Intellectual Output 3

A Framework on adapting coastal built environment to the effects of climate change during design, construction, and retrofitting-A Systematic Review

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Contents

1 Introduction

Climate change has become a predominant problem that the world is confronted with. As IPCC sixth assessment report highlights, anthropogenic Green House Gas (GHGs) emission becomes a key driver of climate change(Working Group| Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021). Coastal regions are experiencing significant impacts due to climate change(Ngo-Duc, 2014; Y. Zhang et al., 2019). In fact, past climate-related disasters such as cyclones, sea-level rise and coastal flooding have elaborated the vulnerabilities of different coastal regions(UNDRR & CRED, 2020). The built environment emits a significant amount of GHGs, so it significantly influences the local climate(Anderson et al., 2015; Holz-Rau & Scheiner, 2019). Also, the built environment has significant impacts on the coastal community's environment(Gibbs, 2020; Malalgoda et al., 2014a). In addition, coastal areas are densely populated with urban centres near the coastal belt contributing to the developing country's economy. This exacerbates the aforementioned issues within the coastal built environment associated with climate change(B. Neumann et al., 2015; Zanetti et al., 2016). With this context, Climate Change Adaptation (CCA) of the built environment is a crucial aspect to cope with the present landscape of climate change and associated impacts(Aguiar et al., 2018; Megahed & Ghoneim, 2020; Stagrum et al., 2020; Working Group| Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021).

Moreover, three landmark global agendas (the Paris Agreement, the Sustainable Development Goals (SDGs), and the Sendai Framework for Disaster Risk Reduction 2015-2030 (SFDRR) were adopted by global leaders aiming to address these issues(Lenzholzer et al., 2020). The key thematic areas addressed by those global agendas (i.e., climate change, sustainable development, and disaster risk reduction) are intrinsically interconnected(Ginige et al., 2013; Malalgoda et al., 2013). At the moment, there is a lack of integration of the climate change adaptation into the coastal built environment during planning, design, construction, maintenance, and retrofitting(Malalgoda et al., 2014a). Improved integration of the adaptation measures will assist in reducing damages and thereby increasing the economic and environmental benefits(IPCC, 2015b; Oecd & Ocde, 2009). Unless these adaptation measures acknowledge the three global agendas, they become inefficient(Cramer et al., 2018; Sanchez Rodriguez et al., 2018; Smit & Pilifosova, n.d.). However, the three global agendas differ from each other. For instance, the Paris Agreement mainly concerned greenhouse gas emissions regarding the mitigation of climate change(Bauer & Menrad, 2019; Lenzholzer et al., 2020; Pickering et al., 2017; Working Group| Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021). At the same time, SGDs and SFDRR are more concerned with rights and quality of life and, more specific on DRR, respectively(COMMIT and CD-LINKS, 2018; UNDRR, 2015, 2019b, 2019a). Hence, identifying tangible CCA measures for the coastal built environment during planning, design, construction, maintenance, and retrofitting aligning with three global agendas is vital for maintaining the functionality of the built environment. This present study is conducted as a part of BEACON (Built Environment leArning for Climate adaptation), a collaborative research project co-funded by the EU Erasmus+ programme of the European Union. The present study developed a conceptual framework for climate change adaptation measures for the coastal built environment aligning with three global agendas.

The present study initially employed a systematic literature review to identify the climate change adaptation measures for the coastal built environment. Then the identified CCA measures were organized as a conceptual framework. As a final stage of the present study, the developed conceptual framework was supposed to validate through the individual county level case study. This developed conceptual framework could be used as a basis to integrate the CCA measures to the coastal built environment to cope with climate change and its impacts. This report includes the findings of the systematic literature review.

2 Background

2.1 Summary of Climate change and its impacts from output 01

Disaster and disaster risks are expected to be rising as climate change increases the frequency and severity of extreme weather events. The BEACON project output 01 recognized sea-level rise, changing weather conditions and precipitation changes as the primary change evidence in the coastal built environment. The consequent hazards due to the climate change evidence were identified as coastal erosion, inundation, extreme weather events, and flooding.

Climate change-related hazards are significantly affecting the built environment over the past years. The project's output 01 identified four types of climate change impacts with respect to the coastal built environment. These include, Physical, Economic, Social and Environmental. As the output 01 report highlights, among four impacts categories, physical impacts are directly connected to the built environment while other impacts categories are indirectly connected. Damage to coastal infrastructure is one of the most visible physical impacts of climate change and associated disaster risks in coastal communities. Seaports, residential and commercial buildings, transportation networks, water distribution systems, stormwater management infrastructure are vital infrastructures within the coastal built environment. The other significant impact due to climate change includes mass movements. As per the output 01 report, mass movement destabilizes hillsides, sediment runs off, destabilizes embankments in most countries. Also, interruptions to emergency facilities, essential services, and critical infrastructure is another physical impact of climate change, specially during climate change-related hazard events. Furthermore, saltwater intrusion and acid rains also have a significant impact on construction material. Urban overheating caused by global warming induces more energy consumption due to heating and cooling needs in residential and commercial buildings. As a result of damages imposed by hazards, the requirement of physical preventative structures rises. Accordingly, this leads to structural changes to the built environment. These changes include physical actions and engineering-based solutions (i.e., Sea walls, breakwater arms, beach nourishment, sand pumping). Subsequently, these alternations will lead to further physical implications such as governance and institutional changes within the coastal buffer zone or revising land-use plans. Also, these physical implications will demand more environmentally friendly and adaptive solutions to cope with climate change, such as nature-based solutions, Eco-DRR initiatives.

The other climate change impact category identified through the output 01 study is economic impacts. The losses attributed to the damages in the coastal infrastructure is captured as the main economic impact due to climate change. The impact of climate change on marine-based sectors such as tourism, fishing, and aquaculture is also a major concern in the coastal built environment. As mentioned before, damages on coastal infrastructure like seaports and transportation systems will indirectly be caused in significant impact on economy of the nations as these coastal infrastructures are considered vital economic assets. Another major economic attribute to climate change is the loss of coastal income and economic depression.

There will be associated costs concerning adaptation and reconstruction due to climate change. This also can be considered as the economic impact.

Output 01 report identified social impacts as another climate change impact category. The threat to human life in terms of casualties and fatalities is one of the most severe impacts of climate change and the accompanying disaster risks. Temperature rise, exposure to UV radiation due to global warming, air pollution and aeroallergens are some of the climate change incidents that have a significant impact on human health. Furthermore, with regards to human health, severe weather conditions have increased the risk of vector and water-borne diseases like Dengue. Lower nutrition level and food security, decreased water quality and availability, decreased availability and increased disruption of health services, and complication in maintaining sanitation and practices during emergencies adds more complications with regards to protecting human health. Furthermore, food insecurity will also arise due to climate change as agriculture is more sensitive to temperature and precipitation changes. Also, as a primary needs for a human, water insecurities can be considered as another social impact due to climate change. As an ultimate result of the life dangers and loss of livelihoods, voluntary and involuntary human migration will occur. This poses additional stresses on urban infrastructure and the built environment's planning activities. Therefore, the cost of relocation and reconstruction is another social impact due to climate change. In addition, persons who are forced to leave their homes and communities will face psychological and socioeconomic stresses.

The other climate change impact category identified through the output 01 study is environmental impacts. Damage to coastal ecosystems, salt marshes, mangrove forests, seagrass beds, soft sediments, coral reefs is identified as the leading environmental impact due to climate change by output 01. Subsequently, damages to the coastal ecosystem will affect the biodiversity as well. Another environmental impact associated with climate change is the alteration of forests' composition, wildlife habitats. Furthermore, impacts on ecosystem function affect the quality of the water resources. Specially, salinization, acid rains, saltwater intrusion caused the reducing freshwater quality. In addition, environmental restoration after a disaster is another environmental impact associated with climate change.

In summary, the BEACON project's output 01 outlines four major impacts categories corresponding to climate change. These are physical, economic, social and environmental impacts. The physical impacts include,

- Damages to coastal infrastructure
- Access interruption to emergency facilities and critical infrastructures
- Degradation of building materials and structures
- Changes in energy consumption
- Demand more environmentally friendly and adaptive built environment architecture
- Need of physical preventive structure
- Governance and institutional changes coastal buffer zone or revising land use plans

The economic impacts include,

- Losses due to damages in the coastal infrastructure
- Loss of coastal income and economic depression
- Loss of employment
- Impact on marine-based industries such as tourism, fisheries, aquaculture
- Impact on planning economic development
- Depletion of resources
- Cost of adaptation and reconstruction

Also, the social impacts include,

- Decreased agriculture/livestock productivity
- Displacement and loss of livelihoods
- Voluntary and involuntary human migration
- Food and freshwater insecurities
- Risk of increased human conflicts resulting in human unrest
- Increased human health risks
- Need of social protection programs
- Threat to human life, causalities, loss of human lives

The impacts on the environment include,

- Damages to coastal ecosystems

- Impact on biodiversity
- Decreased productivity, diversity, and resilience of nearshore marine ecosystem
- Environmental pollution
- Impact of surface, ground, and drinking water quality, aquatic, and terrestrial ecosystem function
- Environmental restoration after a disaster

2.2 Overview of three global agendas

The Paris Agreement is considered as the main international legally binding agreement corresponding to climate change. It was adopted by 196 parties at COP 21 in December 2015 and entered into force in November 2016(UNFCC, 2021b). The Paris Agreement aims to keep global warming below 2 degrees Celsius, preferably 1.5 degrees Celsius, compared to pre-industrial levels(UNFCC, 2021a). This agreement recognizes that it would significantly reduce risks related to climate change, increase the ability to adapt to the adverse impacts of climate change and foster climate resilience(United Nations, 2015). It is in place to reflect equity, the notion of shared but varied duties, and distinct competencies in comprehending various country situations(UNFCC, 2021b; United Nations, 2015). The Convention aims to strengthen the global response to the threat of climate change in the context of sustainable development and efforts to eradicate poverty(UNFCC, 2021a).

Built environments account for a significant amount of global greenhouse gas emissions, contributing significantly to climate change (Sovacool et al., 2021). They house the majority of the world's population and economic activity, yet they are increasingly vulnerable to the effects of climate change(Ellena et al., 2020a). As a result, those involved in the creation and management of built environments must be prepared for climate change(Hürlimann et al., 2022). In addition, the IPCC report highlights that climate change is unprecedented. Also, it is known that climate action cannot be reversed at the moment(Working Group| Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021). Therefore, built environments should be capable of adapting to climate change as they are extremely vulnerable to the effects of climate change(Hürlimann et al., 2022; X. Wang et al., 2020). Hence, as a legally mandated regulatory framework for climate change, Paris

Agreement has to play a significant role in adapting built environments to climate change(Mele et al., 2021; Mumtaz, 2021).

The Sendai Framework for Disaster Risk Reduction (SFDRR) is a legally mandated international framework that corresponds to disaster risk reduction(Djalante & Lassa, 2019; Maini et al., 2017; UNDRR, 2015). It was adopted in 2015 by global leaders in disaster risk reduction. SFDRR sets out four priorities for action and seven targets. The overall objective of the SFDRR is to substantially reduce disaster risk and losses in lives, livelihoods and health and the economic, physical, social, cultural and environmental assets of persons, businesses of nations and communities(Djalante & Lassa, 2019; Saja et al., 2020a, 2020b). The four priorities for actions of the SFDRR includes,

1. Understanding disaster risk
2. Strengthening disaster risk governance to manage disaster risk
3. Investing in disaster risk reduction for resilience
4. Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction

Furthermore, SFDRR sets out seven global targets to reduce disaster risk substantially. The seven global targets are,

- Target A: Substantially reduce the global disaster mortality by 2030
- Target B: Substantially reduce the number of affected people globally by 2030
- Target C: Reduce the disaster economic loss in relation to global gross domestic product
- Target D: Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience
- Target E: Substantially increase the number of countries with local and national disaster risk reduction strategies
- Target F: Substantially enhance international cooperation to developing countries through adequate and sustainable support to complement their national actions for implementation of SFDRR by 2030

- Target G: Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk reduction information and assessment to people by 2030

As climate change increases the frequencies and intensities of extreme weather events, SFDRR has implications for reducing the disaster risk posed by climate change(Busayo & Kalumba, 2020; Jetten et al., 2021; Mysiak et al., 2018; Seidler et al., 2018).

The other landmarks global agenda is the Sustainable Development Goals (SDGs). The United Nations approved the SDGs in 2015 as a universal call to action to end poverty, safeguard the environment, and ensure that by 2030, everyone lives in peace and prosperity(Gu et al., 2019; Mio et al., 2020). It consists of 17 goals and 169 targets that sought to end poverty and the environment. The 17 SDGs are interconnected, recognizing that actions in one area have an impact on outcomes in others and that development must strike a balance between social, economic, and environmental sustainability(Cernev & Fenner, 2020; Government of the Democartic Socialist Republic of Sri Lanka, 2018; Gu et al., 2019; Odey et al., 2021).

At the moment, there is a lack of integration of the climate change adaptation into the built environment during infrastructure planning, design, construction, maintenance, and retrofitting(Busayo & Kalumba, 2020; Seidler et al., 2018). Improved integration of the adaptation measures will assist in mitigating the aforementioned climate change impacts. Unless these adaptation measures acknowledge the three global agendas, they become inefficient(Busayo & Kalumba, 2020; Jetten et al., 2021; Seidler et al., 2018). However, the three global agendas differ from each other. For instance, the Paris Agreement mainly concerned greenhouse gas emissions regarding the mitigation of climate change. At the same time, SGDs and SFDRR are more concerned with rights and quality of life and, more specific on DRR, respectively. Hence, the alignment of the climate change adaptation measures with these agendas is much crucial.

2.3 Coastal built environment

The phrase "built environment" refers to man-made environments for human activity, such as buildings, parks, and green spaces, as well as neighborhoods and cities, which may include supporting infrastructures such as water supply and electricity networks(Joensuu et al., 2020; Rojas-Rueda & Morales-Zamora, 2021; Y. Zhang et al., 2020). The built environment affects every aspect of human life, including the buildings people live in, the water and power distribution networks, and the roads, bridges, and transportation systems people use to get around. It can be broadly defined as man-made or modified structures that offer people places to live, work, and play(Rojas-Rueda & Morales-Zamora, 2021; Y. Zhang et al., 2020). Overall, the built environment can be seen as the material, geographical, and cultural output of the human labour force, which combines material factors and energy in the form of life, work, and recreation(Coleman, 2017). The built environment can be divided into two components as physical and non-physical infrastructures(Ellena et al., 2020b; Travert et al., 2019; Yıldız et al., 2020). The physical infrastructure includes infrastructures, assets and natural ecosystems. At the same time, the non-physical component includes the social, economic, and governance services and systems that are essential to the wellbeing of the human being(Travert et al., 2019; Yıldız et al., 2020). Figure 1 illustrates the built environment components. As Figure 1 depicts, all other components within the built environment have a connection to the governance as these components require a regulatory body to facilitate their intended services properly(Chinyere et al., 2020; da Cruz et al., 2018; Yıldız et al., 2020). The dependency of the people on the built environment has greatly intensified with the recent advancement of technology(Karakas & Yildiz, 2020; Mouratidis et al., 2021). The coastal built environments which are situated along the coastline have become vital since they contribute to the economic growth of the nations significantly(Ellena et al., 2020b; Mouratidis et al., 2021; Yıldız et al., 2020)(Ellena et al., 2020b; Mouratidis et al., 2021; Yıldız et al., 2020). For instance, In Sri Lanka, major transportation infrastructures lie alone the coastal built environment serving the transportation of goods and people. A significant disruption of these transportation systems affects the Sri Lankan economy significantly.

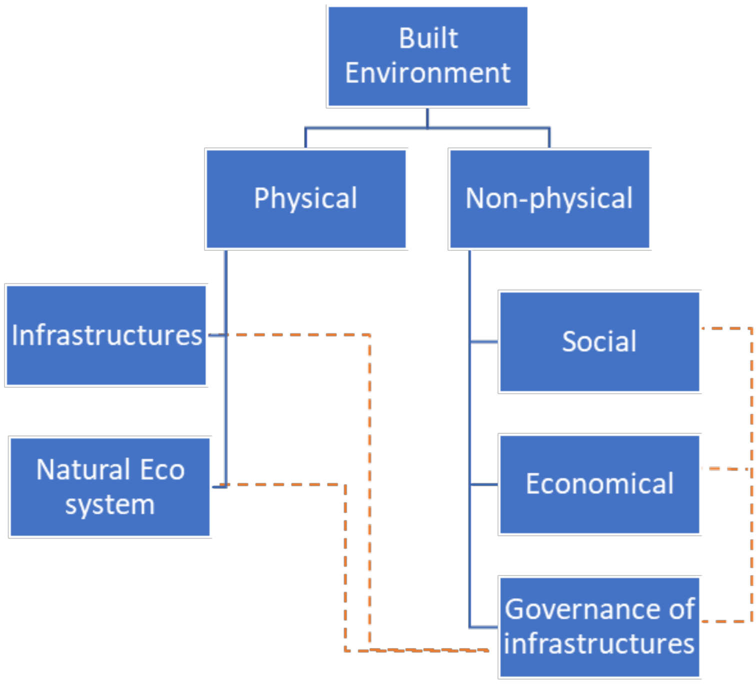

Figure 1 Built environment's component

The built environments are significant victims of disasters. vulnerability and exposure of the built environment to hazards greatly intensified due to many factors, specially technological advancement, rapid expansion due to service demand(UNDRR, 2019b; UNDRR & CRED, 2020; UNDRR; ISC, 2020). Among these hazards, climate change-related hazards caused greater damage to the built environment(Andrić et al., 2019; Hunt & Watkiss, 2011; Zimmerman & Faris, 2010). As aforementioned, climate change impacts are evident at present. The green land coverage is reduced as a result of urbanization. The reduction of urban green land coverage pressures urban ecology, including surface temperature, stormwater-runoff, carbon accumulation and biodiversity increases(Ciscar & Dowling, 2014; Salimi & Al-Ghamdi, 2020a; Seddon et al., 2020; L. Wang et al., 2018). The threats on the built environment from the disasters such as floods, droughts, severe weather events tend to increase due to climate action. In addition, sea-level rise caused inundation of the low-lying areas within the coastal built environment. As concluded from the previous sections, the built environment has become a greater victim of climate change. On the other hand, the built environment has also become the major driver of climate change(Collings & Collings, 2020; Dong et al., 2021; Lampropoulos et al., 2020). Green House Gas(GHGs) emission has caused climate change. The built environment produces a significant portion of the global GHGs. Hence, it contributes to climate change through the production of greenhouse gases (Lenzholzer et al., 2020; Working Group|

Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021). As aforementioned, the majority of the world's population and economic activity are concentrated in built settings, which are more vulnerable to climate change impacts. As a result, those involved in the creation and management of built environments must be prepared for climate change. Many nations have devoted significant attention to climate change adaptation in the context of the built environment to cope with the challenges posed by climate change(Busayo & Kalumba, 2020; Jetten et al., 2021; Lenzholzer et al., 2020; Seidler et al., 2018).

2.4 Climate change adaptation

Even if considerable steps to reduce GHG emissions are implemented, some further degree of climate change will be unavoidable, with severe economic, social, and environmental consequences for communities(Cramer et al., 2018; Pickering et al., 2017; Sanchez Rodriguez et al., 2018). Nations will need to adapt in order to mitigate the negative effects of climate change and to take advantage of the tremendous opportunities that it presents(Seidler et al., 2018; Working Group| Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021). The IPCC defines adaptation as an "adjustment in the natural or human system to a novel or shifting environment or in response to actual or expected stimuli or their effects, which moderates harm or utilizes beneficial opportunities" (IPCC, 2015a). It encompasses efforts to reduce vulnerability and augment capacity through modifications and adjustments in systems(Hosseini et al., 2016; Owen, 2020; Singh et al., 2021). It entails an understanding of how systems may respond appropriately to changes in their environment by coping, adjusting, and altering(Becker et al., 2018; Fedele et al., 2019; IPCC, 2015b; UNDRR, 2019b; UNDRR; ISC, 2020). Adaptation focuses on mitigating negative effects while also building resilience and reaping any benefits that may arise. It is all about preventing disasters, dealing with existing hazards or planning for a future threat that is not (yet) recognized as imminent(Owen, 2020; Singh et al., 2021; UNDRR, 2019b). Adaptation can be reactive, occurring in response to impacts, or proactive, occurring before impacts of climate change become apparent. Most often, proactive adaptations will be less expensive in the long run and more effective than reactionary adaptations(R. Gupta & Gregg, 2012; V. Gupta, 2021). Many nations have devoted significant attention to climate change adaptation and mitigation. Mitigation (efforts to minimize emissions and future climatic changes) is more important than adaptation in dealing with climate change causes. Mitigation aims to address the underlying causes of climate change and provides long-term benefits by minimizing damages and consequent adaptation costs(Bolan et al., 2021; B. V. Gupta, n.d.; R. Gupta & Gregg, 2012; Lenzholzer et al., 2020; Ross, 2017). Adaptation actions include large-scale infrastructure changes, like building coastal defences, heat insulation, revised standards, improved drainage or behavioural shifts like individuals using less water. Furthermore, in the context of the built (R. Gupta & Gregg, 2012; V. Gupta, 2021)environment, climate change adaptation can take several forms and can serve various functions, as presented in Table 1.

Table 1 Bases for characterizing and differentiating adaptation to climate change (Adopted form: (Smit & Pilifosova, 2018))

General differentiating concept or attribute	Examples of terms used
Purposefulness	Autonomous- Planned Spontaneous- Purposeful Automatic- Intentional Natural- Policy Passive- Active
Timing	Anticipatory- Responsive Proactive- Reactive Ex ante- Ex post
Temporal Scope	Short term – Long term Tactical – Strategic Instantaneous- Cumulative Contingency Routine
Spatial Scope	Localized- Widespread
Function/Effects	Retreat, Accommodate, Protect Prevent, Tolerate, Spread, Change, Restore
Form	Structural, Legal, Institutional, Regulatory, Financial, Technological

Performance	Cost, Effectiveness, Efficiency, Implement ability, Equity

Last but not least, climate change adaptation is crucial for the contemporary world. Climate change is generally acknowledged, and policymakers have considered mitigation and adaptation options at both the national and international levels(Bolan et al., 2021; Lenzholzer et al., 2020; Lin et al., 2021). On the other hand, climate change adaptation has emerged as a crucial strategy for reducing the negative effects of climate change that can no longer be prevented, as well as maximizing good socioeconomic prospects, given that no amount of mitigation will be able to avert climate change impacts in future(Hussain et al., 2019; IPCC, 2015a; Salehi et al., 2019). Furthermore, it is crucial point to consider the alignment of the adaptation measures with current global initiatives as aforementioned. As above mentioned, the built environment is the greater victim and a driver of climate change. Thus, it is crucial to integrate climate change adaptation measures that agree with global agendas into the planning, design, construction, maintenance and retrofitting stage of the built environment. Currently, there is a lack of a framework for climate change adaptation in the context of the coastal built environment(Ghbn, 2016; Hussain et al., 2019; Salehi et al., 2019).

3 The overall methodology of the output 03

The present study was planned to be carried out under two-level. As an initial step, a systematic literature review (SLR) was employed to identify the adaptation measures for mitigating the climate change impacts. SLR has led to developing a conceptual framework for climate change adaptation measures of the coastal built environment. Then the open-ended interview questionnaire is supposed to be developed to collect the data for the validation process of the developed framework. The data was planned to collect by country-level by conducting the interviews. The target interviewees include urban planners and policymakers, built environment construction professionals, decision-makers in disaster risk reduction and management. As a final stage of the present study, the developed framework was supposed to validate through qualitative analysis of the interviews.

3.1 Aims of the study

This study seeks to develop a conceptual framework for CCA measures for the coastal built environment during planning, design, construction, maintenance and retrofitting phases that align with the global three agendas (i.e., SFDRR, Paris Agreement, SDGs). As aforementioned, the present study framed the research questions as follows,

1. What are possible CCA measures for critical Infrastructures?
2. What are possible CCA measures for residential and commercial buildings?
3. What are possible CCA measures for mitigating climate change impacts on society?
4. What are possible CCA measures for mitigating climate change impacts on the economy?
5. What are possible CCA measures for mitigating climate change impacts on the governance of the infrastructure?

Consequently, the above research questions directed the research study to global level SLR. Then the CCA measures for the built environment was identified through the analysis. The identified CCA measures and developed conceptual framework are presented in the subsequent sections of this report.

3.2 Systematic Literature Review

SLR is a form of research methodology that addresses specific research questions by collecting, appraising, and summarising all empirical evidence that fits pre-specified eligibility criteria(Baird, 2018). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline was used in performing the SLR in this study. The PRISMA guidelines contain four steps: identification, screening, eligibility, and inclusion(Vicente & Soledad, 2018), as presented in Figure 2.

The literature was gathered from four scientific databases; Scopus, Web of Science, Science Direct and Emerald Insight, to identify the CCA measures for the coastal built environment. These databases were selected due to the availability of a broader range of peer-reviewed journal articles from international publishers. The search query was developed to initiate the searching process as follows,

1. ("Critical Infrastructures" OR "Electricity" OR "Energy" OR "Water" OR "Transportation" OR "Coastal Built Environment" OR "Telecommunication" OR ((" Commercial" OR" Residential") AND" building*"))) AND ("Climate Change" OR "adaptation" OR "measures") AND ("Design" OR "Construction" OR "Retrofitting" OR "Refurbishment", "Rehabilitation" OR "Renovation" OR "Restoration" OR "Maintenance")
2. (”Soci*” OR ”Goveranance” OR ”Econom*”) AND ("Climate Change" OR "adaptation" OR "measures") AND (" Coastal" AND" Built Environment")

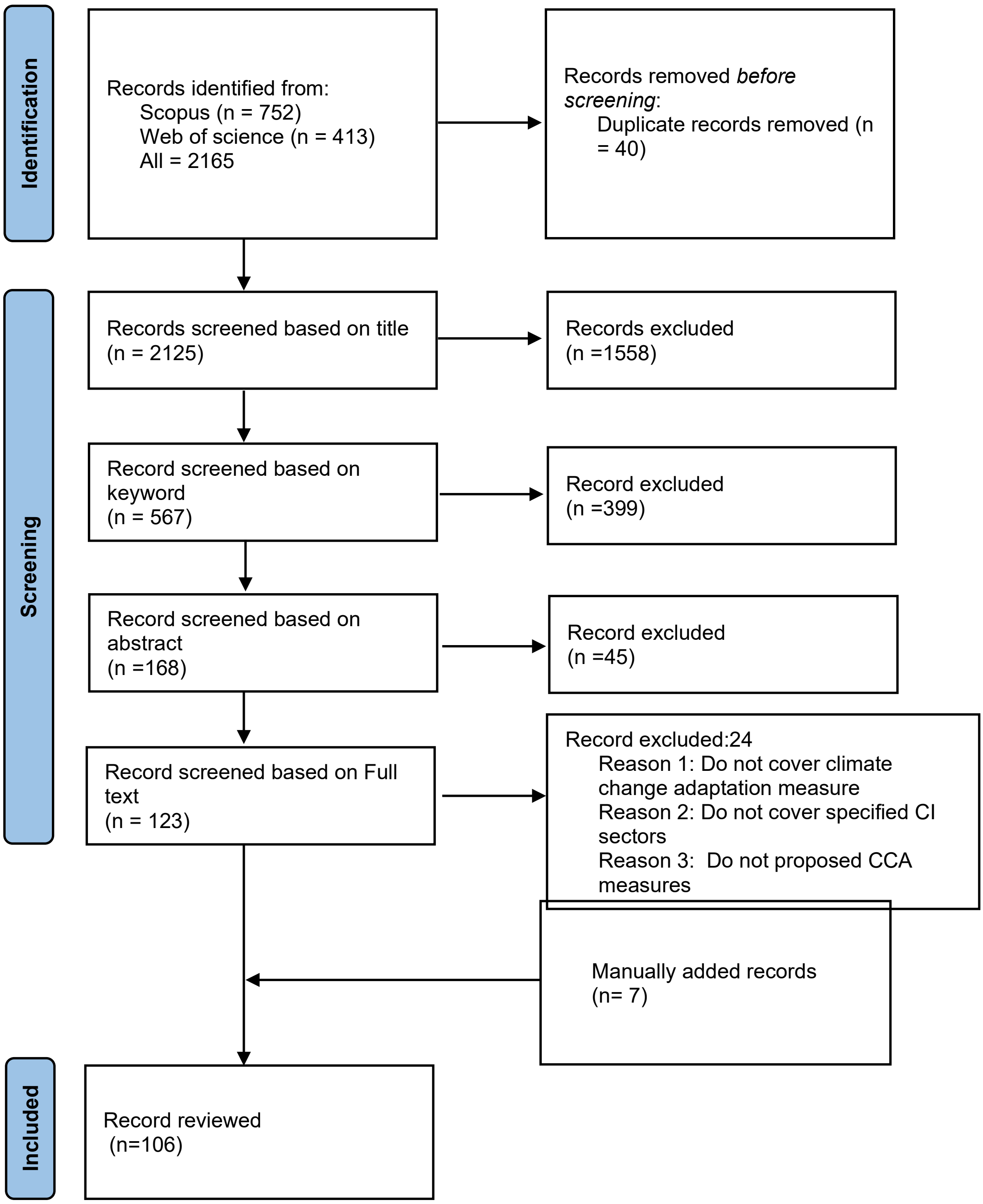

Figure 2 Screening process of the literature

The key terms in the title, keywords, and abstracts were used as inclusion criteria. Due to the higher reliability of the results, the journal articles were chosen from the search criteria. The articles that mostly incorporated a coastal perspective were then chosen at the initial screening to comply with the scope of the study. Moreover, non-English articles and duplicates in the databases were ruled out during the initial screening step.

4 Climate change adaptation measures for the built environment

This section discusses identified adaptation measures for the built environment. As presented above, this study considered the built environment under two major components: Physical and Non-physical. Section 3.1 discusses identified adaptation measures for the physical component of the built environment, while section 3.2 focuses on the adaptation measures for the non-physical component of the built environment.

4.1 Climate change adaptation measures for the physical component of the built environment

As mentioned above, the built environment's physical components include infrastructures and the ecosystem. Among these two components, infrastructures play a vital role in the day-to-day activities of human being. The infrastructures refer to a man-made structure that supports the daily routine of the people(Okoro et al., 2021; Stappers et al., 2018). Infrastructures can be further divided into two primary components: Critical Infrastructures and Residential and commercial buildings. Critical infrastructures are openly defined as the assets, physical structures, technical facilities, or supply chains essential to the social and economic wellbeing and effective functionality of the communities(Abeysinghe et al., 2022; Jayasekara et al., 2022; Shehara et al., 2022). The ecosystem is the other pivotal physical component of the built environment. The ecosystem is made by nature for the survival of human beings. It provides the basic needs of human beings(Grima et al., 2020; Lau et al., 2019). In fact, the ecosystem plays a vital role in the context of disaster risk reduction as well. Therefore, the ecosystem has become a primary component within the built environment(Faivre et al., 2018; Onuma & Tsuge, 2018). This section discusses the identified measures for mitigating climate change impacts on infrastructures and ecosystems.

4.1.1 Adaptation measures for infrastructures

This section presents the identified adaptation measures for the infrastructures. As mentioned above, present study focuses climate change adaptation measures for residential and commercial buildings and critical infrastructures. Figure 3 illustrates the general overview of the focused infrastructure sectors within the literature. As it depicts scholars have devoted significant attention to the climate change adaptation in the context of transportation, water, and residential and commercial buildings.

A few studies have focused other major infrastructure categories such as electricity and energy sector and telecommunication sector.

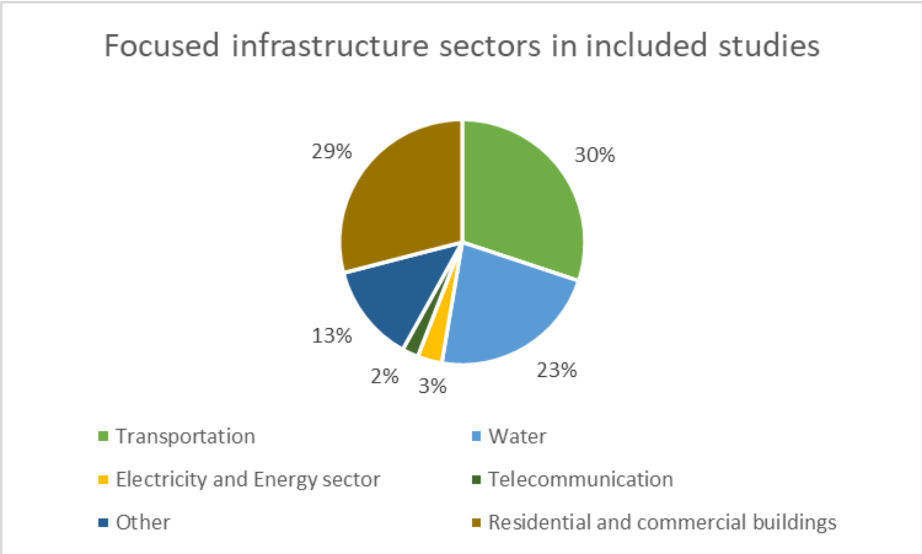

Figure 3 Infrastructure sectors consider in the past studies

The adaptation measures for each infrastructures sector summarizes in Table 2. Table 2 classifies the adaptation measures under three stages of the infrastructure life cycle. These stages include the infrastructure planning stage, infrastructure design and construction stage, and infrastructure maintenance and retrofitting stage. Consideration of adaptation measures within these stages of infrastructure development is crucial for the effective functioning of infrastructures with challenges posed by climate change. The infrastructure planning stage is a crucial step of infrastructure development. It involves the concept of a system approach to installation, operation and management of infrastructures. As aforementioned, infrastructure damages are pivotal in climate change impacts, adaptation measures should be considered in the planning stage of the infrastructure.

On the other hand, under the design and construction stage, built environment professionals consider the material, structural and architectural layouts, energy performance, structural performance, and effective and efficient construction methods to deliver the infrastructure. Within the design and construction stage, climate change adaptation can be integrated into several steps. Specially, under the material selection, infrastructure plans, energy performance steps it can be identified several climate change adaptation measures. The following stage of the infrastructure life cycle is the maintenance and retrofitting stage. This stage involves any activity that is performed to maintain the functionality of the infrastructures. After delivering infrastructure, infrastructures are subjected to maintenance and retrofitting work. Since the infrastructures will deal with different climate change scenarios over their lifetime. Therefore, the frequency of maintenance and retrofitting work of infrastructure increases significantly, affecting the life cycle cost of infrastructures unless they acknowledge the climate change adaptation. Table 2 summarizes and classifies identified adaptation measures for infrastructure sectors under three stages of the infrastructure life cycle.

Table 2 Identified adaptation measures for infrastructures

Infrastructure sector	Adaptation measures	P	D & C	M& R	References
Transportation Infrastructures	comprehensive snow and ice control program that includes pre-wetting surfaces to combat ice on roads and using only coarse gravel on roads to minimize air quality and aquatic impacts.			■	(J. E. Neumann et al., 2015; Picketts et al., 2015)
	Rising the road level to combat the flooding	■	■		(Broadbent et al., 2015; Picketts et al., 2015; Qiao et al., 2020; Scussolini et al., 2017; Strauch et al., 2015)
	Proper asphalt mix design suits for regional climatic conditions		■		(Mohebbi et al., 2020; Picketts et al., 2015; Qiao et al., 2020)
	Alternative mix design for the pavement treatment (e.g., Warm mixes, rubberized asphalt, and pervious concrete)		■	■	(Mohebbi et al., 2020; Picketts et al., 2015; Qiao et al., 2020)

	Consideration of traffic loads on pavements/load restrictions and Traffic demand prediction and pavement design (With the SLR people move to inland increase traffic demand)				(Picketts et al., 2015; Qiao et al., 2020)
	Improved data (Weather event and crashes, collision data, data sharing)				(Cheng et al., 2017; Mohebbi et al., 2020; Picketts et al., 2015)
	A method to predict the maintenance of the road combination with the climate change simulation model (e.g., winter severity index (WSI))				(Batouli & Mostafavi, 2016; Cheng et al., 2017; Strauch et al., 2015)
	Improved drainage system incorporating the Sustainable drainage system (SUDS) principles in the design				(Broadbent et al., 2015; Manocha & Babovic, 2017; Moura et al., 2016; Qiao et al., 2020; Salerno et al., 2018; Strauch et al., 2015)
	Use of high reflective coating to the urban heat island				(V. Gupta, 2021; Major et al., 2018; Mauree et al., 2019; Qiao et al., 2020)
	Hydrological and drainage design considering anticipated increment of the precipitation, water levels				(Broadbent et al., 2015; Oswald Beiler et al.,

					2016; Strauch et al., 2015)
	Planning for/providing alternative routes in the event of a road/railway closure				(Broadbent et al., 2015; Charlesworth et al., 2016)
	Construct roadway over embankments to accept the passage of floodwaters at defined locations (ensuring safe failure)				(Broadbent et al., 2015; Major et al., 2018; Mohebbi et al., 2020)
	Proper sizing of the culverts/ Allow undersized culverts to be overtopped by designing for such failures ensuring safety				(Broadbent et al., 2015; V. Gupta, 2021; Mohebbi et al., 2020; Schulz et al., 2015)
	Use appropriate embankment materials-rock fill at bridge approach, granular materials				(Broadbent et al., 2015; Cervigni et al., 2017)
	Increase longitudinal drains capacities- Ensure Road drainage is routinely shaped by the grader, protect verges and channel side slopes with appropriate vegetation cover, ensure effective longitudinal drainage capacity in cutting to remove flood water				(Broadbent et al., 2015; Strauch et al., 2015)
	Provide cutting slope drainage -adequate and effective drainage cut off drains installed to the top of cutting slopes berms.				(Broadbent et al., 2015; Strauch et al., 2015)

	Harden river defences using retaining walls. Gabion baskets, earth dikes, random rubble				(Broadbent et al., 2015; Cervigni et al., 2017)
	Protection of the structural materials against salinity				(Broadbent et al., 2015; Mohebbi et al., 2020)
	Robust pavement structures-erosion resistant surfacing				(Broadbent et al., 2015; Qiao et al., 2020)
	Use of design guidelines for asset design				(Broadbent et al., 2015; M. B. Neumann et al., 2015)
	Adopting tool for evaluating risk, vulnerability, exposure of the transportation infrastructure				(Broadbent et al., 2015; Cheng et al., 2017; Schweikert et al., 2015; Seah et al., 2021; Strauch et al., 2015; van de Ven et al., 2016)
	Prevent build-up of debris against intermediate supports or under deck soffit through upstream river and development management				(Broadbent et al., 2015; Strauch et al., 2015)
	Maintainable back of wall drainage				(Broadbent et al., 2015; Strauch et al., 2015)

	Scour protection around bridge abutment, wing wall, piers, minor culvert, and headwall/toe wall				(Broadbent et al., 2015; Ghofrani et al., 2016; Strauch et al., 2015)
	Deepen foundation, Pilled foundation, Cut-off sheet piling at the foundation				(Broadbent et al., 2015; Cervigni et al., 2017; V. Gupta, 2021)
	Increase the Vertical clearance of soffit				(Broadbent et al., 2015; Markolf et al., 2019; Minnesota Department of Transportation, 2020; Weilant et al., 2019)
	Designing bridge to accommodate the permanent raising of bridge's deck				(Broadbent et al., 2015; Cervigni et al., 2017; V. Gupta, 2021; Minnesota Department of Transportation, 2020)
	Design as a floating bridge				(Broadbent et al., 2015; Cervigni et al., 2017)

	Improving material quality with mechanical or chemical material stabilization				(Broadbent et al., 2015; V. Gupta, 2021; Markolf et al., 2019)
Residential and commercial buildings	Better insulation of walls, lofts and floors				(Bernier et al., 2015; Haddad et al., 2020; K. T. Huang & Hwang, 2016; Hwang et al., 2009)
	Heating systems (Biomass, gas broiler, micro-CHP)				
	Rainwater harvesting				
	Solar thermal water heating				
	Low energy lighting and more natural lighting				
	Reused or recycled material				(O'Malley et al., 2014; Sari, 2021; Shimoda, 2010)
	Vegetation				
	Use of material with high albedo rating (cool envelope materials)				(Haddad et al., 2020; H. Huang & Zhang, 2016; Ross, 2017)
	The layering of building components				
	Excess of strength				
	Open floor area (can be utilized by partitions)				(Porritt et al., 2012; Sari, 2021; Solecki et al., 2011)
	Shadings for windows				
	Coatings of walls and roof tiles				
	Low-e triple glazing				
	Night Ventilation				

	Window rules				
	Green roofs, roof pond, and green facades				(Sari, 2021; Shimoda, 2010; Solecki et al., 2011; C. Zhang et al., 2021)
	Ventilated roofs and facades				
	Thermal mass including PCMs				
	Ventilative cooling				
	Adiabatic/evaporative cooling				
	Compression refrigeration				
	Absorption refrigeration including desiccant cooling				
	Ground source cooling				
	Sky radiative cooling				
	High-temperature cooling system: Radiant cooling				
	Personal comfort systems				
	Dehumidification including desiccant dehumidification				
	Elevated ground floor				(Ahmad & Afzal, 2020; Hudson, 2020; Nofal & van de Lindt, 2020)
	Foundation strengthens				
	Building dicks				
	Drainage bungs for drains, sinks, and toilets				(R. Gupta & Gregg, 2012; Hudson, 2020)
	Air brick covers				
	Seal gaps around pipe and cable entries				
	Fit nonreturn valves on mains drains				

	Demountable door guards				
	Waterproof membrane on external walls				
	Waterproof render to external walls				
	Building orientation				(Abeysinghe et al., 2020; Charoenkit & Kumar, 2017)
	Placement of Openings				(Abeysinghe et al., 2020; de Ruig et al., 2020; Hudson, 2020)
	Strengthen the superstructure and walls				
	Amphibious buildings				
	Flood proof materials				
	Waterproofed joints				
	Post flood drainage				
	Seawalls				(Al-Faesly et al., 2015; Ardekani & Hosseini, 2012; Esteban et al., 2013; Morin et al., 2008; Wu et al., 2019)
	Elevated building construction				
	Building construction on strong pillars and posts				
	Design for the impact of tsunami wave and debris flow				
	Proper detailing of joints				
	Anchoring building to foundation				
	Increase the weight of the building				
	Openings in ground floor				

	Elevated building				(Han & Mozumder, 2021; Hinkel et al., 2011; Mycoo, 2014; Storbjörk & Hedrén, 2011)
	Wet proofing				
	Dry proofing				
Water Infrastructure	Safety assessment, reinforcement of discharge facilities in spillways				(Cheng et al., 2017; Choi et al., 2017)
	Raising dam level				(Choi et al., 2017; Salimi & Al-Ghamdi, 2020b)
	Building mini dams in downstream of the existing dam				
	Adopting dam rehabilitation evaluation techniques				
	Proper design approaches for drinking water sources (for the local community, Ex: coverage, construction methods to overcome ingress of water)				(Hurlimann & Wilson, 2018; Kohlitz et al., 2020; M. B. Neumann et al., 2015)
	Rainwater harvesting systems for residential buildings to reduce the demand on national water supply				(Kohlitz et al., 2020; Radhakrishnan et al., 2019; Salerno et al., 2018; van Engelenburg et al., 2019)
	Increasing storage and pumping capacities/Resilient tank system				(Shanmugasundaram et al., 2017; van

					Engelenburg et al., 2019; Yerri et al., 2018)
	Physical barriers such as sea walls to minimize impacts of tidal event and Rising elevations of the infrastructure				(Hurlimann & Wilson, 2018; Yerri et al., 2018)
	Design and build floatable critical properties				(Salimi & Al-Ghamdi, 2020b; Yerri et al., 2018)
	Relocating vulnerable critical facilities				
	Adopting green infrastructure				(Emilsson & Ode Sang, 2017; Hatvani-Kovacs et al., 2018; Job et al., 2020a; Lin et al., 2021; Senosiain, 2020; Shanmugasundaram et al., 2017; Trogrlić et al., 2018; Yang et al., 2020)
	Mapping vulnerable areas and Critical facilities				(Haasnoot et al., 2018; Hurlimann & Wilson, 2018; Mikovits et al., 2017; Yerri et al., 2018)
	Collecting critical data for monitoring purposes				(Ghbn, 2016; Job et al., 2020b; Yerri et al., 2018)

	Forecasting model to risk informed decision making				(Ghbn, 2016; Job et al., 2020b; McPhillips et al., 2020; Mikovits et al., 2017; Seah et al., 2021; Yerri et al., 2018)
	Revision of the codes/policies based on forecasting				(Ghbn, 2016; Job et al., 2020b; Salimi & Al-Ghamdi, 2020b; Yerri et al., 2018)
	Reducing impervious surfaces in land use-Stop the water pollution				(Job et al., 2020b; Lin et al., 2021; Manocha & Babovic, 2017; McPhillips et al., 2020; Moura et al., 2016; Senosiain, 2020)
	Green infrastructure techniques to reduce the imperviousness				(Herath et al., 2018; Hurlimann & Wilson, 2018; Lin et al., 2021; Shanmugasundaram et al., 2017; Sharifi et al., 2021a)
	Heating systems for water systems hydraulic fracturing at drill sites to prevent frost				

Energy and electricity sector	Review design thresholds of offshore structures considering climate change				(V. Gupta, 2021; Katopodis & Sfetsos, 2019; Varianou Mikellidou et al., 2018)
	Upgrading oil platforms, the rigs and the number of anchors to make it more resilient to hurricanes				
	Offshore drilling companies should invest in lighting protection for offshore drilling				
	Raising the elevation				
	Plan and training for evacuation of personnel				
	Review of the design of installations located in the coastline.				
	Relocation of critical facilities and securing of equipment (e.g. Anchoring storage tanks, restraining gas cylinders				
	Early warning systems				
	Increasing storage capacities for vital equipment and supplies				
	Investing and managing drainage systems within critical facilities				
	Review of design guidelines considering climate change				
	Implement method for risk assessment				
Telecommunication infrastructure	Replacing copper wire network with waterproof fiberoptic cables				(V. Gupta, 2021; Poblet et al., 2014)
	Using portable or provisional base stations to provide network continuity and backup power sources				
	Tailoring continuity of service plans based on the needs of localities				
	Employing network management techniques for addressing congestion				
Other	Planning for future inland movement due to SLR				(Bahar GEDİKLİ, 2016; Clark et al., 2017;
	Land Use incorporating green concepts				

	Regulating minimum green space ratio				Hatvani-Kovacs et al., 2018; Herath et al., 2018; Manocha & Babovic, 2017; Salerno et al., 2018; Scussolini et al., 2017; Senosiain, 2020; Shanmugasundaram et al., 2017; Sharifi, 2020; Sharifi et al., 2021a; T. Wang et al., 2019)
	Adopting nature-based solution				
	Networks of parks, urban greenery, and open spaces				

** P- Planning, D&C- Design and Construction, M&R- Maintenance and Retrofitting**

Considering all infrastructure, the adaptation measures presented in Table 2 can be comprised into adaptation measures presented in Figure 4.

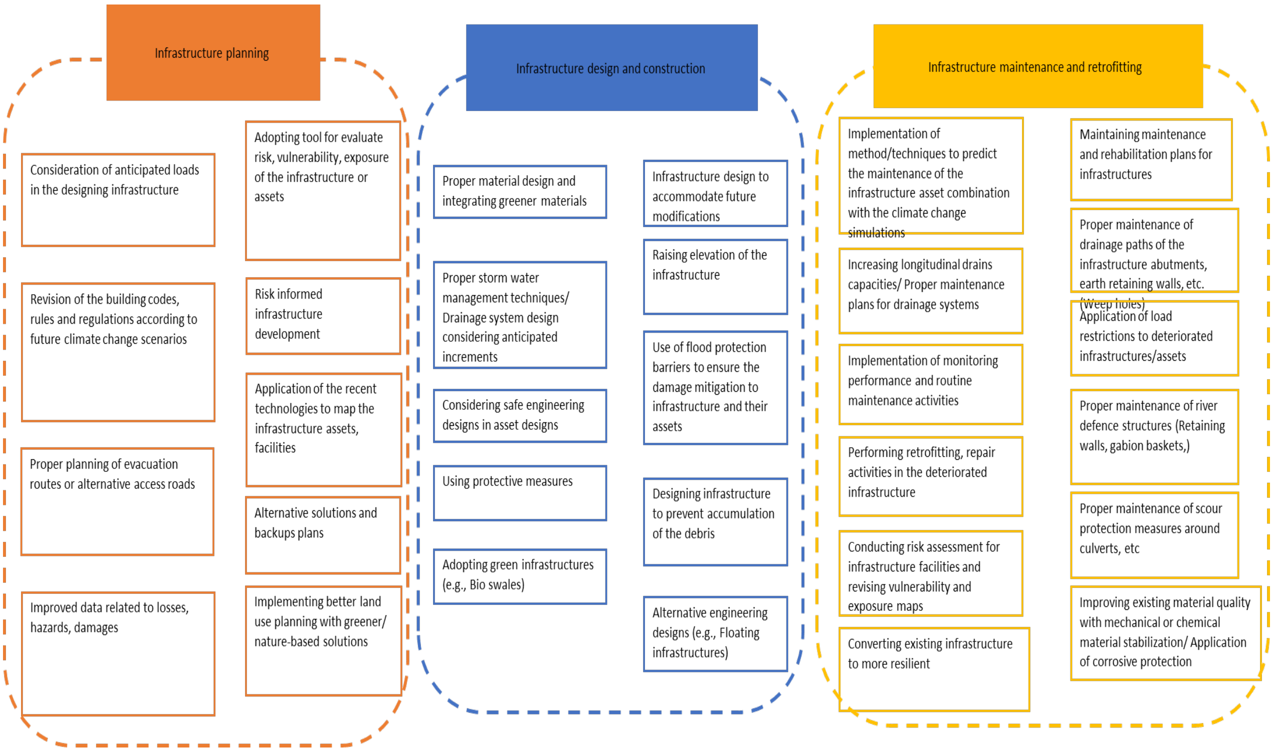

Figure 4 Climate change Adaptation measures for infrastructures

4.1.2 Adaptation measure for protecting eco- system

Another major physical component within the built environment is the ecosystem. The term "ecosystem" refers to the natural forest, parks, wetlands, and mangroves in the present study. These ecosystems play a pivotal role in climate change mitigation, absorbing CO_2(Faivre et al., 2018; Fedele et al., 2019; Lau et al., 2019; van de Ven et al., 2016). Also, they provide shelter for living beings. The identified adaptation measures for protecting the ecosystem include follows(Anjali et al., 2020; Climate Change Secretariat, 2016; Grima et al., 2020),

- Conduct research studies on climate change impact on ecosystems and biodiversity
- Establish a comprehensive program to monitor climate change impacts on key natural ecosystems and biodiversity
- Prepare and implement adaptive management programs for climate-sensitive ecosystems
- Prepare and implement recovery plans for highly threatened ecosystems and species
- Develop research institutes' capacity for conducting research on climate change impacts on ecosystems and biodiversity

Different nations have been defined these adaptation measures in their national adaptation plan for protecting the natural built environment(Climate Change Secretariat, 2016; Collings & Collings, 2020; Faivre et al., 2018; Fedele et al., 2019; Onuma & Tsuge, 2018; Singh et al., 2021; The Climate Change Secretariat of Sri Lanka, 2014). The above measures have been identified through the adaptation action plans.

4.2 Climate change adaptation measures for the non-physical components of the built environment

This section presents the identified climate change adaptation measures for the non-physical components of the built environment. The non-physical component of the built environment can be further categorized into three components: community, economy, governance. The following sections present the climate change adaptation measures for each non-physical component of the built environment.

4.2.1 Adaptation measures for protecting communities

As described above, climate change has caused significant disturbances to the community. Food and freshwater insecurity are the major social impact of climate change. Food security is one of the most critical areas that need special attention in climate adaptation among nations. The agriculture sector is the most climate-sensitive sector. Climate-related hazards have significantly affected agricultural production and farm assets in the recent past(Aryal et al., 2021; Fahad & Wang, 2018; Karimi et al., 2018). Hence, the high climate sensitivity and livelihood dependency of a large section of the population makes food security a highly vulnerable sector to climate change impact that needs special attention for climate change adaptation(Aryal et al., 2021; Fahad & Wang, 2018). Also, displacement and loss of livelihoods is another major impact of climate change on society(Kaluarachchi, 2018; Nikuze et al., 2019; Přívara & Přívarová, 2019). Another area where climate change can have a substantial impact is health. Changes in climatic patterns have been linked to increased health risks in studies worldwide. As a result, making major efforts to adapt to potential health risks related to climate change is a top concern(Chersich & Wright, 2019; Sharifi et al., 2021a, 2021b; Travert et al., 2019). The other social impact of climate change includes the requirement of social protection plans, migration, a threat to human life, causalities, loss of human lives and risk of conflicts among people. In order to mitigate these impacts on society, different nations have taken several adaptation measures. The present study has identified the following climate change adaptation measures for protecting the community from the literature review(Aryal et al., 2021; Aslany & Brincat, 2021; Kaluarachchi, 2018; Karimi et al., 2018; Nikuze et al., 2019; *Regional Plan of Action for SIDS in the African and South East Asian Regions A WHO Special Initiative in Collaboration with UNFCCC and the Fijian Presidency of the COP-23*, 2019),

- Preparation in advance for food and medications, availability of safe water, assurance of accessible public health service during a post-disaster situation
- Increase the accessibility to MHEWs facilities
- Conducting safety drills and evacuation plans
- Implementing proper signboards
- Adopting new agricultural technologies to increase the productivity of the agriculture
- Launch awareness programs on climate change for the public
- Promote climate-resilient building designs and revise building approval systems to increase the climate resilience

4.2.2 Adaptation measures for protecting the economy

This section presents the identified adaptation measures for mitigating the adverse impacts of climate change on the economy. The BEACON project's output 01 report identified several economic impacts. Under economic impacts, losses that occurred due to infrastructure damages was highlighted as a major economic impact. As aforementioned, climate change has caused a significant impact on coastal infrastructures. The cost of retrofitting and repairing of the damaged infrastructure needs capital. In addition, disruption of infrastructure service will affect the nation's economy as these infrastructures assist in the economic gain of most countries. Also, there will be a loss of coastal income, thereby economic depression within nations. As aforementioned, coastal built environments are major economic hotspots among most countries. Therefore, any damage to the coastal built environment causes economic depression. On the other hand, most marine-based industries such as tourism, fisheries, and aquaculture will be affected due to climate change(Becker et al., 2018; Mouratidis et al., 2021; Stappers et al., 2018). One of the major incomes of countries is the marine-based industries. At present, it is evident that climate change has a significant impact on marine-based industries(Johnson et al., 2020; Tegar & Gurning, 2018). Hence, the impact on marine-based industries directly affects the economy of the nations. The other identified economic impacts include the cost of adaptation and reconstruction, loss of employment, depletion of resources, and impact on planning economic development. In order to mitigate these impacts on the economy, different nations have taken several adaptation measures. The present study has identified the following climate change adaptation measures for protecting economies of the coastal built environment(Busayo & Kalumba, 2020; Ellena et al., 2020b; Joensuu et al., 2020; Mouratidis et al., 2021; Singh et al., 2021),

- Introduce innovative risk transfer instruments
- Promote climate-proof infrastructure design practices
- Develop guidelines for economic activities in vulnerable areas
- Identify adaptation actions suitable for respective industries
- Increase the awareness of industrial operators on climate change and its impacts
- Increasing infrastructure protection measures

4.2.3 Adaptation measures for governance

The governance of infrastructures is a crucial element within the built environment. Governance is the broader term(Chinyere et al., 2020; da Cruz et al., 2018). Generally, in the context of the built environment, it refers to the processes of decision-making involved in the control and management aspect of the built environment(Amaratunga et al., 2019; Malalgoda et al., 2013; UNDRR, 2015, 2019b). The governance of the infrastructure has a direct link to another component of the built environment, as presented in Figure 1. Therefore, strengthening governance is crucial for building climate resilience(Amaratunga et al., 2019; Dias et al., 2019; Wedawatta et al., 2016). The following climate change adaptation measures were identified through the present study to adapt governance to climate change(Amaratunga et al., 2019; Dias et al., 2019; Hürlimann et al., 2022; IPCC, 2015a; Malalgoda et al., 2014b),

- Strengthen the mechanisms for sharing information and data among stakeholders
- Defining clear responsibilities and roles for stakeholders
- Undertake a review of relevant macro and sectoral policies, ordinances, acts, statutes and procedures to identify options for mainstreaming climate change adaptation activities

- Develop policy recommendations necessary for addressing vulnerability to impacts of climate change in all development /management projects
- Conduct training programs for government officers and private sector employees on climate change adaptation
- Develop an inventory of international climate donors, funding schemes, training providers, training programs, research agencies/consortiums and events (conferences, seminars) for the benefit of local stakeholders of adaptation
- Establish a national network of research agencies and universities that are carrying out research on climate adaptation for promoting coordinated research and information dissemination

5 Discussion

The systematic literature review related to project output 03 has led to developing a conceptual framework. Figure 8 illustrates the conceptual framework developed in this study. As it can depicts from Figure 8 due to the complexity of the developed framework, this study developed a user-friendly conceptual framework. This section discusses and illustrates the main sections of the developed conceptual framework.

Figure 5 presents the theoretical framework developed for climate change adaptation measures for infrastructure. It presents the summarised climate change adaptation measures how these adaptation measures assist in achieving targets of global agendas. Figure 6 presents a conceptual framework for climate change adaptation measures to mitigate social, economic, environmental, and governance impacts and alignment with global agendas. Table 3 presents how the identified adaptation measures assist in mitigating adverse climate change impacts on the coastal built environment. The first layer of Figure 5 presents the climate change adaptation measures throughout the infrastructure life cycle. In other words, it presents the identified climate change adaptation measures in infrastructure planning, design and construction, and maintenance and operation. Also, the second layer of Figure 5 depicts the main targets of the global three agendas (i.e., Paris agreement, Sendai Framework for Disaster Risk Reduction, Sustainable Development Goals). The Paris Agreement mainly targets reducing greenhouse gas emissions and mitigating the adverse effects on climate action. On the other hand, Sendai Framework for Disaster Risk Reduction is more specific to increasing the resilience of the built environment, while the Sustainable Development Goals are more concerned with the sustainability aspects within the built environment.

Infrastructure maintenance and repair activities are contributing to emitting of greenhouse gases as maintenance and repair activities require material and energy. Increasing the resilience of the infrastructure reduces the maintenance and repair activities of the infrastructure. Hence increasing infrastructure eventually contributes to the reduction of greenhouse gas emissions. Moreover, the achievement of both the Sendai Framework and the Paris Agreement eventually paves the path to achieving the Sustainable Development Goals. The linkages present in Figure 5 and Figure 6 depict adaptation measures' alignment with global agendas. Climate change adaptation measure is crucial in mitigating the adverse impact of climate change on the built environment. The project output 01 identified climate change impacts on the coastal built environment as presented in Figure 7. Table 3 shows the adaptation measures for mitigating the climate change impacts presented in Figure 5 and Figure 6.

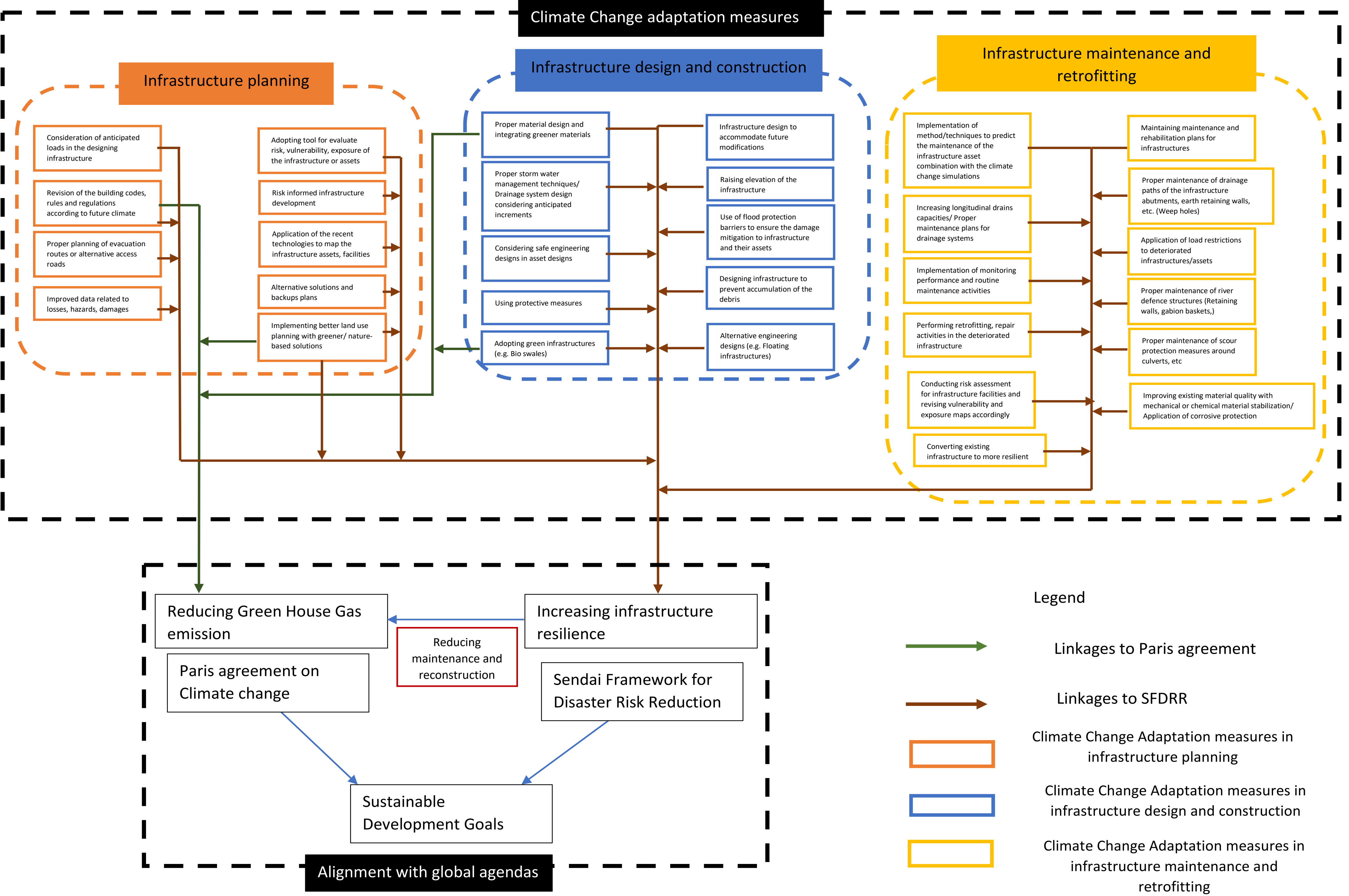

Figure 5 Conceptual Framework for Climate Change Adaptations measures for infrastructure and their alignment with global agenda

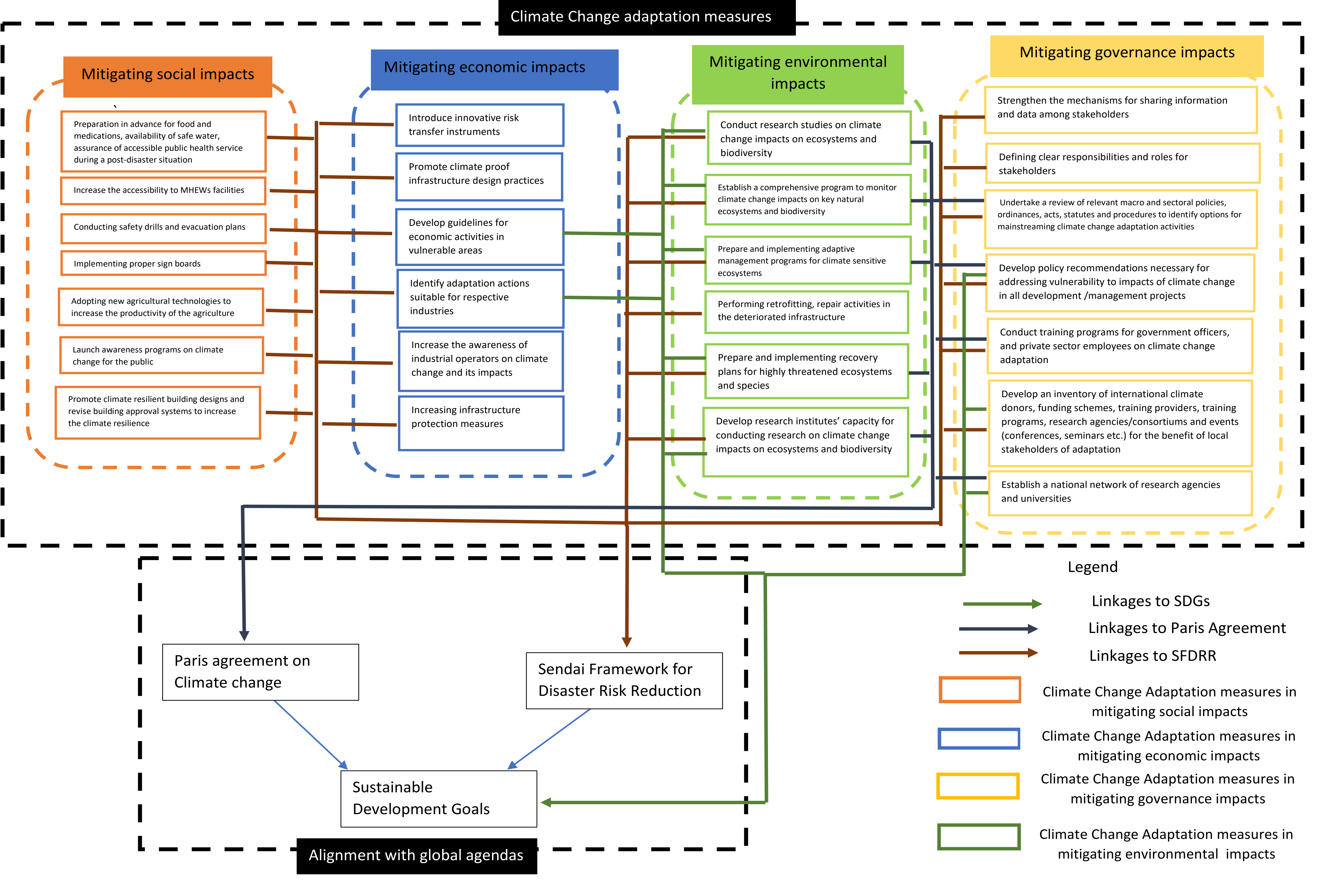

Figure 6 Climate change adaptation measures for mitigating social, economic, environmental and governance impacts

	Climate Change Impacts						
Physical impacts		Economical impacts		Social Impacts		Environmental Impacts	
P1	Damages to Infrastructure	E1	Losses due to damages in the coastal infrastructure	S1	Displacement and loss of livelihoods	EN1	Damages to ecosystems, salt marshes, mangroveforests. Seagrass beds, etc
P2	Access interruption emergency facilities and CIs	E2	Loss of coastal income and economic depression	S2	Voluntary and indvoluntary human migration	EN2	Impact on bio-diversity
P3	Degradation of building materials and structures	E3	Loss of employment	S3	Food and freshwater Insecurities	EN3	Decreased productivity, diversity, and resilience of nearshore marine ecosystem
P4	Changes in energy consumption	E4	Impact on marine based industries such as tourism, fisheris, agriculture	S4	Risk of increased human conflicts resulting in human unrest	EN4	Environmental pollution
P5	Demand more environmentally friendly and adaptive built environment architecture	E5	Impact on planning economic development	S5	Need of social protection programmes	EN5	Impact on water quality
P6	Physical preventive structures	E6	Depletion of resources	S6	Threat to human life, casualities, loss of human lifes	EN6	Environmental restoration after a disaster
P7	Governance and institutional changes coastal buffer zone or revising land use plans	E7	Cost of adaptation and reconstruction				

Figure 7 Climate change impacts identified from the project output report 01

Table 3 Climate Change Adaptation and Climate Change Impacts on Coastal Built Environment

Stage	Climate Change adaptation measures	Climate change impacts
Infrastructure planning	Adopting tool for evaluating risk, vulnerability, exposure of the infrastructure or assets	P1, P3, P6, E1, E5, E7, S1, S6, EN1, EN6
	Risk informed infrastructure development	P1, P3, P6, E1, E5, E7, S1, S6, EN1, EN6
	Application of the recent technologies to map the infrastructure assets, facilities	P1, P2, P3, P7, E5, E6, S5,
	Alternative solutions and backup plans	P1, P2, E1, E2, E3, S5, S6, EN4, EN5
	Consideration of anticipated loads in the designing infrastructure (e.g., consideration of future anticipated traffic load due to inland movement, Wind load)	P1, P3, P4, P6, E1, E2, E5, S1, S5, EN1
	Revision of the building codes, rules, and regulations according to future climate change scenarios	P1, P2, P4, P5, P6, E1, E2, E5, E7, S1, S2, S3,S4, EN1, EN4, EN5
	Proper planning of evacuation routes or alternative access roads	P2, E1, E7, S5, S6, EN6
	Improved data related to losses, hazards, damages	P1, P2, P3, P4, E1, E5, S1, S5, S6, EN5
	Implementing better land-use planning with greener/ nature-based solutions	P1, P2, P5, P7, E7, E6, E5, E1, S5, S6, EN1, EN2, EN3, EN4, EN5, EN6
Infrastructure Design and construction	Proper material design and integrating greener materials	P1, P3, P6, E1, E5, E7, S1, S6, EN1, EN6
	Proper stormwater management techniques/ Drainage system design considering anticipated increments/Sustainable drainage systems	P1, P2, P6, E1, E5, E7, S2, S3, S5, S6, EN5
	Considering safe engineering designs in asset designs	P1, P2, P3, P6, E1, E7, S1, S6, EN6
	Using protective measures	P1, P3, E1, E7, S6, EN3, EN1
	Alternative engineering designs (e.g., Floating infrastructures)	P1, P2, P6, E7, E1, S5, S1, EN4
	Infrastructure design to accommodate future modifications (e.g., Bridge design to accommodate the raising of bridge's deck)	P1, P2, P3, P6, E7, E1, S6, S1, EN6
	Raising the elevation of the infrastructure	P1, P2, P3, P6, E1, E7, S1, S6
	Use of flood protection barriers to ensure the damage mitigation to infrastructure and their assets (e.g., Rock armor structures, concrete masonry block, revetment, geosynthetic container revetment, dikes, seawalls, rocky aprons, breakwater systems)	P1, P2, P3, P6, E1, E7, S6, EN6
	Designing infrastructure to prevent accumulation of the debris (e.g., Debris guards/rack upstream)	P1, P2, P6, E1, E7, S6, EN6
	Adopting green infrastructures (e.g., Bioswales)	P1, P5, E4, E6, E7, S6, S1, EN1, EN2, EN4, EN5, En6

Infrastructure Maintenance and retrofitting	Increasing longitudinal drains capacities/ Proper maintenance plans for drainage systems	P1, P2, P3, P6, P7, E1, E7, S6, S1, EN 5
	Implementation of monitoring performance and routine maintenance activities	P1, P2, P3, P6, E1, E7
	Performing retrofitting repair activities in the deteriorated infrastructure	P1, P2, P3, P6, E7, E1
	Maintaining maintenance and rehabilitation plans and programs for infrastructures	P1, P2, P6, P7, E1, E7,
	Implementation of method/techniques to predict the maintenance of the infrastructure asset combination with the climate change simulations	P1, P2, P3, P6, E1, E7
	Application of load restrictions to deteriorated infrastructures/assets	P1, P2, P3, P6, E1, E7
	Proper maintenance of drainage paths of the infrastructure like bridge abutments, earth retaining walls, (Weep holes)	P1, P2, P3, P6, E1, E7
	Proper maintenance of river defence structures (Retaining walls, gabion baskets)	P1, P2, P3, P6, E1, E7, S1, S6
	Proper maintenance of scour protection measures around culverts.	P1, P2, P3, P6, E1, E7
	Improving existing material quality with mechanical or chemical material stabilization/ Application of corrosive protection	P1, P2, P3, P6, E1, E7
	Conducting a risk assessment for infrastructure facilities and revising vulnerability and exposure maps accordingly	P1, P2, P3, P6, E1, E7
	Converting existing infrastructure to more resilient	P1, P2, P3, P6, E1, E7
Adaptation measure for mitigating social impacts	Preparation in advance for food and medications, availability of safe water, assurance of accessible public health service during a post-disaster situation	S3, S4
	Increase the accessibility to MHEWs facilities	S6, S1

	Conducting safety drills and evacuation plans and implementing proper signboards	S6,S1,S5
	Adopting new agricultural technologies to increase the productivity of the agriculture	S2,S3,S4
	Launch awareness programs on climate change for the public	S6,S5,S1,S2
	Promote climate-resilient building designs and revise building approval systems to increase the climate resilience	S6,S5,S1,S2
Adaptation measures for mitigating economic impacts	Introduce innovative risk transfer instrument	E4,E5,E6
	Promote climate-proof infrastructure design practices	E1, E2,E3,E7,E6
	Develop guidelines for economic activities in vulnerable areas	E5, E3, E1, E6
	Identify adaptation actions suitable for respective industries	E4, E3, E2, E5
	Increase the awareness of industrial operators on climate change and its impacts	E4, E6, E7, E1, E2
	Increasing infrastructure protection measures	E1, E2, E5, E7
Adaptation measures for mitigating environmental impacts	Conduct research studies on climate change impact on ecosystems and biodiversity	EN1, EN2
	Establish a comprehensive program to monitor climate change impacts on key natural ecosystems and biodiversity	EN1,EN3,EN4,EN5,EN6

	Prepare and implement adaptive management programs for climate-sensitive ecosystems	EN1, EN2,EN5,EN3,EN6
	Prepare and implement recovery plans for highly threatened ecosystems and species	EN2, EN3, EN1
	Develop research institutes' capacity for conducting research on climate change impacts on ecosystems and biodiversity	EN4, EN6, EN2, EN3
Adaptation measures for strengthening the governance of the infrastructure	Strengthen the mechanisms for sharing information and data among stakeholders	All
	Defining clear responsibilities and roles for stakeholders	
	Undertake a review of relevant macro and sectoral policies, ordinances, acts, statutes and procedures to identify options for mainstreaming climate change adaptation activities	
	Develop policy recommendations necessary for addressing vulnerability to impacts of climate change in all development /management projects	
	Conduct training programs for government officers and private sector employees on climate change adaptation	

	Develop an inventory of international climate donors, funding schemes, training providers, training programs, research agencies/consortiums and events (conferences, seminars etc.) for the benefit of local stakeholders of adaptation	
	Establish a national network of research agencies and universities that are carrying out research on climate adaptation for promoting coordinated research and information dissemination	

6 Summary and Conclusions

Climate change has become unprecedented, and anthropogenic GHGs emissions unequivocally contributed to change in the climate. Consequently, disaster and disaster risks increase as climate change increases the frequency and severity of extreme weather events. At the moment, climate action is irreversible but can be limited by reducing GHGs emissions. The coastal built environments have become greater victims of disasters. The project output 01 has figured out climate change impacts on the coastal built environment. As highlighted in the project output 01 report, physical impacts regarding climate change are the most closely linked to the built environment. The non-physical elements of economic, social, and environmental impacts due to climate change can be identified as other impacts associated with climate change. Therefore, climate change adaptation is crucial in order to mitigate the adverse impacts of climate change. The present study was carried out to identify the adaptation measures that can be implemented during planning, design and construction and maintenance and retrofitting of the coastal built environment. A global review was conducted on a systematic literature review. The systematic literature review sought adaptation measures practised in the context of the built environment. The present study categorized the built environment as physical and non-physical. Infrastructure and ecosystem were considered main elements under the built environment's physical components. Community, economy and governance of infrastructure are considered the non-physical component of the built environment. The climate change adaptation measures for each element within the built environment were identified through literature analysis.

Then findings of the systematic literature review were organized as the conceptual frameworks presented above. The developed conceptual framework demonstrates climate change adaptation measures, their alignment with global agendas and mitigation of climate change impacts. This developed conceptual framework is yet to be validated through country-based expertise interviews. As the next step of the BEACON output 03, it is planned to conduct the country-based expertise interviews to collect the data for the validation process of the developed conceptual framework. This developed framework can be adapted by a built environment professional to develop a climate-resilient built environment

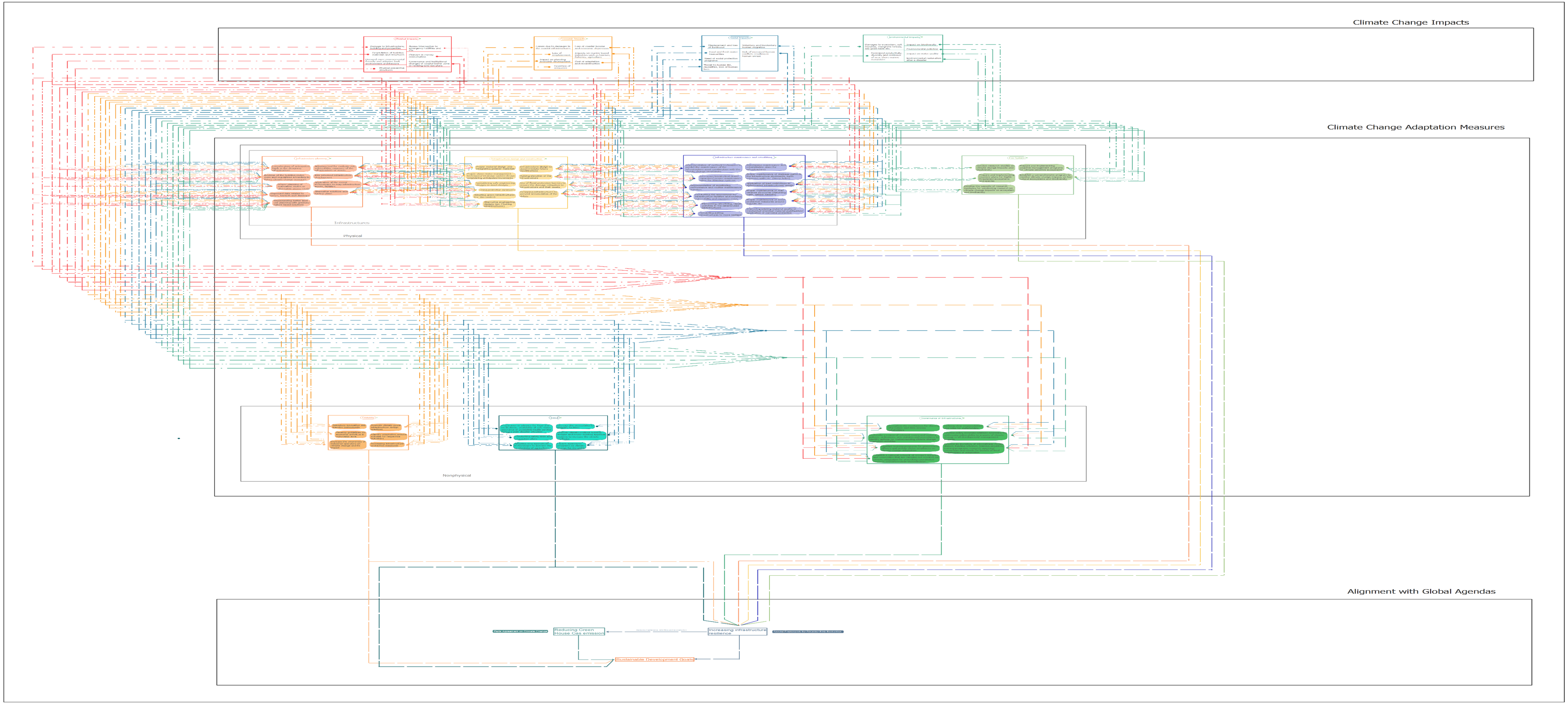

Figure 8 Compiled version of developed conceptual framework

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