ISSN 1533-9211

DOI: 10.5281/zenodo.22127018

CLIMATE-RESILIENT CONSTRUCTION IN SOUTH AFRICA: ADAPTATION STRATEGIES FOR BUILDINGS AND INFRASTRUCTURE UNDER EXTREME WEATHER CONDITIONS

T.L NKOSI and S.H.P. CHIKAFALIMANI

[1,2]Construction Management & Quantity Surveying, Durban University of Technology, Durban, RSA.
Email: [1]thalenten@dut.ac.za, [2]SamuelC@dut.ac.za

Abstract

South Africa is increasingly exposed to climate-related hazards, including intense rainfall and flooding, prolonged drought, heatwaves, severe wind events, wildfires and coastal storm surges. These hazards interact with ageing infrastructure, rapid urbanisation, unequal settlement conditions, maintenance backlogs and constrained municipal capacity, increasing risks to buildings, transport systems, water and sanitation networks, energy infrastructure and construction supply chains. This article examines climate-resilient construction as an adaptation imperative for the South African built environment. Using a narrative review of policy directions and built-environment adaptation literature, the article identifies practical strategies at building, infrastructure and governance levels. Key measures include climate-risk-informed site selection and land-use planning; flood-resilient building design; passive thermal design; water-sensitive urban design; durable and locally appropriate materials; nature-based solutions; asset maintenance; climate-informed design standards; and lifecycle-based procurement. The paper argues that resilience should not be treated as an add-on technical feature, but as a core performance requirement embedded across planning, design, construction, operation and renewal. It further proposes an integrated climate-resilient construction framework for South Africa that links hazard assessment, vulnerability reduction, adaptive design, implementation capacity and post-event learning. The paper concludes that coordinated action by government, built-environment professionals, contractors, financiers and communities is essential to ensure that infrastructure investments remain safe, functional, inclusive and economically viable under changing climatic conditions.

Keywords: Built Environment.; Climate Resilience; Construction Management; Extreme Weather; Infrastructure Adaptation; Resilient Buildings; South Africa.

1. INTRODUCTION

Climate change is no longer a distant environmental concern for the construction sector; it is an immediate and material risk to the planning, delivery, performance and maintenance of the built environment. In South Africa, climate variability and climate change are expected to intensify multiple hazards, including extreme rainfall, flooding, drought, water scarcity, high temperatures, heat stress, severe winds, wildfires and coastal hazards, with effects differing considerably across provinces, municipalities and settlement types (Ziervogel *et al*., 2014). These hazards pose direct risks to buildings, transport infrastructure, water and sanitation systems, energy networks and construction sites, while also disrupting supply chains, delaying project delivery and increasing the lifecycle costs of built assets (Sovacool *et al*., 2018). The 2022 KwaZulu-Natal floods, for example, demonstrated how extreme rainfall can simultaneously damage housing, roads, bridges, water systems and public facilities, revealing the systemic vulnerability of critical infrastructure networks to climate-related disasters

ISSN 1533-9211
DOI: 10.5281/zenodo.22127018

(Dlamini, Nhleko and Ubisi, 2024). The consequences of extreme weather are particularly acute where infrastructure is inadequately maintained, stormwater systems are undersized or obstructed, and development has taken place in flood-prone or environmentally sensitive locations. Poor drainage maintenance, solid-waste accumulation and impervious urban surfaces can intensify surface runoff, thereby increasing the likelihood and severity of flooding in densely populated urban areas (Williams *et al*., 2019). In addition, the ageing condition of municipal infrastructure in many South African cities and towns reduces the capacity of critical assets to absorb, resist and recover from climate shocks (Nhemachena, Matchaya and Nhemachena, 2014). Climate-related infrastructure failure should therefore not be interpreted solely as a consequence of an extreme event; rather, it commonly reflects the interaction between hazard exposure, weak maintenance systems, inadequate planning and existing socioeconomic vulnerability (Roberts, 2010).

Informal settlements and low-income communities are disproportionately exposed to climate risk because many households occupy marginal land located near rivers, wetlands, steep slopes, transport corridors or other high-risk areas. Rapid urbanisation, limited access to affordable formal housing and persistent spatial inequality have contributed to the expansion of settlements in locations that are highly exposed to flooding and other environmental hazards (Sutherland, Scott and Nel, 2016). Research in Durban has shown that informal-settlement vulnerability is shaped not only by exposure to floods and severe storms, but also by inadequate drainage, poor-quality housing, insecure tenure, limited access to services and constrained household capacity to recover after disasters (Williams *et al*., 2019). Recent evidence from KwaZulu-Natal similarly indicates that flood risk is intensified by housing shortages, poverty and the location of settlements in high-risk areas, underscoring the importance of spatially informed disaster-risk-reduction planning (Dlamini, Nhleko and Ubisi, 2024).

Climate-resilient construction must consequently be understood as more than a technical or engineering response. It is also a social equity, governance and developmental imperative because decisions about where and how infrastructure is built influence the distribution of climate risk across communities. Adaptation interventions that focus exclusively on physical hardening may be insufficient if they do not address the underlying drivers of vulnerability, including unequal access to land, infrastructure, housing finance, municipal services and participation in decision-making (Ziervogel *et al*., 2017). A resilience-oriented approach should therefore combine robust engineering design with risk-sensitive land-use planning, ecosystem protection, inclusive housing delivery, community engagement and sustained infrastructure maintenance (Pelling and Garschagen, 2019).

South Africa's evolving climate-policy environment increasingly positions adaptation as integral to sustainable development and public infrastructure planning. National adaptation priorities include strengthening water and sanitation systems, improving disaster-risk management, protecting vulnerable settlements, and increasing the resilience of strategic transport and economic infrastructure. The national adaptation agenda further recognises that climate resilience must be embedded across sectors and spheres of government rather than treated as a separate environmental programme (Department of Forestry, Fisheries and the

The Seybold REPORT
ISSN 1533-9211
DOI: 10.5281/zenodo.22127018

Environment, 2020). This policy direction creates a strong rationale for incorporating climate-risk considerations into project appraisal, design briefs, procurement processes, construction practices, asset management and infrastructure renewal.

Accordingly, this article examines adaptation strategies for buildings and infrastructure under extreme weather conditions in South Africa. Specifically, it identifies the principal climate risks affecting construction activities and built assets; discusses practical adaptation measures for buildings and infrastructure; examines institutional, financial and implementation barriers; and proposes an integrated framework to support climate-resilient construction practice. By linking technical design interventions with governance, planning and social considerations, the article contributes to the growing discourse on how South Africa can deliver a built environment that is safer, more adaptive and more equitable under changing climatic conditions.

2. CLIMATE RISKS TO THE SOUTH AFRICAN BUILT ENVIRONMENT

South Africa's built environment is exposed to a diverse and spatially differentiated range of climate-related hazards. The nature and severity of these risks vary according to geographic location, climatic zone, settlement pattern, topography, infrastructure condition and socioeconomic circumstances (Ziervogel *et al*., 2014). Coastal settlements and infrastructure corridors are particularly vulnerable to sea-level rise, coastal erosion, storm surges, high waves and strong wind conditions, all of which may damage coastal roads, ports, buildings, bulk services and tourism infrastructure (Knight, 2025). Inland urban areas are increasingly exposed to pluvial flooding, heatwaves, water stress and periods of drought, particularly where rapid urbanisation has increased impermeable surfaces and placed pressure on ageing drainage and water-supply infrastructure (Roberts, 2010). The South African Green Book identifies inland flooding, drought, wildfire and coastal flooding as major climate-related threats to settlements, illustrating the need for localised and risk-sensitive planning responses (Van Niekerk, 2020).

The Western Cape is especially susceptible to recurring drought, water scarcity, wildfire and rainfall variability, which place pressure on water-dependent infrastructure, agricultural systems, residential developments and construction operations (Ziervogel *et al*., 2014). Drought conditions can constrain the availability of water for concrete mixing, dust suppression, compaction, cleaning and other construction-related activities, while also increasing competition between domestic, industrial and construction water users (Nhamo, Mabhaudhi and Modi, 2019). High temperatures may further affect the durability and performance of construction materials, increase cooling requirements in buildings and create occupational health and safety risks for outdoor workers (Sovacool *et al*., 2021). In KwaZulu-Natal and other eastern parts of South Africa, the combination of intense rainfall, steep terrain, river catchments and dense settlement patterns creates a particularly high risk of flooding, landslides, erosion and storm-related infrastructure failure (Dlamini, Nhleko and Ubisi, 2024). Extreme weather affects construction and built assets through several interrelated pathways. First, it can directly damage buildings and physical infrastructure. Floodwater may undermine foundations, scour bridge abutments, erode road embankments, overload stormwater drainage networks, damage electrical installations and compromise structural components exposed to prolonged moisture (Thurman *et al*., 2023). Heavy rainfall and associated slope failures can also damage retaining structures, water pipelines, sewer networks and access roads, thereby increasing repair costs and disrupting the delivery of essential services (Sivakumar and Fazel-Rastgar, 2021).

The April 2022 KwaZulu-Natal floods provide a critical illustration of this risk, as the event caused extensive damage to roads, bridges, water infrastructure, schools, health facilities and residential buildings across eThekwini and surrounding areas (Mthembu and Hlabangane, 2023). Climate attribution research has further found that the rainfall associated with the April 2022 Durban flood event was substantially intensified by anthropogenic climate change, highlighting the importance of designing for changing rather than historical climatic conditions (Pinto et al., 2025).**wits.ac**

Second, climate-related disasters can interrupt the functioning of interconnected infrastructure systems. Failure in one infrastructure system may trigger cascading effects across transport, energy, water, sanitation, communication and emergency-response services (Pescaroli and Alexander, 2015). For example, flooding may wash away roads and bridges, restrict access to hospitals and water-treatment facilities, disrupt electricity supply, damage telecommunications infrastructure and delay the movement of emergency personnel, construction materials and essential goods (Ogie, Perez and Dignum, 2020). Such failures are especially significant in metropolitan areas, where the continuous operation of infrastructure networks is essential for economic activity, public health and service delivery (Markolf *et al*., 2019).

Third, climate hazards increase project-level risks during the construction phase. Heavy rainfall can delay excavation, earthworks, foundation construction, concrete placement, roadworks and material transportation, while also increasing erosion, sedimentation and site-safety risks (Aghimien *et al*., 2018).

Excessive heat can reduce worker productivity, increase dehydration and heat-stress risks, and affect the curing and workability of concrete if construction processes are not appropriately managed (Kjellstrom, Freyberg and Lemke, 2018). Flood-related damage to roads, rail networks and ports can also interrupt construction supply chains, delay the delivery of materials and plant, and increase project costs through downtime, disruption and contractual claims (Doloi, 2013).

Fourth, climate hazards magnify pre-existing infrastructure vulnerabilities. Ageing assets, inadequate preventative maintenance, insufficient drainage capacity, poor-quality construction and limited municipal financial resources reduce the ability of infrastructure systems to resist, absorb and recover from extreme events (Nhemachena, Matchaya and Nhemachena, 2014).

The challenge is therefore not merely to rebuild damaged infrastructure after disasters, but to strengthen roads, railways, water systems, ports, settlements and public facilities so that they can continue to operate under more intense rainfall, heat stress, high winds, drought and coastal hazards. This requires climate-informed design standards, lifecycle asset management, resilient procurement practices and coordinated planning across the built-environment professions and all spheres of government (Williams *et al*., 2019).

ISSN 1533-9211
DOI: 10.5281/zenodo.22127018

3. ADAPTATION STRATEGIES FOR BUILDINGS

Climate-resilient buildings should be planned, designed, constructed and maintained to anticipate climate hazards over their full-service life rather than merely complying with historical climatic conditions. Building-level adaptation is particularly important in South Africa because climate-related risks intersect with rapid urbanisation, uneven infrastructure provision, housing deficits and widespread exposure of vulnerable households to flooding, heat and water insecurity (Ziervogel *et al*., 2014). Effective strategies should consequently combine risk-informed site planning, flood-resilient detailing, passive thermal design, water conservation and lifecycle-oriented material selection.

3.1 Climate-risk-informed site planning

Many of the most cost-effective resilience decisions are made before construction begins, particularly through appropriate site selection, layout planning and development control (Hallegatte, 2009). Site appraisal should therefore incorporate flood-line mapping, stormwater modelling, geotechnical investigations, slope-stability assessments, wildfire-risk assessments, coastal-hazard analysis and local heat-risk assessment before a project is approved or designed (Van Niekerk, 2020). In flood-prone areas, development should be avoided where possible, particularly within floodplains, wetlands, riparian buffers and natural drainage corridors, because development in these locations can increase exposure while also reducing the natural capacity of ecosystems to attenuate floodwater (Douglas *et al*., 2008). Where development cannot reasonably be avoided, design teams should demonstrate that risks can be reduced to an acceptable level through appropriate elevation, drainage, protective works, emergency access, stormwater management and evacuation arrangements (Schanze, 2017). Construction on unstable slopes should be preceded by detailed geotechnical assessment because intense rainfall may trigger erosion, landslides and foundation instability, especially where vegetation has been removed or drainage is poorly managed (Gariano and Guzzetti, 2016). Municipal spatial development frameworks and land-use management processes should incorporate both current climate hazards and projected future climate conditions, rather than relying exclusively on historical records that may no longer represent future risk levels (Roberts, 2010). This is especially important in rapidly urbanising South African municipalities, where housing and infrastructure pressure can encourage development in environmentally sensitive or high-risk areas (Williams *et al*., 2019).

3.2 Flood-resilient building design

Flood-resilient building design should aim to prevent water ingress where possible, limit structural and material damage if inundation occurs, protect critical services and allow buildings to recover quickly after a flood event (Escarameia, Tagg and Walliman, 2018). In exposed locations, finished floor levels should be raised above locally determined flood-design levels, with an additional safety margin where future rainfall intensity or flood levels are likely to increase (Kreibich *et al*., 2015). Positive site drainage should direct surface water away from buildings, while safe overland-flow routes should be retained to prevent water from being trapped against walls, foundations and entrances (Jha, Bloch and Lamond, 2012). Flood-

The Seybold Report
ISSN 1533-9211
DOI: 10.5281/zenodo.22127018

resistant materials should be used in areas most likely to experience water contact, particularly lower wall sections, floor finishes, insulation systems and service zones (Kelman and Spence, 2004). Electrical distribution boards, backup generators, pumps, boilers and other critical mechanical equipment should be installed above anticipated flood levels to reduce electrical hazards and support rapid reoccupation following an event (Joyce *et al*., 2018). Plumbing systems can incorporate non-return valves to reduce sewage backflow during flood conditions, while roofs, gutters and downpipes should be designed to accommodate high-intensity rainfall and prevent uncontrolled runoff around the building perimeter (Fletcher *et al*., 2015).

For low-income housing, schools, clinics and community facilities, adaptation measures must be affordable, easy to maintain and appropriate to local construction methods. Practical interventions such as secure roof fixings, raised thresholds, improved drainage channels, larger gutters, waterproofing treatments and properly anchored lightweight structures can significantly reduce weather-related damage without requiring complex technologies (Satterthwaite *et al*., 2020). Such measures are particularly relevant in informal settlements, where poor drainage, inadequate building materials and settlement location contribute to heightened flood vulnerability (Dlamini, Nhleko and Ubisi, 2024).

3.3 Heat-resilient and passive design

Increasing temperatures and more frequent heatwaves make thermal comfort, indoor environmental quality and energy resilience central considerations in building design (Kjellstrom *et al*., 2016). Buildings should first minimise unwanted heat gain through passive strategies before relying on energy-intensive mechanical cooling systems (Givoni, 1998). Appropriate orientation, external shading, roof insulation, reflective roof finishes, natural ventilation, thermal mass, vegetated outdoor spaces and carefully designed window-to-wall ratios can reduce indoor temperatures and cooling demand (Mahlobo, 2020). In South African climatic conditions, effective solar shading is widely recognised as a key passive-design strategy for improving indoor comfort and reducing energy use across different building types (Van der Walt and Rautenbach, 2018). Passive cooling is especially valuable where households cannot afford air-conditioning or where electricity supply is unreliable. A South African experimental study of informal housing found that cool roof-coating interventions can reduce internal temperatures, indicating the potential value of low-cost passive cooling measures for heat-exposed households (Mahlobo, 2020). Schools, clinics, social housing, elderly-care facilities and other buildings serving vulnerable groups should receive priority attention because children, older persons and individuals with existing health conditions may face elevated risks during heatwave events (Vandentorren *et al*., 2006).

3.4 Water resilience

Water scarcity and drought require buildings to reduce potable-water demand and, where technically feasible and legally permissible, diversify non-potable water sources (Nhamo, Mabhaudhi and Modi, 2019). Water-efficient fittings, pressure management, leak detection, rainwater harvesting, greywater reuse, drought-tolerant landscaping and on-site storage can reduce dependence on municipal supply and improve household-level water security (Armitage *et al*., 2013). Research on formal residential areas in South Africa suggests that the combined use of rainwater harvesting, greywater reuse and groundwater sources can substantially reduce theoretical potable municipal-water demand, although the practical implications for water quality, system management and municipal planning require careful consideration (Haarhoff and Van der Merwe, 2017). Rainwater-harvesting systems should be designed according to local rainfall patterns, roof-catchment area, storage capacity, water-demand profile, water-quality requirements and maintenance capability (Campisano *et al*., 2017). Rainwater should not automatically be treated as suitable for drinking without appropriate treatment and testing, particularly where roof surfaces, storage conditions or local pollution sources may affect quality (Ahmed *et al*., 2011). Greywater systems should similarly be designed for clearly defined non-potable uses, such as toilet flushing or irrigation, and should include appropriate treatment, plumbing separation, user guidance and maintenance procedures to manage health risks (Eriksson *et al*., 2002).

3.5 Material durability and maintainability

Material selection should respond to anticipated exposure to moisture, ultraviolet radiation, high temperatures, wildfire, corrosion, wind loading and repeated wetting-and-drying cycles (Häkkinen and Belloni, 2011). Climate-resilient construction does not necessarily depend on costly imported products; rather, it requires locally appropriate materials and assemblies that can withstand foreseeable climate stressors, be maintained with available skills and resources, and deliver acceptable performance throughout their intended service life (Horne, 2009). In coastal areas, designers should consider corrosion-resistant components and protective coatings because salt-laden air can accelerate material deterioration and reduce the durability of steel, reinforced concrete and mechanical systems (Bertolini *et al*., 2013). Wind-resistant roof systems, secure connections, moisture-tolerant finishes, fire-resistant external materials and durable external surfaces should be selected in accordance with site-specific hazards and expected exposure conditions (Calkins, 2009). Lifecycle cost analysis should guide material and design decisions because the lowest initial construction cost may produce substantially higher repair, replacement, disruption and maintenance costs over the life of the building (Gluch and Baumann, 2004). A lifecycle approach therefore enables clients and project teams to assess resilience investments in terms of long-term performance, reduced disruption, lower maintenance burdens and improved occupant safety rather than only short-term capital expenditure.

4. INFRASTRUCTURE ADAPTATION STRATEGIES

Climate-resilient infrastructure is fundamental to South Africa's economic development, public safety and continuity of essential services because extreme weather can disrupt interconnected transport, water, sanitation, energy and communication systems. Infrastructure adaptation should therefore combine climate-risk assessment, resilient engineering design, ecosystem-based measures, preventative maintenance and coordinated management of critical infrastructure networks (Markolf *et al*., 2019). South Africa's national adaptation agenda recognises resilient infrastructure, water security, disaster-risk reduction and climate-resilient

The Seybold Report
ISSN 1533-9211
DOI: 10.5281/zenodo.22127018

human settlements as core adaptation priorities, reinforcing the need to integrate climate risks into infrastructure planning, financing, construction and asset management (Department of Forestry, Fisheries and the Environment, 2020).

4.1 Resilient transport infrastructure

Transport infrastructure is essential for economic activity, emergency response, access to health and education facilities, and the functioning of construction and wider supply chains (Beukes, 2019). Roads, bridges, railways and ports are increasingly exposed to intense rainfall, river flooding, heat stress, severe winds, wildfire and coastal hazards, which can undermine their structural integrity and operational reliability (Lane-Visser and Vanderschuren, 2023).

A South African assessment of climate-related transport risk found that flooding and wildfire could expose substantial portions of Cape Town's transport infrastructure to damage, demonstrating the financial implications of inadequate climate adaptation in urban transport systems (Lane-Visser and Vanderschuren, 2023).

Adaptation measures for roads and bridges should include increasing drainage capacity, protecting road embankments from erosion, strengthening bridge foundations against scour, improving slope stabilisation and considering climate-responsive pavement materials that can tolerate higher temperatures and repeated wetting-and-drying cycles (Archer *et al*., 2015).

New transport infrastructure should incorporate projected future rainfall intensities and flood levels into its planning and design, rather than depending exclusively on historical climate data (Beukes, 2019). Raised road alignments, adequately sized culverts, open drainage channels and protected floodways may reduce flood-related isolation and improve access to rural communities during severe rainfall events (Beukes, 2019).

In coastal areas, the planning and design of transport infrastructure should account for sea-level rise, coastal erosion, wave overtopping, storm surge and high-wind exposure, particularly for roads, railways and ports located near estuaries and shorelines (Theron and Rossouw, 2008). This may require managed setbacks, elevated structures, coastal protection works, improved drainage and, where risk cannot be reduced cost-effectively, the relocation of exposed assets (Hinkel *et al*., 2018).

Transport-resilience measures should also include real-time weather monitoring, early-warning systems, emergency route planning and rapid post-event inspection procedures to support operational continuity during severe weather (Vinet *et al*., 2019). Infrastructure failure frequently results from insufficient maintenance as well as inadequate design. Blocked stormwater inlets, damaged culverts, eroded channels, potholes, neglected bridge components and delayed repairs can turn moderate rainfall into major road and access failures (Mashamaite, 2025).

Resilient transport systems therefore require funded asset-management programmes, routine condition assessments, preventative maintenance, climate-risk screening of maintenance priorities and timely rehabilitation of vulnerable infrastructure elements (Lane-Visser and Vanderschuren, 2023).

ISSN 1533-9211
DOI: 10.5281/zenodo.22127018

4.2 Water, sanitation and stormwater systems

Water and sanitation infrastructure must be designed and operated to manage both drought and flood conditions, which may occur in the same municipality across different seasons or years (Muller, 2018). During drought, adaptation measures include diversifying water sources, reducing distribution losses, implementing demand-management measures, promoting water reuse, expanding storage where appropriate and protecting strategic water-source areas (Nhamo, Mabhaudhi and Modi, 2019). During intense rainfall, wastewater treatment works, pump stations, sewer networks and water-treatment facilities require protection against inundation, inflow and infiltration, power outages and contamination events that can compromise public health and environmental quality (Armitage *et al*., 2013). Urban stormwater management should move beyond the conventional objective of rapidly conveying runoff away from developed sites through piped drainage systems. Water-sensitive urban design promotes an integrated approach that seeks to slow, store, infiltrate, treat and, where feasible, reuse stormwater while improving urban liveability and ecological performance (Fisher-Jeffes, Carden and Armitage, 2017). Measures such as detention ponds, bioswales, permeable paving, infiltration zones, constructed wetlands, rain gardens and restored river corridors can reduce runoff volumes and peak flows while improving water quality and providing environmental amenities (Fletcher *et al*., 2015).

Water-sensitive design offers particular value in South African cities where conventional stormwater systems are already overloaded, expensive to extend or poorly maintained. A South African framework for water-sensitive urban design emphasises that implementation should integrate technical infrastructure with land-use planning, governance arrangements and community participation, rather than treating stormwater management as a purely engineering function (Carden and Fell, 2021). Such integrated approaches can reduce flood exposure, strengthen water security and create multifunctional public spaces that support biodiversity, recreation and urban cooling (Fisher-Jeffes, Carden and Armitage, 2017).

4.3 Nature-based solutions

Nature-based solutions complement conventional engineering by using ecosystems and ecological processes to reduce climate risks and improve infrastructure performance (Cohen-Shacham *et al*., 2016). Wetlands, riparian buffers, coastal dunes, urban forests, vegetated open spaces and restored floodplains can attenuate runoff, reduce erosion, improve water quality, enhance urban cooling and support biodiversity (Kabisch *et al*., 2017). In South African settlements, the protection and rehabilitation of wetlands is especially important because wetlands can store water, reduce downstream flood peaks and improve water quality by filtering sediments and pollutants (Kotze, Ellery and Grenfell, 2012). For example, wetland rehabilitation upstream of a settlement may reduce the speed and volume of floodwater reaching downstream communities while also improving ecological functioning and supporting water-related livelihoods (Rebelo, Finlayson and Nagabhatla, 2018). Nature-based measures should not be treated as substitutes for essential engineered infrastructure, particularly where high-density development requires formal drainage, flood protection and sanitation systems. Instead, hybrid solutions that combine engineered infrastructure with

The Seybold REPORT

ISSN 1533-9211

DOI: 10.5281/zenodo.22127018

restored ecosystems can provide greater resilience, lower lifecycle costs and multiple social and environmental co-benefits (Seddon *et al*., 2020).

4.4 Energy and critical facilities

Hospitals, clinics, schools, emergency operations centres, shelters, water-treatment works and wastewater-treatment facilities require enhanced resilience because their failure during extreme weather can cause severe and immediate social consequences (Ouyang, 2014). Critical facilities should incorporate protected electrical installations, backup power supply, fuel-storage arrangements, redundant communication systems, secure water storage, heat-resilient internal spaces and reliable emergency access routes (Krausmann *et al*., 2011). In flood-prone areas, critical electrical and mechanical systems should be elevated or protected above design flood levels to limit damage and enable essential services to resume rapidly after an event (Joyce *et al*., 2018). Critical-infrastructure planning should identify and manage interdependencies between systems. A water-treatment plant, for instance, depends on electricity for pumping and treatment, functioning roads for the delivery of chemicals and maintenance access, telecommunications for operational coordination, and skilled personnel who must be able to reach the facility during an emergency (Rinaldi, Peerenboom and Kelly, 2001). Failure in one system may therefore trigger cascading disruption across several other sectors, increasing the scale and duration of a disaster's impacts (Pescaroli and Alexander, 2015). Climate-resilient infrastructure planning must consequently assess system-wide risk, provide redundancy where feasible and establish coordinated emergency-response arrangements rather than treating roads, water, energy and communication assets as independent systems.

5. GOVERNANCE, PROCUREMENT AND DELIVERY CHALLENGES

Technical interventions alone cannot deliver climate resilience in South Africa because effective adaptation depends on governance arrangements that integrate climate science, spatial planning, engineering, procurement, finance, maintenance and community participation across national, provincial and local spheres of government. Although the Climate Change Act 22 of 2024 establishes a statutory framework requiring provincial, metropolitan and district authorities to assess climate risks and develop response implementation plans integrated with planning instruments, implementation remains constrained by fragmented institutional responsibilities, uneven municipal capacity, limited climate-data access, skills shortages, insufficient funding and weak regulatory enforcement (Republic of South Africa, 2024). Climate risks are also frequently inadequately incorporated into infrastructure design criteria, while maintenance backlogs, underfunded asset management and procurement systems focused primarily on lowest initial cost can undermine the long-term performance of public assets (Pieterse and Du Toit, 2025). Addressing these barriers requires procurement reform through tender requirements that specify climate-risk assessment, minimum resilience performance standards, lifecycle cost evaluation and maintenance obligations, alongside contractor requirements for weather-responsive programming, drainage and erosion controls, heat-stress protection and material-preservation measures; such reforms would shift

ISSN 1533-9211

DOI: 10.5281/zenodo.22127018

construction delivery from reactive post-disaster repair towards proactive, climate-informed infrastructure investment.

6. PROPOSED CLIMATE-RESILIENT CONSTRUCTION FRAMEWORK

Figure 1 presents the proposed Climate-Resilient Construction Delivery Framework for South Africa. The framework conceptualises climate resilience as a continuous and iterative project-lifecycle process, beginning with climate-risk assessment and vulnerability analysis, followed by adaptive design and resilient project delivery, and concluding with post-event monitoring and institutional learning. Governance, finance, climate information, community participation and lifecycle asset management operate as cross-cutting enablers throughout all framework stages. The framework supports a transition from reactive post-disaster reconstruction towards anticipatory, risk-informed and adaptive construction investment.

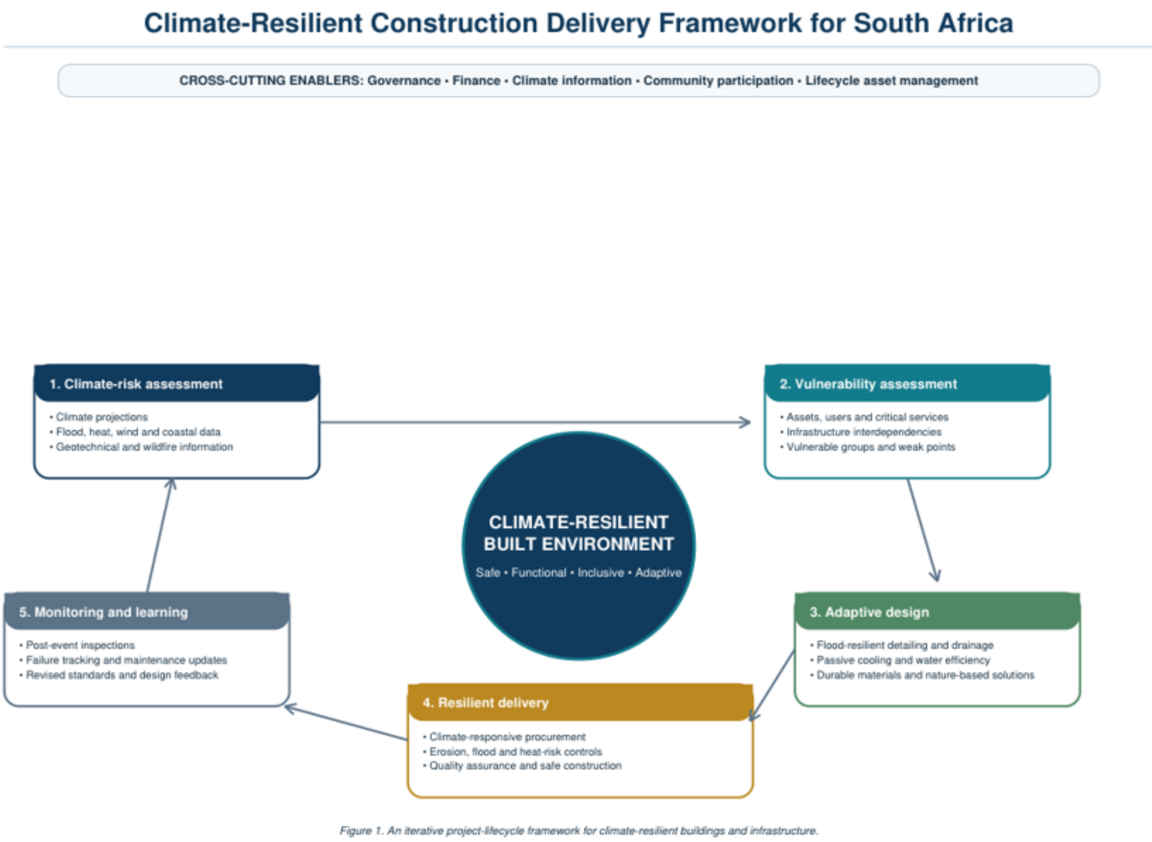

Figure 1: Proposed Climate-Resilient Construction Delivery Framework for South Africa

Source: Authors' own conceptualisation, informed by Ziervogel et al. (2014), Roberts (2010), Williams et al. (2019), Markolf et al. (2019), and Seddon et al. (2020).

ISSN 1533-9211
DOI: 10.5281/zenodo.22127018

Climate-resilient construction is no longer optional for South Africa; it is an essential requirement for safeguarding lives, sustaining economic activity and protecting long-term public and private infrastructure investment. As floods, droughts, heatwaves, severe storms and coastal hazards become more disruptive, the construction sector must move beyond reactive repair towards anticipatory, climate-informed planning, design, procurement, delivery and asset management. The proposed Climate-Resilient Construction Delivery Framework provides a practical basis for integrating climate-risk assessment, vulnerability analysis, adaptive design, resilient construction practices and continuous learning across the lifecycle of buildings and infrastructure. Its successful implementation will depend on coordinated governance, adequate financing, improved technical capacity, effective regulation and meaningful community participation. By embedding resilience into everyday built-environment decisions, South Africa can develop buildings and infrastructure that are safer, more functional, socially inclusive and better able to withstand changing climatic conditions.

7. CONCLUSION

Climate-resilient construction is essential for safeguarding South Africa's buildings, infrastructure, communities and economy against increasingly frequent and severe floods, droughts, heatwaves, wildfires, strong winds and coastal hazards. The construction sector must therefore move beyond reactive post-disaster repair by embedding climate-risk assessment, vulnerability analysis, adaptive design, resilient procurement, quality construction, preventative maintenance and post-event learning throughout the lifecycle of built assets. Building-level interventions, including flood-resistant detailing, passive cooling, water-efficient systems and durable materials, should be combined with resilient transport, water, sanitation, energy and stormwater infrastructure, supported where appropriate by nature-based solutions. However, technical interventions alone are insufficient; successful implementation requires coordinated governance, strengthened municipal capacity, adequate financing, climate-informed planning, lifecycle procurement and meaningful community participation. The proposed Climate-Resilient Construction Delivery Framework provides a practical basis for shifting South Africa towards anticipatory, inclusive and climate-informed infrastructure investment, enabling the built environment to remain safe, functional and adaptive under changing climatic conditions.

References

1) Ahmed, W., Huygens, F., Goonetilleke, A. and Gardner, T. (2011) 'Real-time PCR detection of pathogenic microorganisms in roof-harvested rainwater in southeast Queensland, Australia', *Applied and Environmental Microbiology*, 77(15), pp. 5490–5496.

2) Armitage, N., Vice, M., Fisher-Jeffes, L., Winter, K., Spiegel, A. and Dunstan, J. (2013) *The South African guidelines for sustainable drainage systems*. Pretoria: Water Research Commission.

3) Beukes, E. (2019) 'Rural transport and climate change in South Africa', *Jàmbá: Journal of Disaster Risk Studies*, 11(3), a718.

4) Bertolini, L., Elsener, B., Pedeferri, P., Polder, R. and Andrade, C. (2013) *Corrosion of steel in concrete: Prevention, diagnosis, repair*. 2nd edn. Weinheim: Wiley-VCH.

The Seybold REPORT

ISSN 1533-9211

DOI: 10.5281/zenodo.22127018

5) Campisano, A., Butler, D., Ward, S., Burns, M.J., Friedler, E., DeBusk, K., Fisher-Jeffes, L.N., Ghisi, E., Rahman, A., Furumai, H. and Han, M. (2017) 'Urban rainwater harvesting systems: Research, implementation and future perspectives', *Water Research*, 115, pp. 195–209.

6) Carden, K. and Fell, J. (2021) 'A community of practice approach to planning water-sensitive cities in South Africa', *Urban Planning*, 6(4), pp. 316–329.

7) Cohen-Shacham, E., Walters, G., Janzen, C. and Maginnis, S. (eds.) (2016) *Nature-based solutions to address global societal challenges*. Gland: International Union for Conservation of Nature.

8) Department of Forestry, Fisheries and the Environment (DFFE) (2020) *National Climate Change Adaptation Strategy: Republic of South Africa*. Pretoria: Department of Forestry, Fisheries and the Environment.

9) Dlamini, S., Nhleko, B. and Ubisi, N. (2024) 'Understanding socioeconomic risk and vulnerability to climate change-induced disasters: The case of informal settlements in KwaZulu-Natal, South Africa', *Journal of Asian and African Studies*. doi: 10.1177/00219096241275398.

10) Douglas, I., Alam, K., Maghenda, M., McDonnell, Y., McLean, L. and Campbell, J. (2008) 'Unjust waters: Climate change, flooding and the urban poor in Africa', *Environment and Urbanization*, 20(1), pp. 187–205.

11) Eriksson, E., Auffarth, K., Henze, M. and Ledin, A. (2002) 'Characteristics of grey wastewater', *Urban Water*, 4(1), pp. 85–104.

12) Escarameia, M., Tagg, A. and Walliman, N. (2018) 'Improving the flood resilience of buildings through flood-resistant design and construction', *Proceedings of the Institution of Civil Engineers – Water Management*, 171(6), pp. 303–315.

13) Fisher-Jeffes, L., Carden, K. and Armitage, N. (2017) 'A water sensitive urban design framework for South Africa', *Town and Regional Planning*, 71, pp. 1–10.

14) Fletcher, T.D., Shuster, W., Hunt, W.F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J.-L., Mikkelsen, P.S., Rivard, G., Uhl, M., Dagenais, D. and Viklander, M. (2015) 'SUDS, LID, BMPs, WSUD and more: The evolution and application of terminology surrounding urban drainage', *Urban Water Journal*, 12(7), pp. 525–542.

15) Folke, C., Hahn, T., Olsson, P. and Norberg, J. (2005) 'Adaptive governance of social-ecological systems', *Annual Review of Environment and Resources*, 30, pp. 441–473.

16) Gariano, S.L. and Guzzetti, F. (2016) 'Landslides in a changing climate', *Earth-Science Reviews*, 162, pp. 227–252.

17) Givoni, B. (1998) *Climate considerations in building and urban design*. New York: Van Nostrand Reinhold.

18) Gluch, P. and Baumann, H. (2004) 'The life cycle costing approach: A conceptual discussion of its usefulness for environmental decision-making', *Building and Environment*, 39(5), pp. 571–580.

19) Haarhoff, J. and Van der Merwe, B. (2017) 'Supplementary household water sources to augment potable water supply in South Africa', *Water SA*, 43(4), pp. 639–650.

20) Hallegatte, S. (2009) 'Strategies to adapt to an uncertain climate change', *Global Environmental Change*, 19(2), pp. 240–247.

21) Häkkinen, T. and Belloni, K. (2011) 'Barriers and drivers for sustainable building', *Building Research and Information*, 39(3), pp. 239–255.

22) Hinkel, J., Aerts, J.C.J.H., Brown, S., Jiménez, J.A., Lincke, D., Nicholls, R.J., Scussolini, P. and Addo, K.A. (2018) 'The ability of societies to adapt to twenty-first-century sea-level rise', *Nature Climate Change*, 8, pp. 570–578.

ISSN 1533-9211

DOI: 10.5281/zenodo.22127018

23) Horne, R. (2009) 'Limits to environmental sustainability in the built environment', *Built Environment*, 35(2), pp. 175–189.

24) Jha, A.K., Bloch, R. and Lamond, J. (2012) *Cities and flooding: A guide to integrated urban flood risk management for the 21st century*. Washington, DC: World Bank.

25) Joyce, J., Chang, N.-B., Harji, R. and Ruppert, T. (2018) 'Flood-resilient infrastructure and adaptation measures for critical facilities', *Sustainable Cities and Society*, 38, pp. 107–118.

26) Kabisch, N., Korn, H., Stadler, J. and Bonn, A. (eds.) (2017) *Nature-based solutions to climate change adaptation in urban areas: Linkages between science, policy and practice*. Cham: Springer.

27) Kelman, I. and Spence, R. (2004) 'An overview of flood actions on buildings', *Engineering Geology*, 73(3–4), pp. 297–309.

28) Kjellstrom, T., Freyberg, C. and Lemke, B. (2018) 'Heat, human performance, and occupational health: A key issue for the assessment of global climate change impacts', *Annual Review of Public Health*, 39, pp. 97–112.

29) Knight, J. (2025) 'Challenges for coastal management and conservation under climate change in South Africa', *Koedoe*, 67(1), a1845.

30) Kotze, D.C., Ellery, W.N. and Grenfell, M.C. (2012) 'Wetland management in South Africa: A review of the current state of knowledge', *Water SA*, 38(1), pp. 1–10.

31) Krausmann, E., Cruz, A.M. and Affeltranger, B. (2011) 'The impact of the 11 March 2011, Great East Japan earthquake and tsunami on industrial facilities and infrastructure', *Natural Hazards*, 59, pp. 1–17.

32) Kreibich, H., Van den Bergh, J.C.J.M., Bouwer, L.M., Bubeck, P., Ciavola, P., Duhr, S., Klostermann, J.E.M., Mazzoleni, S., Meurs, H., Moel, H., Balica, S.F., Bouwer, L.M., et al. (2015) 'Costing natural hazards: New challenges and perspectives', *Natural Hazards and Earth System Sciences*, 15, pp. 1–20.

33) Lane-Visser, T.E. and Vanderschuren, M.J.W.A. (2023) 'A climate-impact-related transport infrastructure risk assessment for the City of Cape Town', *Journal of the South African Institution of Civil Engineering*, 65(4), Article 1622.

34) Mahlobo, T. (2020) 'Passive cooling for thermal comfort in informal housing', *Journal of Energy in Southern Africa*, 31(1), pp. 1–12.

35) Mannakkara, S. and Wilkinson, S. (2014) 'Re-conceptualising "building back better" to improve post-disaster recovery', *International Journal of Managing Projects in Business*, 7(3), pp. 327–341.

36) Markolf, S.A., Chester, M.V., Eisenberg, D.A., Iwaniec, D.M., Davidson, C.I., Zimmerman, R. and Miller, T.R. (2019) 'Interdependent infrastructure as linked social, ecological, and technological systems', *Environmental Research Letters*, 13(12), 124007.

37) Meerow, S., Newell, J.P. and Stults, M. (2016) 'Defining urban resilience: A review', *Landscape and Urban Planning*, 147, pp. 38–49.

38) Muller, M. (2018) 'Lessons from Cape Town's drought', *Nature Sustainability*, 1, pp. 558–560.

39) Nhamo, L., Mabhaudhi, T. and Modi, A.T. (2019) 'Preparedness of South African agriculture for climate change', *Agriculture and Food Security*, 8, Article 39.

40) Ouyang, M. (2014) 'Review on modeling and simulation of interdependent critical infrastructure systems', *Reliability Engineering and System Safety*, 121, pp. 43–60.

41) Pescaroli, G. and Alexander, D. (2015) 'A definition of cascading disasters and cascading effects: Going beyond the "toppling dominos" metaphor', *Planet@Risk*, 3(1), pp. 58–67.

ISSN 1533-9211
DOI: 10.5281/zenodo.22127018

42) Republic of South Africa (2024) *Climate Change Act 22 of 2024*. Government Gazette No. 50966, 23 July. Pretoria: Government Printer.

43) Rinaldi, S.M., Peerenboom, J.P. and Kelly, T.K. (2001) 'Identifying, understanding, and analysing critical infrastructure interdependencies', *IEEE Control Systems Magazine*, 21(6), pp. 11–25.

44) Roberts, D. (2010) 'Prioritizing climate change adaptation and local level resilience in Durban, South Africa', *Environment and Urbanization*, 22(2), pp. 397–413.

45) Satterthwaite, D., Archer, D., Colenbrander, S., Dodman, D., Hardoy, J. and Patel, S. (2020) 'Building resilience to climate change in informal settlements', *One Earth*, 2(2), pp. 143–156.

46) Schanze, J. (2017) 'Nature-based solutions in flood risk management: Buzzword or innovation?', *Journal of Flood Risk Management*, 10(3), pp. 281–282.

47) Seddon, N., Chausson, A., Berry, P., Girardin, C.A.J., Smith, A. and Turner, B. (2020) 'Understanding the value and limits of nature-based solutions to climate change and other global challenges', *Philosophical Transactions of the Royal Society B*, 375(1794), 20190120.

48) Sovacool, B.K., Martiskainen, M., Hook, A. and Baker, L. (2021) Decarbonization and its discontents: A critical energy justice perspective on four low-carbon transitions', *Climatic Change*, 164, Article 41.

49) Theron, A.K. and Rossouw, M. (2008) 'Analysis of potential coastal-zone climate-change impacts and possible response options in South Africa', *Journal of the South African Institution of Civil Engineering*, 50(2), pp. 13–19.

50) Van Niekerk, W. (2020) 'Introducing the Green Book: A practical planning tool for climate resilience in South African settlements', *Town and Regional Planning*, 77, pp. 79–88.

51) Vandentorren, S., Bretin, P., Zeghnoun, A., Mandereau-Bruno, L., Croisier, A., Cochet, C., Rigaud, E., Declercq, B. and Ledrans, M. (2006) 'August 2003 heat wave in France: Risk factors for death of elderly people living at home', *European Journal of Public Health*, 16(6), pp. 583–591.

52) Vinet, F., Boissier, L. and Defossez, S. (2019) 'Deaths related to flash floods in southern France: A new assessment', *Natural Hazards and Earth System Sciences*, 19, pp. 589–606.

53) Williams, D.S., Máñez Costa, M., Sutherland, C., Celliers, L. and Scheffran, J. (2019) 'Vulnerability of informal settlements in the context of rapid urbanization and climate change', *Environment and Urbanization*, 31(1), pp. 157–176. doi: 10.1177/0956247818819694.

54) Ziervogel, G., New, M., Archer van Garderen, E., Midgley, G., Taylor, A., Hamann, R., Stuart-Hill, S., Myers, J. and Warburton, M. (2014) 'Climate change impacts and adaptation in South Africa', *Wiley Interdisciplinary Reviews: Climate Change*, 5(5), pp. 605–620. doi: 10.1002/wcc.295.