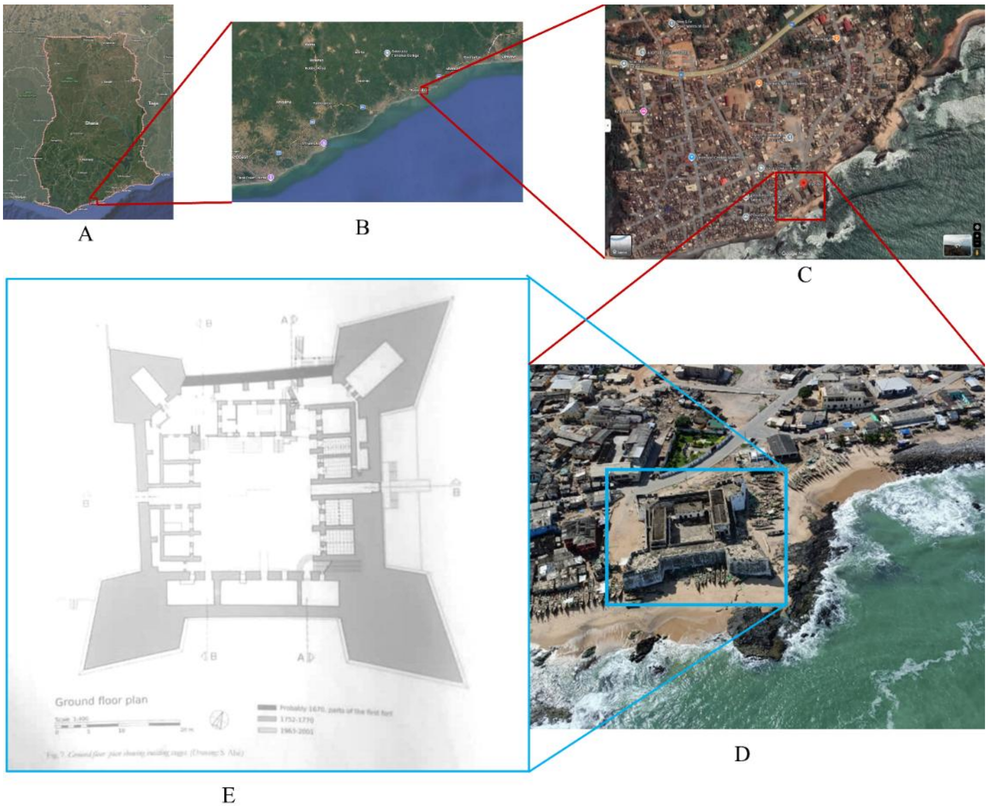
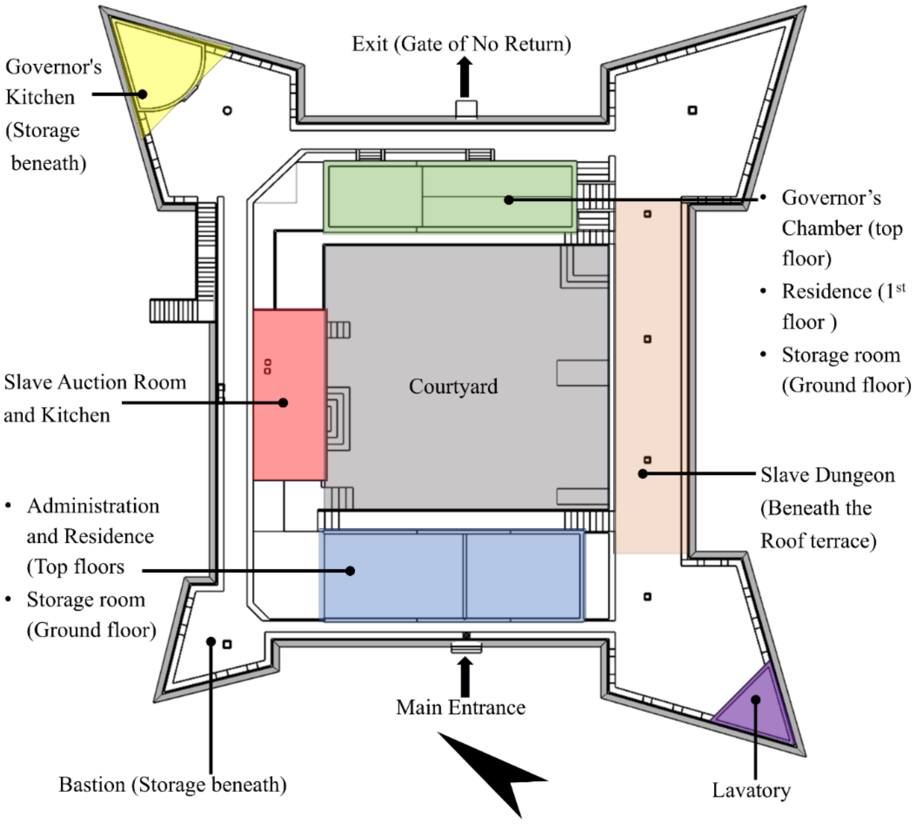
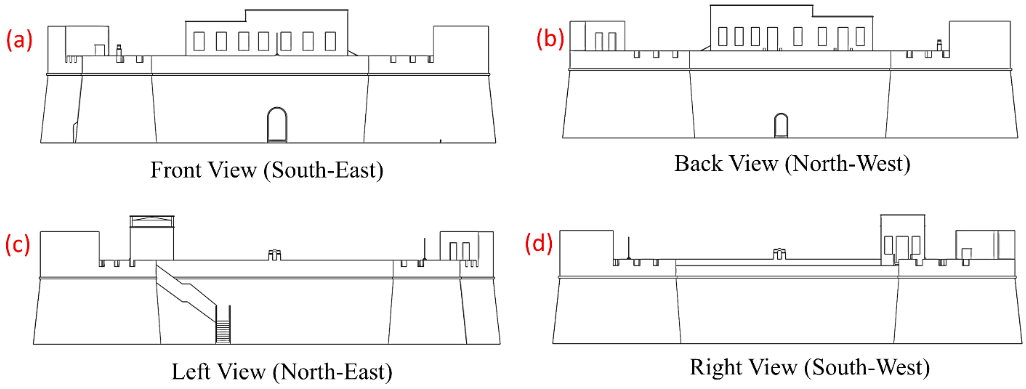


*Fig.2. Location of Fort Williams. (**A&B**) Map of Ghana (Google map, 2025), (**C&D**) Anomabo Township (Google map), (**E**) Fort Williams - Floor plan. (Source: Fort Williams Site Management.)*



Note: Not drawn to scale.

Fig.3. Spatial Organization from aerial view (Source: Drawn by author, 2025)



Front View (South-East)

Back View (North-West)

Left View (North-East)

Right View (South-West)

Fig.4. Elevations/Views of Fort Williams (Source: Drawn by author, 2025)

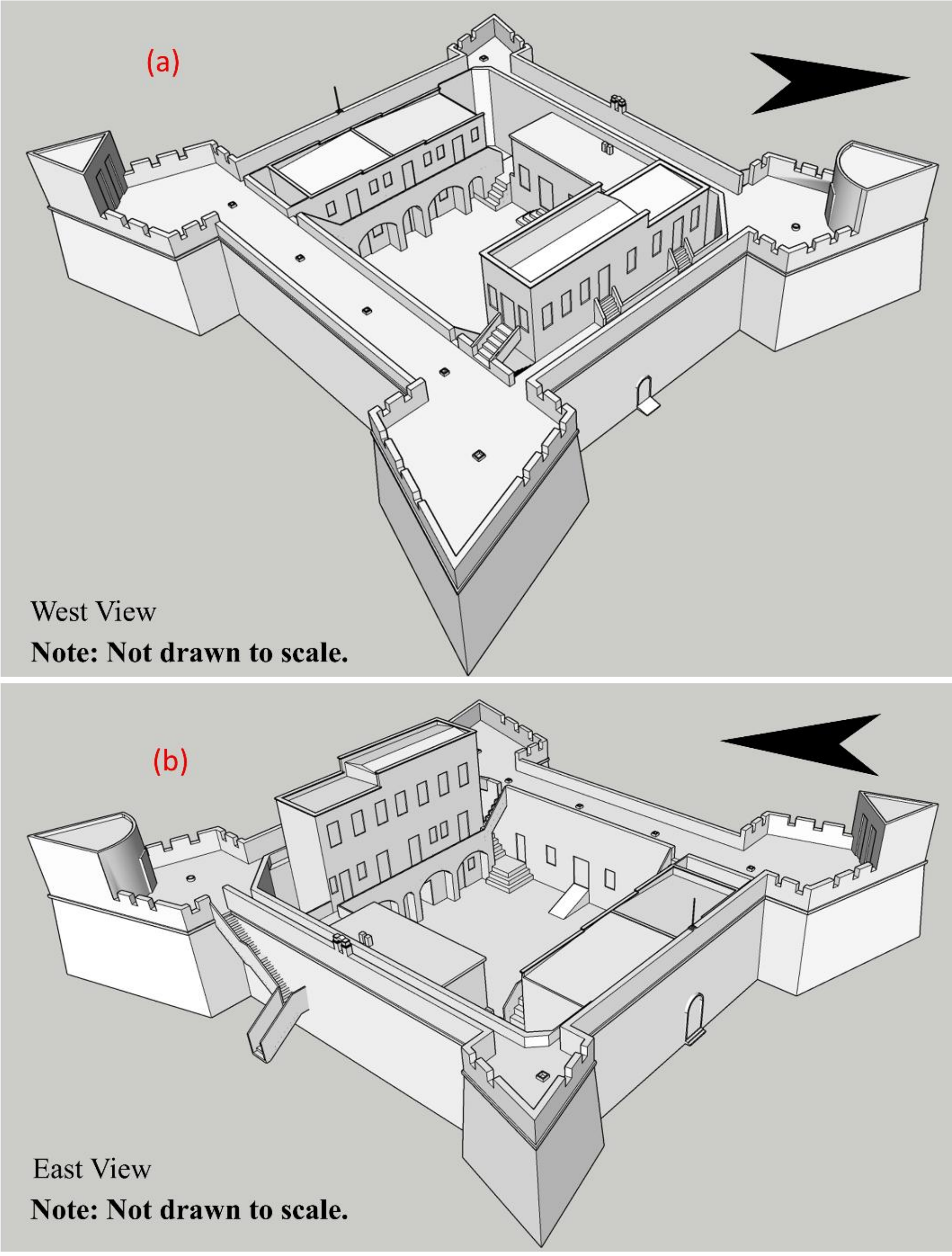
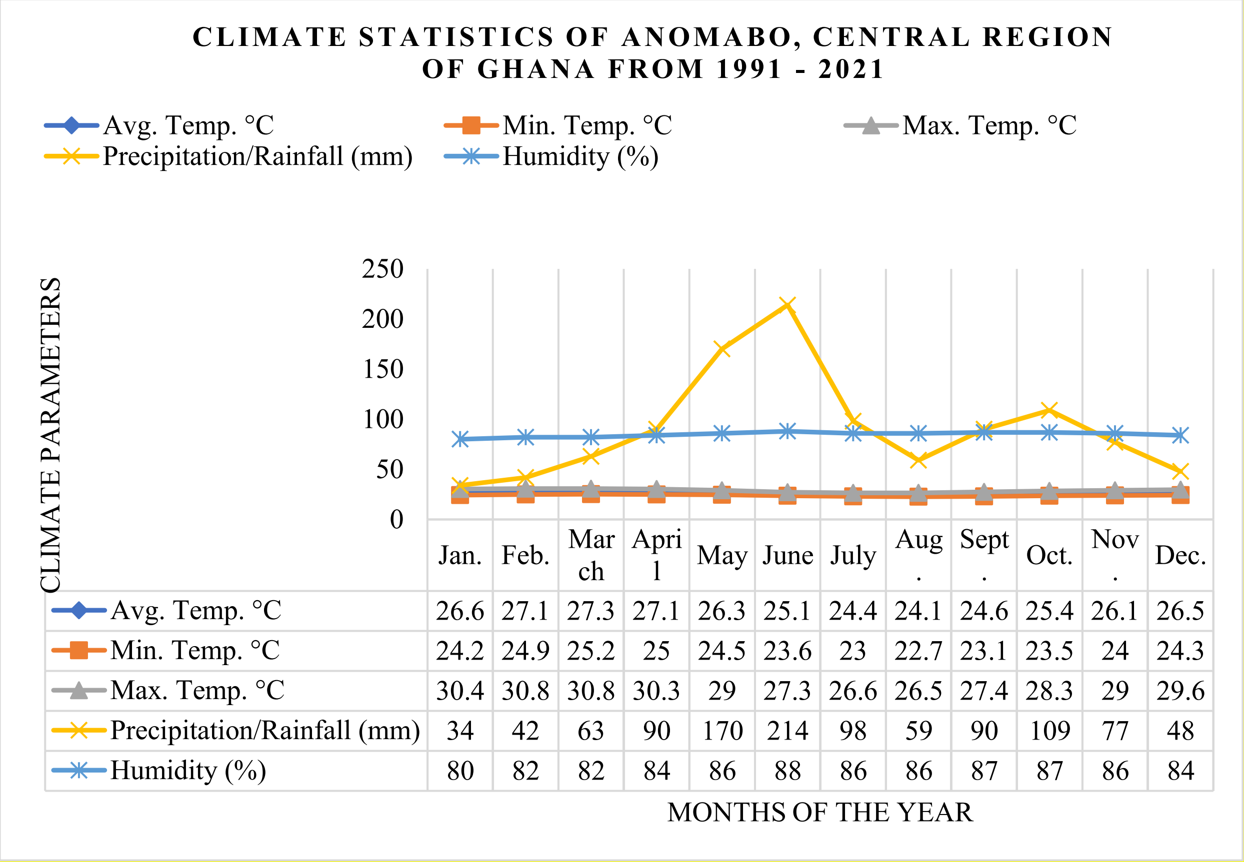


Fig.5. 3D Renderings of Fort Williams (Source: Drawn by author, 2025)

3.3 Environmental Context

Anomabo has a humid tropical coastal climate with a mean annual temperature of 24.1–27.3 °C. and relative humidity of 80–88%. A bimodal rainfall from May–June and September–October with a persistent marine aerosols and salt-laden winds. Figure 6 gives the climate statistics of Anomabo from 1991 to 2021.



	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Avg. Temp. °C	26.6	27.1	27.3	27.1	26.3	25.1	24.4	24.1	24.6	25.4	26.1	26.5
Min. Temp. °C	24.2	24.9	25.2	25	24.5	23.6	23	22.7	23.1	23.5	24	24.3
Max. Temp. °C	30.4	30.8	30.8	30.3	29	27.3	26.6	26.5	27.4	28.3	29	29.6
Precipitation/Rainfall (mm)	34	42	63	90	170	214	98	59	90	109	77	48
Humidity (%)	80	82	82	84	86	88	86	86	87	87	86	84

Fig.6. Climate Statistics of Anomabo, Central Region of Ghana from 1991 – 2021.

Source: *Climate Data, 2025*

3.4 Visual Survey Protocol

The survey was conducted in January 2025. Each accessible space (courtyard, terrace, kitchen, auction room, dungeons, governor's chamber, kitchen, lavatory, staircase, storage rooms, administrative/residential rooms, exterior defense wall, upper exterior walls) was examined. The deterioration types were recorded using a standardized checklist derived from ICOMOS-ISCS (2008) terminology. Photographs were also taken with scale references and a causal loop diagram was developed to integrate the findings.

Salt-induced: surface efflorescence, sub-florescence (crypto-florescence), plaster delamination, plaster spalling/loss, brick/stone scaling/powdering, salt staining/discoloration.

Biological: algal biofilm (green), cyanobacterial colonization (black/green), fungal growth (mould), moss colonization, biological patina/soiling.

IV. RESULTS

4.1 General Observations

Externally, the fort's walls have been freshly painted, giving a superficial impression of good condition. However, the interior courtyard reveals extensive deterioration (Figures 7–8). Roofs show local failures, biological growth is widespread, and mortar joints are eroded. Despite this, the overall geometry and spatial hierarchy remain intact.

Fig.7. Exterior Walls of Fort Williams Source: Site investigation by author, 2025.

Fig.8. Courtyard within Fort Williams Source: Site investigation by author, 2025.

4.2 Deterioration Types and Distribution

Table 2 presents the observed deteriorations per location. The most affected areas are the wall bases, terrace, courtyard, governor's chamber, and areas with roof leaks or poor ventilation.

Table 2. Observed Deteriorations at Fort Williams.

Location	**Deteriorations**										
	Efflorescence & Salt Crystallization						**Damp & Microbial Growth**				
	Surface Efflorescence	Sub-florescence (Crypto-florescence)	Plaster Delamination Due to Salt	Plaster Spalling / Loss	Brick/Stone Surface Scaling / Powdering.	Salt Staining / Discoloration / Paint Loss	Algal Biofilm (Green)	Cyanobacterial Colonization (Black/Green)	Fungal Growth (Mold)	Moss Colonization	Biological Patina / Soiling
Courtyard	●	●	●	●	●	●		●	●	●	●
Terrace	●	●	●	●	●	●					●
Kitchen	●	●	●			●			●	●	●
Auction Room	●	●	●			●			●	●	●
Dungeons	●					●	●			●	
Governor's Chamber	●	●	●			●	●			●	
Governor's Kitchen	●	●	●			●					
Lavatory	●	●	●			●					
Staircase	●	●	●			●					●
Storage	●					●	●			●	

Rooms											
Admin./ Residential Rooms	●	●				●	●			●	
Exterior Defense Wall		●				●		●	●	●	
Upper Exterior Walls	●	●	●	●		●		●	●		

4.3 Efflorescence and Salt Crystallization

At Fort Williams, white powdery efflorescence is common on surfaces in the courtyard, terrace and most of the interiors. These deposits form where salt-laden moisture rising by capillary action evaporates at the masonry surface, leaving dissolved salts behind. More damaging is sub-florescence (crypto-florescence), where salts crystallize beneath the surface within the pore structure. This generates crystallization pressure that exceeds the tensile strength of historic bricks and mortars, causing plaster delamination, spalling, and brick scaling (Figure 9 a–e). Severe deterioration is concentrated at wall bases, matching the classic rising-damp salt zonation model. Plaster detachment and paint failure occur at material interfaces where impervious layers trap crystallizing salts. The most advanced damage shows complete loss of plaster and surface disintegration of brick, particularly in areas with chronic moisture exposure and no historic damp-proof course.

Fig.9a–e: Salt efflorescence, plaster failure and brick disintegration. Source: Site investigation by author, 2025.

4.4 Dampness and Biological Colonization

The results again show persistent dampness is widespread at Fort Williams, originating from rising capillary groundwater, wind-driven rain, sea spray, and roof leaks. This sustained moisture supports extensive biological colonization. Green-black algal biofilms cover interior walls and ceilings (Figure 10 a–d), while cyanobacteria and fungal growth appear on both interior and exterior surfaces. Moss colonization is visible on damp exterior walls and roof areas (Figure 10 e–f). Biological growth is most intense at wall bases, where capillary rise maintains continuous wetness, and in poorly ventilated spaces such as dungeons and storage rooms. The biofilms retain moisture, prolonging evaporation and creates favorable conditions for further biological activity. Dark staining from photosynthetic pigments and metabolic byproducts is evident across multiple surfaces. No active intervention has been applied yet, allowing natural succession from pioneering algae to complex fungal and moss communities.

Fig.10a–f: biological colonization. Source: Site investigation by author, 2025.

4.5 Causal Loop Diagram

At Fort Williams, dampness caused by rising capillary moisture, rain penetration, and marine aerosols supplies the water that dissolves soluble salts within the masonry. As moisture moves toward evaporation surfaces, salt crystallization occurs initially as harmless surface efflorescence, then progresses into a destructive sub-florescence within the masonry pores. The crystallization pressure fractures mortar and brick, creating micro-cracks. These cracks pave way for more moisture which transports additional salts, intensifying the cycle. Persistent dampness or moisture also sustains biological growth (algae, fungi) that retains more moisture, prolonging evaporation and salt activity. The combined effect is accelerated plaster delamination, spalling, material loss, and rising damp-driven vertical zonation of decay. Interrupting moisture sources is therefore the only way to break this self-reinforcing loop as shown in figure 11 below.

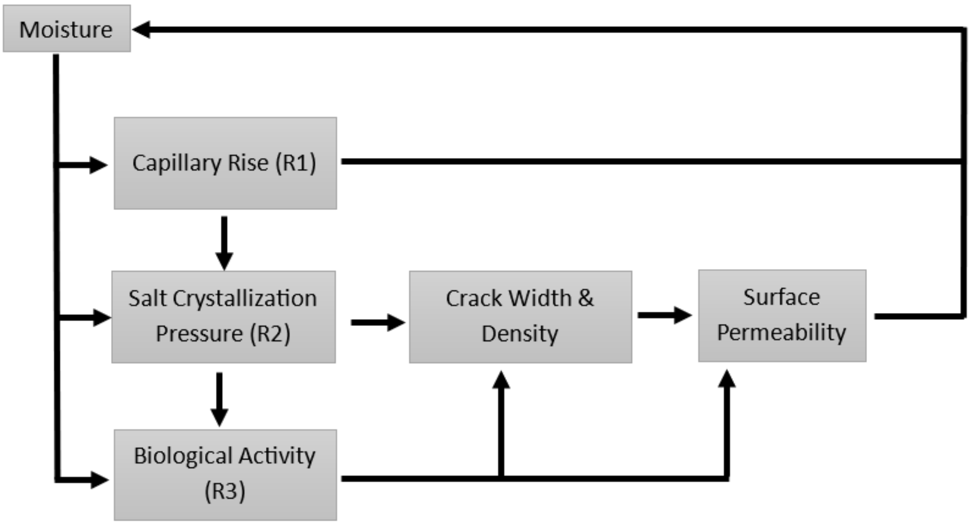


Fig.11: Causal loop diagram: Moisture-Driven Deterioration Cycles. (Source: Designed by author, 2025)

V. DISCUSSION

5.1 Formation Mechanisms.

Efflorescence and Salt Crystallization: The deterioration observed at Fort Williams is consistent with established models of salt decay in coastal masonry (Manohar et al., 2023; Woolfitt, 2019). The convergence of multiple salt sources such as marine sodium chloride from sea spray and aerosol deposition, plus sulphates, nitrates, and chlorides carried by rising groundwater, creates an exceptionally aggressive decay environment (Manohar et al., 2023; Franzoni et al., 2014). The absence of any historic damp-proof course allows uninterrupted capillary rise, drawing saline solutions from the moisture or water sources into the porous brick and lime mortar fabric (Franzoni et al., 2014).

The critical distinction between surface efflorescence and sub-florescence explains the spatial pattern of damage. Where evaporation occurs slowly at the masonry surface, salts precipitate as harmless white powdery deposits (Woolfitt, 2019; Wijnhorst et al., 2024). However, at Fort Williams, evaporation rates often exceed the rate of solution transport, forcing crystallization within the pore network just behind the surface (Wijnhorst et al., 2024). This sub-florescence generates crystallization pressure that can exceed the tensile strength of historic materials (Thaulow et al., 2004). Scherer demonstrated that this pressure arises from supersaturation required for crystal nucleation in confined pores, with magnitude depending on the supersaturation ratio and interfacial energy between crystal and pore wall (Manohar et al., 2023).

The concentration of severe damage at wall bases matches Charola's synthesis of Arnold's four-zone model of salt-affected walls (Charola, 2000). The lowest zone, closest to the ground, retains more soluble salts in solution and shows less damage. The most deteriorated zone occurs immediately above, where less soluble salts such as sodium sulphate precipitate, generating the expansive forces responsible for spalling, delamination, and material loss (Charola, 2000). This vertical zonation is clearly visible at Fort Williams (Figure 9 c–e).

The damage mechanism is intensified by phase transformations of salts in response to environmental fluctuations. Sodium sulphate, common in coastal groundwaters, undergoes repeated transitions between anhydrous thenardite and hydrous mirabilite forms under changing temperature and relative humidity (Thaulow et al., 2004). Each dissolution-recrystallisation cycle generates cyclical stresses that progressively fatigue the material structure (Franzoni et al., 2014). Research on heritage brick structures has documented that the simultaneous presence of sodium chloride and sodium sulphate produces complex deterioration patterns different from single-salt systems (Manohar et al., 2023). The observed progression from plaster staining (c) to render failure (b) to complete material loss (e) represents the temporal evolution of salt damage (Franzoni et al., 2014). Critically, delamination and paint failure at material boundaries occur when impervious layers trap crystallizing salts (Woolfitt, 2019; Charola, 2000). This explains why surface treatments applied to salt-laden masonry inevitably fail, because salts continue migrating toward drying surfaces and accumulate beneath any impermeable coating. Therefore, any sustainable conservation strategy must prioritize moisture source control before attempting desalination or re-plastering.

Dampness and Biological Colonization: As identified earlier, persistent dampness is the primary driver of biological colonization at Fort Williams, and its sources are multiple: rising capillary moisture from saline groundwater, wind-driven rain penetrating exposed walls, marine aerosol deposition, and failed roof coverings. This combination creates a microenvironment where relative humidity remains elevated throughout much of the year, sustained by the bimodal rainfall pattern and coastal humidity (80–88%). Quantitative studies of fungal communities in heritage contexts have shown that humidity explains 19.2% of fungal community composition, the highest single variance factor (Li et al., 2020). This relationship underscores why the persistent dampness documented at Fort Williams has resulted in extensive biological colonization across multiple surface types and orientations.

The porous nature of brick masonry, with its inherent roughness and capillary structure, enables water retention within the material fabric, creating microenvironments where moisture remains available for extended periods even when surface conditions appear dry (Gregorini, 2020). Algae and cyanobacteria function as pioneering colonizers in the biodeterioration sequence, establishing the initial biological foothold on damp masonry surfaces. These microorganisms maintain metabolic activity only when appropriate combinations of dampness, warmth, and light coincide, yet they demonstrate remarkable tolerance to climatic variations, surviving dry periods through dormancy and resuming growth rapidly when moisture returns (Jan, 2020). This adaptive capacity explains the persistent green-black staining on interior walls (Figure 10 a–d), which reappears even after dry spells.

The distinction between interior and exterior colonization patterns arises from differences in moisture sources and microclimatic regimes. Exterior walls experience direct wind-driven rain, marine aerosol deposition, and cyclical wetting-drying driven by solar radiation (Jan, 2020). Interior colonization results primarily from capillary moisture rising from foundations, condensation on cold surfaces, or leakage through failed roof membranes. These sources produce more sustained substrate dampness without the desiccating effects of direct sunlight and wind. The biological communities at Fort Williams represent a successional sequence beginning with algal pioneers and progressing toward complex assemblages including fungi, mosses, and potentially lichens. Algae establish first because they require only moisture, light, and minimal nutrients derived from atmospheric deposition or substrate dissolution (Cutler, 2019). Their photosynthetic activity produces organic compounds that accumulate on and within the masonry surface, creating nutrient-enriched conditions that support subsequent colonization by heterotrophic fungi and mosses (Jan, 2020).

The deterioration mechanisms accompanying biological growth operate through multiple pathways. Biochemically, microbial metabolic activities produce organic acids that dissolve mineral binders in mortars and plasters, while chelating agents complex with metal ions in the masonry matrix, accelerating material loss (Stewart et al., 2019). Physically, algal and fungal hyphae penetrate surface pores and expand during wetting-drying cycles, exerting mechanical stresses that loosen mineral grains and exacerbate existing micro-fractures (Jan, 2020). The preferential colonization at wall bases aligns with the vertical moisture gradient from capillary rise. Significantly, the dark staining observed results from both photosynthetic pigments within living organisms and the accumulation of metabolic byproducts and trapped atmospheric particulates within the biofilm matrix (Jan, 2020). The biological growth at Fort Williams both indicates and accelerates underlying material decay. While surface colonization alone may appear primarily aesthetic, the sustained presence of moisture-retaining biofilms prolongs surface wetness, creating self-perpetuating conditions that favor continued biological activity and progressively more severe material deterioration (Stewart et al., 2019). Therefore, as earlier emphasized; effective intervention must first eliminate the moisture sources that sustain biological communities; biocide treatment alone, without moisture control, will only provide temporary relief.

5.2 Implications for Conservation

The findings lead to a clear hierarchy of interventions:

1. **Source control** (drainage, roof repair, damp-proof course) must precede any aesthetic or surface treatment.
2. **Desalination** (poulticing) is essential before re-plastering; otherwise, salts will migrate into new plaster.
3. **Sacrificial lime plasters** (more porous than the original brick) are recommended to allow salts to concentrate in the plaster, which can later be replaced.
4. **Biocides** should be used sparingly and only after moisture reduction, with preference for low-toxicity products (e.g., benzalkonium chloride).

6. Proposed Conservation Framework

Based on the diagnosis, a phased, pathology-specific intervention framework as in table 3 is proposed.

Table 3. Phased Intervention Framework for Fort Williams

Phase	Timeframe	Primary Actions	Materials / Methods	Key Conservation Principle
Phase 1: Source control & monitoring.	0–12 months	•Moisture mapping (non-destructive meter) •Excavate around walls, install French drain •Insert breathable DPC (stainless steel or slotted) •Repair all roof leaks, gutters •Improve ventilation	Moisture meter, gravel + geotextile, stainless steel DPC, roofing materials and ventilation grilles.	Root-cause treatment.
Phase 2: Primary conservation (desalination + biocide).	12–24 months	•Dry brush efflorescence (no water washing) •Apply clay/cellulose poultices to salt-affected areas; repeat until conductivity low •Inject lime grout (NHL 2) where plaster delaminated but sound	Attapulgite/arbocel poultice, deionized water, conductivity meter, NHL 2 grout, benzalkonium chloride, soft brushes and HEPA vacuum.	Minimal intervention and reversibility.

		•Remove loose failed plaster •Apply biocide (benzalkonium chloride 0.5-2%) to biological growth, then rinse with deionized water		
Phase 3: Detailed restoration (lime plaster & brick replacement).	24–48 months	•Reinstate plaster with NHL 2 or 3.5 lime plaster (sacrificial, more porous than brick) •Consolidate friable bricks with limewater or ethyl silicate (test area first) •Replace bricks with >20% section loss using handmade, low-strength bricks bedded in NHL 2 mortar •Finish with breathable limewash (no impervious paints)	NHL 2/3.5 lime plaster, limewater or ethyl silicate, replacement bricks, NHL 2 mortar and limewash.	Authenticity and material compatibility.
Phase 4: Perpetual maintenance.	Ongoing	•Annual repeat photography (fixed points, end of wet season) •Annual moisture meter readings at baseline points •Inspect drains, roof, DPC annually •Spot biocide treatment only if growth returns •Maintain intervention log	Photographic reference, moisture meter, inspection checklist and maintenance log	Monitoring and feedback.

VI. CONCLUSION

This study demonstrates that a systematic, visual-based pathological assessment guided by ICOMOS principles can produce robust, actionable conservation decisions for coastal heritage masonry, even without characterization of mineral composition. The case of Fort Williams reveals a self-reinforcing deterioration cycle driven by uncontrolled moisture, leading to salt crystallization, cracking, biological growth, and material loss. Interrupting moisture sources is the only sustainable intervention.

Limitations.

The study lacked laboratory salt analysis (XRD, ion chromatography) therefore all formation mechanisms were inferential. Being a single-site study, findings may not fully represent research findings on other Ghanaian forts and castles. This is a proposed framework which has not been implemented yet and therefore no post-intervention monitoring data was available.

Recommendation for future research.

The absence of laboratory analysis means findings remain inferential and therefore future work should integrate field tests, targeted lab analysis and comparative assessments of other Ghanaian coastal forts. Additionally, sustainable management must integrate socio-economic considerations, adaptive reuse strategies, local stakeholder engagement, and respectful interpretation of the fort’s complex historical legacy.

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DISCLOSURE STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data (photographs and field notes) are available from the corresponding author upon reasonable request.

AUTHORS' CONTRIBUTIONS

Cephas Teyie[1]: Conceptualization, Methodology, Data collection and curation, Writing and editing, Original draft preparation.

Han Weicheng[2*]: Perfecting of research direction and Reviewing.

All authors read and approved the final manuscript.

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