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Towards 'Climate Proof' Infrastructure Projects

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Abstract

We construct our Infrastructure Projects (IP) with certain design life, during which we expect that they will be effective; however, in certain cases they are inadequate and fail. Since this failure can be partly attributed to the impacts of Climate Change (CC), we are urged to develop 'climate proof' IP. In this work, we pose the following research question "what IP do we need that can be 'climate proof'?". To answer this question, we performed a literature survey and firstly identify the main CC impacts of our IP that we present with a flow chart. Secondly, we describe critically with examples that our 'climate proof' IP need to be resilient, green, smart, innovative, and with low carbon footprint. Thirdly, we discuss the important role of social equity in the prioritization of our 'climate proof' IP, the significance of private funding, mainly via public-private partnerships, and the necessity of well informed and properly educated engineers and other scientists, who are expected to materialize our 'climate proof' IP.

Keywords: Climate change; Infrastructure projects; Climate proofing; Climate resilience

Abbreviations: CC: Climate Change; GHG: Greenhouse Gases; SDGs: Sustainable Development Goals; IP: Infrastructure Projects; ICT: Information and Communication Technologies; CEF: Connecting Europe Facility; ERDF: European Regional Development Fund; CF: Cohesion Fund; JTF: Just Transition Fund; BIM: Building Information Modelling; DLT: Distributed Ledger Technologies

Introduction

Climate Change (CC) refers to significant changes in average conditions of climate indicators, such as temperature, precipitation, wind patterns, and other aspects of climate, which occur over years, decades, centuries, or longer; CC involves longer-term trends, such as shifts toward warmer, wetter, or drier conditions. These trends can be caused by natural variability in climate over time, as well as human activities that add greenhouse gases (GHG) to the atmosphere like burning fossil fuels for energy [1]. CC generates natural hazards that become natural disasters when people's lives and livelihoods are destroyed [2]. Tables 1-3 that show the main characteristics of natural disasters worldwide in last according to the Centre for Research on the Epidemiology of Disasters denote the following:

(1) The world encountered 1178 natural disasters that are mainly (90%) climate-related,

(2) 292 million of people were affected by natural disasters that were floods (25%), storms (25%), droughts (17%) and wildfires (2%),

(3) Economic losses due to natural disasters were $163.4 billion, with storms (55%), floods (27%), wildfires (9%) and droughts (4%) accounting for approximately 95 % of the total costs [3].

Table 1: Number of natural disasters worldwide.

Natural Disaster	2018	2019	2020
Droughts	17	15	9
Floods	144	196	201
Temperature Changes	27	21	5
Severe Storms/Winds	97	91	147
Wildfires	10	14	8
Landslides	13	25	19
Total climate related	308	362	389
Total	338	442	398

Table 2: Number of people affected in millions.

Natural Disaster	2018	2019	2020
Droughts	26	23	19
Floods	34	35	34
Temperature Changes	0	0	0
Severe Storms/Winds	20	38	45
Wildfires	0	10	0
Landslides	0	0	0
Total climate related	80	106	98
Total	85	108	99

Table 3: Economic losses in billions of US dollars.

Natural Disaster	2018	2019	2020
Droughts	9.4	0.135	7.5
Floods	19.7	36.82	51.45
Temperature Changes	0	0	0
Severe Storms/Winds	72.8	57.63	93.22
Wildfires	22.8	3.73	11.17
Landslides	0.93	0.2	0.13
Total climate related	125.6	98.52	163.4
Total	133.7	100.9	172.4

ASCE defines the following 17 categories of Infrastructure Projects (IP): roads, ports, rail, bridges, aviation, dams, drinking water, energy, hazardous waste, inland waterways, levees, parks and recreation, schools, solid waste, storm water, transit, and wastewater [4]. We design our IP with certain design life, during which we expect that they will be effective. In certain cases, however, IP is proven to be inadequate and fails; this failure that seems to be increasing in the last years is partly attributed to CC, which enhances natural hazards that subsequently become natural disasters. When we do not consider CC in the design of IP, the latter cannot only mitigate, but they also create risk. For example, a levee keeps water out from a specific area, but it also keeps water in if the levee is overrun or if the area is flooded due to local heavy rainfall. In the last years, administrations realized the importance of the interaction between IP and CC. In September 2015, all United Nations Member States countries adopted a set of Sustainable Development Goals (SDGs) to end poverty, protect the planet and ensure prosperity for all, which are set to be achieved by 2030 [5]. Goals SDG 9 "Industry, Innovation and Infrastructure", and SDG 11 "Sustainable Cities and Communities", are directly connected with IP and CC. On the 3rd of March 2021, ASCE released the quadrennial Report Card for America's IP [4] that are assessed using the grades: A (exceptional), B (good), C (mediocre), D (poor) and E (failing), according to which USA's infrastructure received a C- grade showing a modest gain from D+ in 2017 and made the following recommendations:

a) Smart investment is required that will only be possible with strong leadership, decisive action, and a clear vision for nation's infrastructure.

b) Increased, long-term, consistent investment is required (the country is spending half of what is required to support its IP) to close the nearly $2.6 trillion 10-year investment gap.

c) Advancements in resilience are required including new approaches, materials, and technologies to ensure that IP can withstand or quickly recover from natural or man-made hazards. On the 10th of August 2021, the Senate passed the bipartisan (President Joe Biden's infrastructure) bill that includes new spending of $550 billion on transportation (roads, bridges, and rail), utilities (high speed internet and water), pollution cleanup, and other actions to combat CC, including $28 billion for power grid infrastructure, resiliency, and reliability (in part to help expand the reach of clean energy) and $46 billion to, in part, mitigate damage from floods, wildfires, and droughts. On the 29th of July 2021, the European Commission published the "Technical guidance on the climate proofing of infrastructure in the period 2021-2027" [6]. Climate proofing is a process that integrates CC mitigation (neutrality) and adaptation (resilience) measures into the development of IP. The guidance meets the following requirements laid down in the legislation for several EU funds, notably Invest EU, Connecting Europe Facility (CEF), European Regional Development Fund (ERDF), Cohesion Fund (CF), and the Just Transition Fund (JTF):

a) consistency with the Paris Agreement and EU climate objectives.

b) following the principles "energy efficiency first" and "do no significant harm". The guidance can be used by Institutional, and private European investors to make informed decisions on IP following a procedure that includes assessment of climate-related risks their IP may face in the coming years based on data that could include national or regional CC projections, or the long-awaited update of a UN climate science report expected in August. If significant risks are identified, the developer should redesign the IP to manage and reduce them; that for example could involve changing the design of physical assets to cope with high temperatures or creating emergency response systems for floods [7-9].

In this work, we pose the following research question "what IP do we need that can be 'climate proof'?". To answer this question, we perform a literature survey and firstly identify the main CC impacts of our IP that we present with a flow chart. Secondly, we describe critically with examples the characteristics that our IP should have to be 'climate proof'. Thirdly, we discuss the issues of social equity in the prioritization of our 'climate proof' IP, the significance of private funding, and the necessity of well informed and properly educated engineers and other scientists, who are expected to materialize our 'climate proof' IP.

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Climate Change impacts on Infrastructure Projects

Based on the literature, we created the flow chart of Figure 1 that shows the main impacts of CC on IP with their paths starting from the "climate indicator" change and the "natural hazard" development. To simplify Figure 1, we included the 6 main natural hazards of Table 1 and the 6 broad categories of IP that are shown in Table 4. For each category of IP, there exist various measures to adapt to a CC impact that we need to consider in the development stages of the IP [10,11]. For example, Figure 1 depicts that the increase of the climate indicator "air temperature" creates the hazard "temperature changes" that results in the impact "Damages to roads, rail tracks, bridges and pavements" of the IP "TRANSPORT". We may face the impact on the specific IP "roads", by adapting its design via planting roadside vegetation to decrease the exposure of roads to heat and provide cooling through green and blue infrastructure, such as parks and lakes, but also road-side trees or other shading [12]. Generally, there are various methods in the literature for each category of IP how to adapt to a CC impact by modifying its design and construction for this purpose

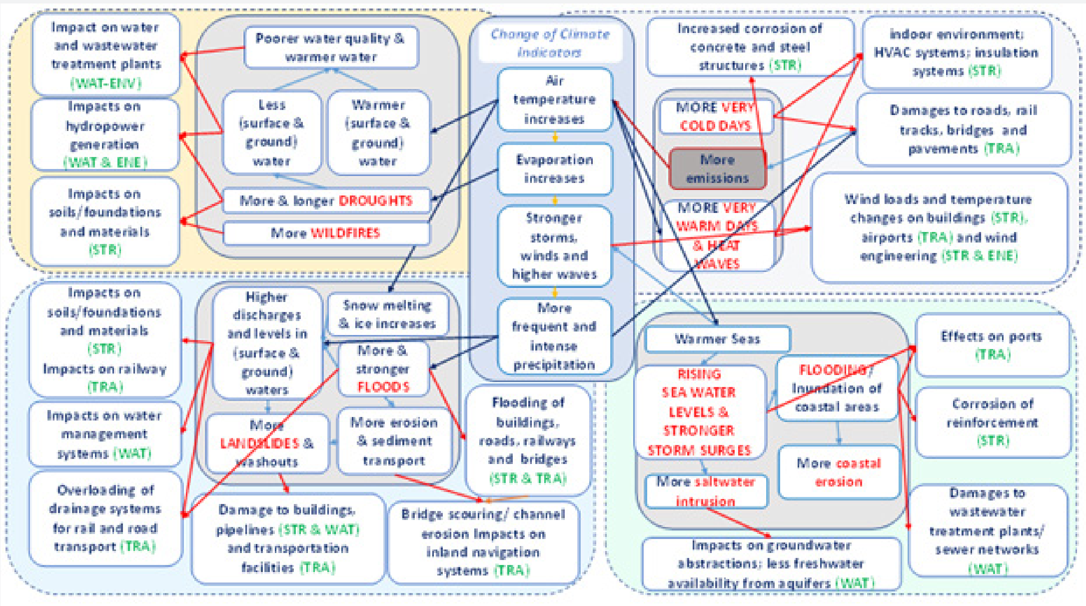

Figure 1: Flow chart of the main impacts of CC on IP.

Table 4: Category of IP and its symbol in Figure 1.

Category of IP	Symbol
TRANSPORT: Roads, ports, rail, bridges, transit, aviation, transit etc.	TRA
WATER: inland waterways, dams, drinking water, storm water, levees, etc.	WAT
ENERGY	ENE
ENVIRONMENT: Wastewater, hazardous waste, solid waste, etc.	ENV
TELECOMMUNICATIONS	TEL
BUILDINGS / built systems: Hospitals, government buildings, schools, etc.	STR

The needs for 'Climate Proof' Infrastructure Projects

In this section of the paper, we describe the basic needs to develop 'climate proof' IP based on the existing international literature and experience.

1. We need resilient IP that "bent but not break". Many existing or even new IP do not consider CC impacts; thus, they can create risks. We need to design and build our new IP to be resilient, to adapt to CC and be capable of "bend but not break"; in this way, they are able to recover in what will likely be increasingly intimidating conditions.

The six principles for resilient IP (P1 to P6) and their goals (G1 to G6) are the following [13]:

(P1) Adaptively transforming – (G1) Adapt and transform to changing needs.

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(P2) Environmentally integrated – (G2) Work in a positively integrated way with the natural environment.

(P3) Protected by design – (G3) Design infrastructure that is prepared for hazards.

(P4) Socially engaged – (G4) Develop active engagement, involvement, and participation with people.

(P5) Shared responsibility – (G5) Share information and expertise for coordinated benefits.

(P6) Continuously learning – (G6) Develop understanding and insight into infrastructure resilience.

2. We need green IP. Green infrastructure is a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services, such as water purification, air quality, space for recreation and climate proofing [14]. This network of green (land) and blue (water) spaces can improve environmental conditions and therefore citizens' health and quality of life; moreover, it supports a green economy, creates job opportunities, and enhances biodiversity. Green IPs are proposed by the European Commission within the framework of the Green Infrastructure Strategy [15], which

a. The development of Green IP across the EU to deliver economic, social, and ecological benefits and to contribute to sustainable growth,

b. Their mplementation at EU, regional, national, and local levels via its integration into EU funding streams.

The Green Infrastructure Strategy integrates into the relevant policies as follows:

a. CC policies via ecosystem-based adaptation [16],

b. And innovation policies via Nature-Based Solutions (NBS) [17],

c. Policies via natural water retention measures [18],

d. Policies via focusing on delivering multiple ecosystem services and rich biodiversity [19].

We may use Green IP to mitigate the adverse CC impacts, for example via:

a. Tree species and forestry practices that are less vulnerable to storms and fires,

b. Heat islands in urban areas [20], and

c. Aside land corridors for species migration [21].

Green IPs are especially important for natural flood management in river basins and coastal areas, for example by:

a. Natural flows by realigning coastal areas [22],

b. Rivers with their floodplain [23],

c. Wetlands to store flood water and slow down floods,

d. Reservoirs in agricultural areas to store flood water during flood events,

e. Sustainable urban drainage using green spaces, permeable surfaces, and green roofs [24,25].

3. We need smart IP. We are continuously seeking to improve the effectiveness of our IP; this pursuit combined with the growth of information and communication technologies (ICT) has led to the concept of smart IP (cyber-physical systems), wherein enabling technologies, such as connected sensors and big data analytics are integrated with physical infrastructure to achieve real-time monitoring, efficient decision-making, and enhanced service delivery [26]. The potential benefits of smart IP include:

a) Maintenance costs

b) Damage, and disruption costs (traffic congestion or power blackout)

c) Quality and value of service (on-demand use and flexible tariffs)

d) Protection of human life (less road accidents or better response to disasters, including these related to CC).

These advantages contribute to sustainable urban growth [27]. Smart IP has been applied in several areas, including electricity distribution systems [28], water and wastewater services [29], automatic toll collection systems [30], intelligent transport systems [31], emergency services and monitoring of critical infrastructure assets, such as tunnels, bridges, and dams [32]. Most of the above-mentioned applications are realized in smart cities, that are municipalities using ICT to increase operational efficiency, share information with the public and improve both the quality of government services and citizen welfare. The key components of smart cities are the following [33]:

a. Smart buildings that can reduce 30% water consumption, 40% energy consumption and 30% maintenance costs.

b. Smart mobility reduces congestion and fosters greener, cheaper, and faster transportation options, usually via the exploitation of big data collected from various mobility patterns to help holistically optimize traffic conditions.

c. Smart energy management systems to automate, monitor, and optimize energy distribution and usage, via sensors, advanced meters, renewable energy sources, digital controls, and analytic tools, including distributed renewable generation, microgrids, smart grid technologies, energy storage, automated demand response, and virtual power plants.

d. Smart water management that typically uses digital

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technology to help save water, cut costs, and improve water distribution reliability and transparency; typically, it involves the performance of analyses of the available flow and pressure data in real-time to detect anomalies, such as leaks.

e. Smart waste management that reduces waste, categorizes waste types at the source, and develops waste-handling methods via the use of sensors, connectivity, and the Internet of Things.

f. Smart health systems, for example via using big data to make predictions or identify population health hotspots, such as epidemics or health impacts during extreme weather events.

4. We need innovative IP. We require innovative solutions and creative engineering achievements in our IP. Innovation is thriving at all stages of infrastructure development and exciting new ideas are being generated around the world; these include the following [34]:

a. Building Information Modelling (BIM). BIM involves a digital model (software program) of a building that provides information on its components in all its development stages, beyond 2-D technical drawings and Computer Aided Design, and allows professionals, from the architects to the engineers to the building managers, to collaborate. BIM is widely believed to have the potential to unlock 15-25% savings in the global infrastructure market by 2025 [35]. Moreover, BIM goes beyond just time and money savings and provides opportunities in the construction industry not only for 'climate proof' buildings, but also in waste and energy management [36].

b. 3D printing. It is an additive manufacturing process that creates a physical (3D) object from a digital design; the process works by laying down thin layers of material in the form of liquid or powdered plastic, metal, or cement, and then fusing the layers together [37]. While BIM improves the design of IP, 3D printing changes the way IP are physically constructed on-site. There are various ways how 3D printing battles CC, including the reduction of product waste and the emissions. 3D printing applications in IP include construction components, such as concrete with minimal material waste, fasteners with enhanced design flexibility, construction tools, high-performance steerable and effective telecom antennas, and valves [38], but also whole buildings [39] and bridges [40].

c. Mass timber constructions. Mass timber is increasingly replacing other building materials like cement and steel; new products like CLT (Cross-Laminated Timber, formed by stacking and gluing perpendicular layers of wood) and Glulam (Glue-laminated timber, formed by stacking and gluing layers of wood directly on top of each other) are allowing for even higher and stronger wood buildings. Mjøstårnet in Brumunddal, Norway, is the world's tallest timber building; it is an 18-storey and 85.4 m tall mixed-use building that was completed in March 2019 [41]. The substitution of conventional building materials by mass timber is expected to reduce construction phase emissions by 69%, which corresponds to an average reduction of 216 kg CO_2e/m^2 of floor area, while wood in half of new urban construction may achieve 9% of 2030 emissions goals [42]. It should be noted, however, that attention should also be paid to the thermal effects of such a substitution or the degree to which climate benefits might be either exaggerated or offset by the thermodynamics of changing forest landscapes as well as urban building morphology and materiality. This area of research, as well as the forest management strategies and building design criteria that might arise from it, represent a significant challenge for a generation of architects, engineers, and climate scientists focused on the restoration of our climate and the rebalancing of global ecosystems [43].

d. Plastic roads. They are made either entirely of recycled plastic components or mixed with other materials, such as asphalt used in traditional road construction. Advantages over asphalt include a quicker installation time, triple the service life and introducing an effective way to recycle the plastic that ends up in our oceans and landfills [34]. Plastic roads are hollow to allow room for utility pipe placement and rainwater drainage; they are also covered in a special coating to prevent the release of microplastics, which often end up our food supply. In 2021, 703 km of highways in India were constructed using plastic waste [44].

e. Distributed Ledger Technologies (DLT). DTL such as blockchain, have the potential to improve current processes and systems by acting as a digital enabler across the infrastructure value chain [45]. Blockchain is a digital ledger or database that helps to verify and trace multistep transactions. While it might be best known as the architecture behind crypto Bitcoin, it is finding uses in everything from tracking the sustainability of products to the real-time monitoring of pollution [46]. Blockchain can eliminate the many layers of contracts and middlemen that sit between the conception and delivery of an IP. Blockchain's potential to undergird smart contracts can be used to pay for important aspects of an infrastructure asset (for example, a subway car or important parts of a ventilation system) by releasing direct payments over time to the supplier, the shipping company, or the installer without a web of separate contracts and intermediate parties [34]. A case study report from the OECD identified the key areas where blockchain is already impacting the provision of sustainable infrastructure services and presents four original case studies where blockchain could unlock value across the infrastructure life cycle [45].

5. We need IP with reduced carbon footprint. Approximately 70% of global GHG emissions come from the construction and operation of IP, including mainly buildings, and transport. The Overseas Development Institute estimates that over 720 million people could be pushed back into extreme poverty by 2050 because of CC impacts, while the World Health Organization

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projects that the number of deaths attributable to the harmful effects of emissions from key infrastructure industries will rise from the current 150,000 per year to 250,000 by 2030 [47]. Thus, we need to use more low-carbon IP, such as decarbonized buildings, railway (instead of carbon-emitting trucks), metros and light rail (instead of cars), renewable energy projects, such as solar, wind, and hydropower (instead of IP using fossil fuels). The development of digital technology brings the opportunity to reduce current high carbon footprints; a recent study indicated that the digitalization level regarding carbon-related areas is still at an early stage, and efforts should be taken both academically and practically to drive the digital development confronting the harsh CC issue [48].

Ensuring that our IP is resilient, green, smart, innovative, and with low carbon footprint is not enough. We need to prioritize our IP; we need to identify which IP needs to be materialized today vs. where we can take a wait-and-see approach to adapt our IP as the climate changes. Theoretically, we may combine the information of Tables 1-3 that show the most significant climate hazards and Figure 1 that depicts the main impacts of these hazards on IP to decide which IP deserves priority. In practice, however, this simplified approach is not feasible due to many other factors, such as the interaction of IP with our society that must ensure community resilience as well. If electricity systems fail during a storm, we need to make sure backup plans are in place so that people still have access to water, heat, and medical care. These plans should start with our most vulnerable communities. Thus, we need IP with social equity. Based on a study by FEMA on urban flooding [49], the poor, racial and ethnic minorities, the elderly, renters, non-native English speakers, and those with mobility challenges were disproportionately affected by floods in each area. A major difference across the metropolitan areas was the level of citizen empowerment, which ranged from highly organized neighborhood and citizen groups (Chicago) to low levels of citizen engagement (Baltimore). Privileged households are more likely to have resources to navigate disasters by relocating, paying for repairs, and using savings to compensate for lost income. So, disadvantaged households are often much more affected, even for the same level of physical disruption. They are also often more affected due to living in higher-risk areas. Further, under-served communities often struggle to access recovery funding and advocate for infrastructure repairs. Also, recently, strong linkages have been found between design features of the built environment and historical housing policies that may be directly responsible for disproportionate exposure of underserved populations to current heat events. Addressing urban heat island effects through attention to both built and natural infrastructure in cities can help address these inequities. We need to engage sociologists, psychologists, communicators, and educators along with engineers in addressing equity issues around IP. Also, we may need to update the methods used for assessing risk and vulnerability and to determine cost-benefit tradeoffs so that small or poor communities are no longer overlooked [50]. The role of private funding in the development of IP is also very important. We need to enhance the attractiveness of IP for private funding and the formation of public-private partnerships (PPP) [51]. For this, we need improved transparency in the IP generation process, higher certainty concerning the framework conditions for project execution and reduced risk for the operation phase. A long-term infrastructure pipeline and better, broader, and more independent cost benefit analysis are the major levers to reach this [52].

Last but not least, we need well-informed and properly educated engineers and other scientists. Universities, Research Institutes, Associations, Societies and Organizations should include in their teaching-education-capacity building and research programs, subjects that are related to 'climate proof' IPs. Some indicative examples are the master's course 'Urban Digital Transformation & Innovation: Governance and Economics of Cities' of the Erasmus University Rotterdam [53], the 8-weeks course 'Delivering Sustainable Infrastructure: Theory and Practice for Construction' of the University of Cambridge [54], and the training course entitled 'Climate Proofing of Infrastructure Investments' of the Centre for Rural Development (SLE) of Humboldt-Universität Zu Berlin [55]. Analogous actions have been performed by civil engineering organizations, such as ICE and the ASCE. ICE created a climate literacy Programme and plans to mirror that in its requirements for both Membership and Fellowship grades [56], while ASCE focuses on how to make infrastructure more resilient against climate change [57].

Conclusion

We posed the following research question "what IP do we need that can be 'climate proof'?". To answer this question, we performed a literature review and first identified the main CC impacts of our IP that we presented with a flow chart. Secondly, we described critically with examples that our 'climate proof' IP need to be resilient, green, smart, innovative, and with low carbon footprint. Thirdly, we discussed the important role of social equity in the prioritization of our 'climate proof' IP, the significance of private funding, mainly via public-private partnerships, and the necessity of well informed and properly educated engineers and other scientists, who are expected to materialize our 'climate proof' IP.

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References

1. https://www.epa.gov/climatechange-science/frequently-asked-questions-about-climate-change#climate-change
2. https://public.wmo.int/en/our-mandate/focus-areas/natural-

How to cite this article: A Stamou. Towards 'Climate Proof' Infrastructure Projects. Civil Eng Res J. 2022; 13(3): 555861.
DOI: 10.19080/CERJ.2021.13.555861

hazards-and-disaster-risk-reduction

3. (2022) CRED. Centre for Research on the Epidemiology of Disasters; https://www.cred.be
4. https://infrastructurereportcard.org/
5. https://www.undp.org/iraq/sustainable-development
6. goals?utm_source=EN&utm_medium=GSR&utm_content=US_UNDP_PaidSearch_Brand_English&utm_campaign=CENTRAL&c_src=CENTRAL&c_src2=GSR&gclid=Cj0KCQjw--2aBhD5ARIsALiRlwB99p9ZdtNXI_7XI_I-oqv3odnQo73pgsDQQXJZ3-CI4Dts4FBmniYaApijEALw_wcB
7. https://ec.europa.eu/clima/sites/default/files/adaptation/what/docs/climate_proofing_guidance_en.pdf
8. Mitsopoulos G, Bloutsos A, Panagiotatou E, Baltas E, Stamou A (2022) Design Aspects of an Early Warning System for Flash Floods: The Case of the Town of Mandra in Attica, Greece. From Snow to Sea. Proceedings of the 39th IAHR World Congress 19-24.
9. Stamou A, Mitsopoulos G, Baltas E (2022) Identification of the weak points in the application of a methodology for the design of Flood Early Warning Systems in Climate Change Conditions. The case of the town of Mandra, Attica, Greece, 7th IAHR Europe Congress: Innovative Water Management in a Changing Climate. Athens, Greece 7-9.
10. Mitsopoulos G, Panagiotatou E, Sant V, Baltas E, Diakakis M, Lekkas E, Stamou A (2022) Optimizing the Performance of Coupled 1D/2D Hydrodynamic Models for Early Warning of Flash Floods. Water 14(15).
11. Olsen, Rolf & Ayyub, Bilal & Walker, Dan & Barros, Ana & Medina et al. (2015). Adapting Infrastructure and Civil Engineering Practice to a Changing Climate.
12. Stamou AI (2019) Adapting Civil Engineering Design to Climate Change, HELASCO Conference The Consulting Industry facing New Markets. Requirements and Instruments, Athens, Greece pp: 26-27.
13. Zaki SA, Toh HJ, Yakub F, Mohd Saudi AS, Ardila-Rey JA, et al. (2020) Effects of Roadside Trees and Road Orientation on Thermal Environment in a Tropical City. Sustainability 12: 1053.
14. https://www.undrr.org/publication/principles-resilient-infrastructure
15. https://ec.europa.eu/environment/nature/ecosystems/pdf/Green%20Infrastructure/GI_climate_adaptation.pdf
16. https://ec.europa.eu/environment/nature/ecosystems/strategy/index_en.htm
17. Fabio Rubio Scarano (2017) Ecosystem-based adaptation to climate change: concept, scalability and a role for conservation science. Perspectives in Ecology and Conservation 15(2): 65-73.
18. Panagiotatou E, Stamou A (2022) Mathematical Modelling of Nature-Based Solutions for flood risk reduction under Climate Change conditions. 7th IAHR Europe Congress: Innovative Water Management in a Changing Climate. Athens, Greece pp: 7-9.
19. Zelenakova, Martina, Diaconu, Daniel, Haarstad, Ketil (2017) Urban Water Retention Measures. Procedia Engineering. 190: 419-426.
20. Iris Maria Hertog, Sara Brogaard, Torsten Krause (2022) Barriers to expanding continuous cover forestry in Sweden for delivering multiple ecosystem services, Ecosystem Services. 53: 101392.
21. Walter LF, Leyre EI, Alice N, Maris K, Edward AM (2018) Coping with the impacts of urban heat islands. A literature-based study on understanding urban heat vulnerability and the need for resilience in cities in a global climate change context. Journal of Cleaner Production 171: 1140-1149.
22. Hilty, Jodi & Worboys, Graeme & Keeley, Annika & Woodley, Stephen & Lausche, et al. (2020) Guidelines for conserving connectivity through ecological networks and corridors.
23. Guerry AD, Silver J, Beagle J, Wyatt K, Arkema K, et al. (2022) Protection and restoration of coastal habitats yield multiple benefits for urban residents as sea levels rise. npj Urban Sustain 2: 13.
24. Serra-Llobet Anna, Jähnig Sonja C, Geist Juergen, Kondolf Mathias G, Damm Christian, et al. (2022) Restoring Rivers and Floodplains for Habitat and Flood Risk Reduction: Experiences in Multi-Benefit Floodplain Management From California and Germany. Frontiers in Environmental Science.
25. https://www.epa.gov/heatislands/using-green-roofs-reduce-heat-islands
26. Grabowski ZJ, McPhearson T, Matsler AM, Groffman P, Pickett Steward TA, (2022). What is green infrastructure? A study of definitions in US city planning. Frontiers in Ecology and the Environment, Front Ecol Environ 20(3): 1540-9295.
27. Weiss A (2009) Smart infrastructure matches supply and demand Networker. 13(3): 18-25.
28. Morimoto R (2010) Estimating the benefits of effectively and proactively maintaining infrastructure with the innovative smart infrastructure sensor system. Socio-economic Planning Sciences 44(4): 247 257.
29. Jayachandran M, Prasada Rao K, Ranjith Kumar G, Kalaivani C, Kalaiarasy C, et al. (2022) Operational concerns and solutions in smart electricity distribution systems. Utilities Policy 74: 101329.
30. Martin Oberascher, Wolfgang Rauch, Robert Sitzenfrei, (2022) Towards a smart water city: A comprehensive review of applications, data requirements, and communication technologies for integrated management. Sustainable Cities and Society 76: 103442.
31. Nag, Dipanjan & Roy, Anibrata & Goswami, Arkopal (2020) Estimating Environmental Benefits of Electronic Toll Collection (ETC). 10.1007/978-981-32-9042-6_35.
32. Mohammed Sarrab, Supriya Pulparambil, Medhat Awadalla (2020) Development of an IoT based real-time traffic monitoring system for city governance. Global Transitions 2: 230-245.
33. Hareesh R, Senthil Kumar RK, Kalluri R, Bindhumadhava BS (2022) Critical Infrastructure Asset Discovery and Monitoring for Cyber Security. In: Pillai RK, Ghatikar G, Sonavane VL, Singh BP (eds) ISUW 2020. Lecture Notes in Electrical Engineering, Springer, Singapore 847: 289-300.
34. https://roboticsbiz.com/key-components-of-smart-city-infrastructure-an-overview/
35. https://www.weforum.org/agenda/2019/09/6-revolutionary-techniques-about-to-transform-our-infrastructure/
36. www.eubim.eu
37. https://blog.wavin.com/en-gb/can-bim-help-the-construction-industry-to-tackle-climate-change
38. https://www.investopedia.com/terms/1/3d-printing.asp
39. https://www.fabbaloo.com/news/3d-printing-and-infrastructure-investments-in-developing-countries
40. https://www.procore.com/jobsite/6-of-the-worlds-most-impressive-3d-printed-buildings/
41. https://www.3dnatives.com/en/3d-printed-bridge-051120214/

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DOI: 10.19080/CERJ.2021.13.555861

42. Austin Himes, Gwen Busby (2020) Wood buildings as a climate solution. Developments in the Built Environment 4: 100030.

43. Churkina G, Organschi A (2022) Will a Transition to Timber Construction Cool the Climate? Sustainability 14(7): 4271.

44. https://guinnessworldrecords.com/world-records/79569-tallest-wooden-building/

45. https://timesofindia.indiatimes.com/auto/news/india-constructed-703-km-of-highways-using-plastic-waste/articleshow/84883086.cms

46. https://www.oecd.org/finance/Blockchain-technologies-as-a-digital-enabler-for-sustainable-infrastructure-key-findings.pdf

47. https://www.unep.org/news-and-stories/story/battle-against-climate-crisis-dont-overlook-blockchain

48. https://blogs.worldbank.org/ppps/low-carbon-infrastructure-essential-solution-climate-change

49. Yan J, Qiuchen Lu, Junqing Tang, Long Chen, Jingke Hong, et al. (2022) Digital Tools for Revealing and Reducing Carbon Footprint in Infrastructure. Building, and City Scopes. Buildings 12(8): 1097.

50. (2019) Framing the Challenge of Urban Flooding in the United States. National Academies of Sciences, Engineering, and Medicine. Washington, DC, USA.

51. https://www.rand.org/blog/2021/06/promoting-social-equity-in-infrastructure-planning.html

52. Ali MM, Javad MS (2022) Chapter 9-Public–private-partnerships (PPP) enabled smart city funding and financing. Smart Cities Policies and Financing, Elsevier pp: 117-131.

53. https://blogs.iadb.org/sostenibilidad/en/three-ways-to-improve-the-quality-of-infrastructure-investments/

54. https://www.findamasters.com/masters-degrees/erasmus-university-rotterdam/

55. https://advanceonline.cam.ac.uk/courses/delivering-sustainable-infrastructure-theory-and-practice-for-construction

56. https://www.unccd.int/cbm/climate-proofing-infrastructure-investments-sle-training

57. https://www.ice.org.uk/news-insight/media-centre/press-releases-list/climate-change-is-overlooked-in-infrastructure-projects-civil-engineers-warn/

58. https://www.asce.org/publications-and-news/civil-engineering-source/civil-engineering-magazine/issues/magazine-issue/article/2022/01/how-to-make-infrastructure-more-resilient-against-climate-change

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