A CONCEPTUAL FRAMEWORK FOR UNDERSTANDING ADAPTATION PLANNING OF URBAN ROAD INFRASTRUCTURE

J.S. CAÑAVERA HERRERA, S. HAIGH & K. MACASKILL
Department of Engineering, University of Cambridge, United Kingdom
jsc80@cam.ac.uk, skh20@cam.ac.uk, kam71@cam.ac.uk
A. MONCASTER
School of Engineering and Innovation, The Open University, United Kingdom
alice.moncaster@open.ac.uk

ABSTRACT

In the field of adaptation of road infrastructure, several frameworks for decision-making are available, but these have focused mainly on the adaptation of national or regional road network systems. Although the protection of these systems from the possible impacts of climate change is important, protecting road infrastructure in urban contexts is equally important for the efficient functioning of society. Consequently, it is imperative to understand the particularities of adapting road infrastructure in cities, however, existing frameworks may not be appropriate for this purpose. With this in mind, this paper presents a conceptual framework called the "Expanded Adaptation Action Cycles" (EAAC). This framework conceptualizes adaptation planning as an iterative action-learning cycle. In each iteration of the planning cycle, decision-makers implement adaptation actions based on their best current knowledge while at the same time learn how to better adapt their systems in the next iteration. Adaptation can be implemented at different scales (i.e. resistance, incremental adaptation or transformational adaptation) depending on the level of risks expected and the amount of change desired in the system. Decision-makers, therefore, can decide for adaptation that increases and concentrates investment on existing pathways and practices (resistance), creates marginal changes in the system (incremental adaptation), or generates fundamental change to the functioning of the system (transformational adaptation). A case study of the decision-making processes for the development and maintenance of the road network of Bogotá, Colombia was conducted to demonstrate the utility of this framework in an urban setting. Transport planners in Bogotá are currently trying to increase their understanding of the possible impacts of climate change over its principal road infrastructure through a study called "Red Vial Vital". Additionally, the main adaptation actions expected for the city are the use of "green infrastructure" and sustainable urban drainage systems. Analysing the information using the EAAC framework indicates that the city is currently at the early stages of its adaptation planning and that the adaptation measures being considered suggest that, at most, the city is aiming for implementing incremental adaptation. Moreover, the analysis identified the presence of barriers to effective adaptation planning specific to cities such as a high degree of decentralization of urban authority. This shows how the EAAC framework provides the ability to understand the relative position of a city's approach to adaptation planning within a wider spectrum of possibilities, providing insight into the potential impact of possible planning interventions.

1. INTRODUCTION

Cities will play a leading role in the management of climate change in the 21st century [1–4]. The recent special report from the Intergovernmental Panel on Climate Change of the United Nations (IPCC) confirms that adaptation efforts will be as important as mitigation efforts since we can no longer stop climate change from happening at least to some degree all around the globe [5]. Transport infrastructure forms part of the systems on which cities rely most heavily for their efficient functioning. Therefore, the adaptation of these systems to the changing climate is crucial for the success of cities in the future. However, as Dhar and Khirfan [2] found in their systematic review of adaptation research in urban planning and design literature, adaptation of urban transport is still not well studied and there is a need for the development of useful adaptation guidelines for applying adaptive actions to transport infrastructure at the local level.

Effective adaptation planning is needed to increase the resilience of urban settlements against the impacts of climate change. Climate adaptation planning can be defined as "social and decision processes that facilitate the implementation of interventions to reduce vulnerability and/or take advantage of potential opportunities associated with climate variability and change" [6]. Moreover, adaptation planning requires the consideration of different factors other than climate change such as key non-climatic challenges, like social and economic inequality, and economic development plans [7]. This type of planning can be seen as a social learning process that should leave room for experimentation and flexibility [8–12]. However, due to the levels of uncertainty associated with climate change, adaptation planning can be a difficult task and there is always the risk of succumbing to maladaptation pathways [12,13]. Nevertheless, uncertainty should never be used as a reason for not acting.

Aiming to tackle the operationalisation of climate change adaptation planning, road authorities around the world have developed different frameworks that serve as decision-making guidelines for the selection of adaptive actions for the transport networks they manage. Most examples that can be found of these frameworks have been developed for national highways, such as the ones developed by the World Road Association [14], the Federal Highways Association (USA) [15], the UK Highways Agency [16], National Academy of Sciences (USA) [17], the Ministry of Transport of Colombia [18], the Federal Highway Research Institute (Germany) [19] and Rattanachot et al [20]. Fewer easily-accessible examples can be found for urban transport networks, such as those developed by Eichhorst [8] and the Ministry of Transport of Colombia [21]. This suggests that there is a lower level of development of guidelines for planning and implementing adaptive actions to transport infrastructure at the urban level.

This paper presents a conceptual framework for understanding adaptation planning of urban road infrastructure, the "Expanded Adaptation Action Cycles", and demonstrates its utility by applying it to a case study of Bogotá, Colombia. Urban road infrastructure is understood in this paper as a complex sociotechnical system in which interactions exist between social infrastructure, technical infrastructure and the environment [22]. As Amoaning-Yankson and Amekudzi-Kennedy [23] suggest, there is evidence that shows that following a sociotechnical focus on transportation planning brings large added benefits to the resilience of transportation infrastructure systems and the societies they serve. This paper will first describe the conceptual framework and its assumptions, then follow with a description of the methodology used for evidence collection and a description of the case study and will conclude by presenting the findings of the application of the conceptual framework and their analysis.

2. CONCEPTUAL FRAMEWORK

Adaptation to climate change can be described as the simultaneous management of climate risks and change in sociotechnical systems. Changes due to adaptation can occur at any scale and at different levels of transformation depending on the level of climate risk faced.

These changes can occur in sociotechnical systems in individuals, technology, institutions, livelihoods, the environment, people's behaviour, and society's discourse [24].

Depending on the depth of change pursued, adaptation to climate change can be implemented at different scales. As Wise et al. state, each scale of adaptation "implies different intentions, outcomes and planning horizons and therefore requires different capabilities, tools, and processes for its design and implementation" [12]. Different classifications of the scales of adaptation have been proposed, but most of them coincide in identifying two main scales of adaptation: incremental adaptation and transformative (transformational) adaptation [11,12,24–29].

This research adopts Pelling et al.'s [24] typology of adaptation scales as a basis for the conceptual framework presented in this paper. This typology is adopted as it is more comprehensive than other frameworks through the inclusion of an additional scale of adaptation called "resistance" below the scales of incremental and transformation adaptation. The three scales of adaptation are shown in Table 1. The definitions of each scale, their advantages and disadvantages are borrowed from Pelling et al [24]. The last column of Table 1 presents various theoretical examples of adaptation actions in the context of road infrastructure for each scale which is a new contribution to the framework, which has not been previously applied to transportation. The examples were selected to fit into each category according to the definition of each scale. It is important to note that the list of examples is not exhaustive, but an attempt to comprehensively cover a range of actions.

2.1. The Expanded Adaptation Action Cycles (EAAC) framework

This paper proposes a modified version of a conceptual framework developed by Park et al. called "Adaptation Action Cycles" (AAC) [11]. This modified version has been named the "Expanded Adaptation Action Cycles" (EAAC) framework to acknowledge the foundation provided by Park et al.'s concept. This new framework aims to support insight into the decision-making processes and the associated resource needs (i.e. information, policy support, financial resources, technology, etc.) of adaptation planning. This is with the purpose to help decision-makers and policy-makers to obtain more informed considerations of the different adaptation pathways available to them and their implementation, so the sociotechnical systems they manage are able to cope with future and present climate risks and the required levels of change. The EAAC framework adopts many of the aspects of the AAC framework, such as focusing on the typical decision-making timeframes of enterprises and human systems (typically less than ten years).

While the AAC framework includes only the scales of incremental and transformation adaptation, the EAAC framework expands on it by including two more scales of adaptation: resistance and no adaptation. These additional scales are included to capture more comprehensively all the available adaptation pathways. Additionally, the scale of no adaptation is included since it should not be omitted that in the practice many stakeholders take the active decision of not adapting, which could be justified in some cases.

In this framework, adaptation planning is conceptualized as an iterative action-learning cycle. In each iteration, decision-makers implement adaptation actions based on the best currently available knowledge while at the same time (through evaluation and monitoring) learn how to improve the adaptation of their systems in the next iteration. Figure 1 shows a schematic representation of the EAAC framework in which the scales of resistance, incremental and transformation adaptation are depicted as three concentric action-learning cycles that operate as mutually exclusive and distinct processes. At the centre of Figure 1 is the option of ‘no adaptation’, depicted as a point, as it constitutes a decision and not a process. The three concentric cycles shown in Figure 1 represent the differences in the scale of resources needed in each adaptation process (i.e. human, political, financial, environmental, etc.), and the level of change pursued on each scale in the sociotechnical system. The scale of resources needed and the level of change increase moving outwards from the central point.

Table 1 - Pelling et al.'s [24] *scales of adaptation typology and examples of adaptation actions in the context of road infrastructure for each scale.*

Scale of adaptation	Definition	Advantages	Disadvantages	Examples
Resistance	• Increased and concentrated investment in existing development pathways, infrastructure, institutions and practices	• Allows for 'business-as-usual': established stakeholders and institutional regimes are already in place and are supported by capital throughput. Investments are externally visible examples of risk management that produce political advantage.	• This 'all-or-nothing' strategy can narrow down worldview and technical capacity restricting management options and reducing flexibility over time so generating hidden vulnerability within system structures.	• Standard road maintenance practices to cope with weather events (i.e. regular cleaning of drainage structures, dealing with cracks and potholes). • Securing more budget for maintenance operations. • Use of standard insurance options for all assets at risk.
Incremental adaptation	• Marginal changes in infrastructure, institutions and practices that foster flexibility and fulfil capacity while not directly threatening systems' integrity.	• Enables re-organisation without causing major systemic disruption. Diversity in development vision and pathways, human resources and supporting systems can be built gradually over time rendering transactions cost more politically palatable. • Allows for system flexibility, diversity, supports redundancy and incrementally can open scope for experiments in decision-making enhancing broader governance objectives.	• Committed to functional persistence, it does not allow for challenges to the underlying values and assumptions that give rise to systemic vulnerability.	• Novel materials and novel construction and maintenance techniques. • Use of SUDS and 'green' infrastructure in combination with urban roads. • Review of land use planning legislation and of road construction standards. • Development of new climate change policies and strategies in the road sector. • New financing or insurance options to prepare for future climate disturbances. • Better climate data management and future-focused planning in the road sector.
Transformation adaptation	• Fundamental change to the functioning of systems.	• Opens new areas of policy response by going beyond existing systemic forms. Allows deep-rooted causes of risk and vulnerability to be addressed as part of a reorientation of development pathway towards social justice and sustainable development.	• Can cause significant and unexpected secondary costs as systems reach a new equilibrium. • It risks undermining the stability of economies, ecosystems or societies. • The poorest may be the most exposed to the transactions costs of transformation in the short term.	• The reorganisation of the road sector's institutional arrangements in a city. • A significant change in the use of roads in a city (i.e. the transformation of vehicle roads to pedestrian roads with "green" infrastructure). • The shift in prioritisation methods beyond economic appraisal to more sustainable decision-making methods.

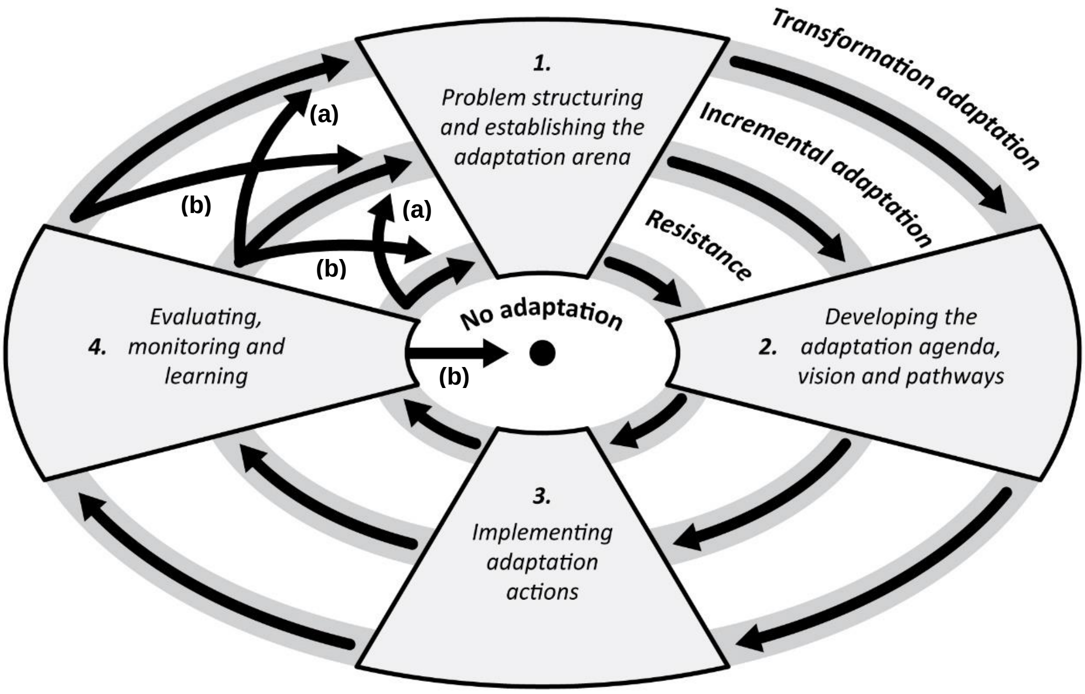

Figure 1 - Schematic representation of the Expanded Adaptation Action Cycles, depicting three concentric, but linked, action learning cycles, instead of two, operating at different scales, and at the centre the option of "no adaptation", depicted as a point as it constitutes the result of a decision process. Each action learning cycle cycles through the same four activity clusters. The transition between scales can be an outcome of the knowledge or skills gained through accomplishing the evaluative, monitoring and learning activities. The process can work in either direction, transitioning to a higher ('a' arrows) or lower ('b' arrows) scale of adaptation. Additionally, barriers can hinder the effective implementation of actions in each activity cluster or block the transitions shown.

The scale of adaptation required would depend on the level of risks faced. For example, the decision to not adapt is only rational when the current and anticipated risks are moderate or low [7], while at the other extreme, transformation is required when the risks are so high that they can overwhelm the sociotechnical systems [26]. The authors hypothesize that there is a 'gravitational pull' towards the centre of Figure 1, as there is always a tendency to reduce to lower scales of adaptation after effectively completing the processes on higher scales. For instance, after effectively adapting (i.e. the adaptive capacity of the system is increased), changes needed to maintain the function of a sociotechnical system would be less and societies would perceive less need to invest resources in adaptation. As a consequence, adaptation efforts in sociotechnical systems would remain usually between the resistance and incremental adaptation scales. Additionally, this framework supports the idea that different scales of adaptation may be needed simultaneously at different spatial scales and sites in a sociotechnical system for the effective management of climate change.

As shown in Figure 1, each of the resistance, incremental adaptation and transformation adaptation processes cycle through the same four activity clusters: 1) 'Problem structuring and establishing of the arena', 2) 'Developing the adaptation agenda, vision and pathway', 3) 'Implementing adaptation actions', and 4) 'Evaluating, monitoring and learning'. The transition between scales can be an outcome of the knowledge or skills gained through accomplishing the evaluative, monitoring and learning activities, but this transition is not a guaranteed process. The process can work in either direction, transitioning to a higher or lower scale of adaptation as shown by the (a) and (b) arrows in Figure 1. For example, after gaining more accurate knowledge about the possible climate change impacts over a sociotechnical system, risks could be found to be higher or lower than expected, meaning that different actions could be needed in each scenario, leading to the implementation of a higher or lower scale of adaptation. Furthermore, problems can arise such as negative outcomes from the adaptation process, or different barriers that can hinder the effective implementation of actions in each activity cluster or block the transitions between clusters or scales of adaptation. Therefore, continuous evaluation and monitoring are necessary to identify and overcome these problems to be able to achieve effective adaptation.

This framework can be used to perform a systematic assessment of the decision-making processes in adaptation planning and the information needs and policy support required by these processes by using a series of key questions proposed by Park et al. [11]. These questions offer decision-makers the possibility to develop more informed considerations of adaptation options and their implementation. Table 2 presents these questions and the stage of the adaptation cycle in which they should be used for this systematic assessment. These analytical questions are used later in this paper to guide the analysis of the findings.

Table 2 - Stage of the adaptation cycle and questions used to operationalise it [11].

Stage of the planning cycle	Questions used for the assessment
1. Problem structuring and establishing of the arena	• What is the nature of vulnerability and the perceived risk? • Who or what adapts? • What do they adapt and why?
2. Developing the adaptation agenda, vision and pathway	• How do they adapt (processes)? • What are the opportunities for adaptation? • Costs and/or benefits of decisions?
3. Implementing adaptation options	• What implementation methods and resources are used? • What constraints or incentivizes implementation? • What impacts the results?
4. Evaluating, monitoring and learning	• How well do they adapt? • How does the system change? • What are the plans for the future?

3. EVIDENCE COLLECTION

This research collected evidence through semi-structured interviews, complemented by an analysis of relevant local policy documents and technical reports. The interviews and document analysis were conducted as part of an in-depth case study of the decision-making processes for the development and maintenance of road infrastructure in Bogotá, Colombia and the level of consideration of climate change adaptation in these processes.

Semi-structured interviews were conducted with forty-eight local professionals in transport planning, urban planning, climate change, risk management and politics. Participants were selected following non-random sampling methods. Potential participants were selected based on the relevance of their job positions in the most prominent public and private organisations of the transport, environmental, urban planning and disaster risk management sectors of the city. The interviews were conducted in Bogotá, Colombia during two fieldwork campaigns, one between December 2016 and January 2017 and the other between December 2017 and January 2018. The interviews were typically between 30 and 70 minutes.

Relevant publicly available local policy documents about transport planning, urban planning, climate change action and risk management were used for the analysis. Additional documents provided by some interviewees (i.e., not publicly available technical reports) were also analysed.

Table 3 – Most relevant codes used in the analysis of the interviews' transcripts and case study documents.

Code	Definition
1. Adaptation	All mentions to the definition and understanding of adaptation as a concept by the interviewees, and the theories they mention about adaptation.
1.a. Confusion with other concepts	All instances in which adaptation is confused or associated incorrectly with other concepts such as mitigation or standard environmental management.
1.b. Adaptation vs. development	Evidence of the perception of conflict between adaptation and development needs by the interviewees.
1.c. Ecosystems-based adaptation	All references to ecosystems-based adaptation.
1.d. Adaptation by stealth	All instances in which adaptation is conceptually being hidden behind other concepts in the practice.
2. Adaptation planning	All mentions to adaptation planning in Bogotá.
2.a. Adaptation actions	All references to the different adaptation actions found or planned in the city of Bogotá according to the typology by Biagini et al [30].
2.b. Adaptation institutional arrangements	All mentions to the different adaptation planning institutional arrangements in Bogotá made by the interviewees or found in the analysed documents.
3. Climate change	All mentions to climate change.
3.a. Climate change effects	All references to climate change effects in Bogotá and impacts on the transport infrastructure of the city made by the interviewees or found in the analysed documents.
3.b. Climate change perceptions	Evidence of the perceptions and thoughts that the interviewees have regarding climate change and its effects.
4. Planning cycle	All the references to the adaptation planning cycle and its different phases according to the EAAC framework in Bogotá.
4.a. Problem structuring	This code collects all the references to the "Problem structuring and establishing of the arena" phase of the planning cycle according to the EAAC framework.
4.b. Agenda formulation	This code collects all the references to the "Developing the adaptation agenda, vision and pathway" phase of the planning cycle according to the EAAC framework.
4.c. Implementation	This code collects all the references to the "Implementing adaptation options" phase of the planning cycle according to the EAAC framework.
4.d. Evaluation and monitoring	This code collects all the references to the "Evaluating, monitoring and learning" phase of the planning cycle according to the EAAC framework.
5. Transport planning	All mentions to the processes, documents and philosophies of Bogotá's transport planning.
5.a. Transport planning documents	All references to transport planning documents of Bogotá.
5.b. Construction	All mentions to the construction of new transport infrastructure in Bogotá.
5.c. Maintenance	All mentions to the maintenance of transport infrastructure in Bogotá.
5.d. Planning principles and prioritization	The planning principles and prioritisation methods used in the transportation planning processes of Bogotá.
5.e. Transport institutional arrangements	All references to the different institutional arrangements that guide transport planning in Bogotá.

Both the interviews' transcripts and the case study documents were coded using codes related to the concepts of adaptation, adaptation planning, climate change or transport planning. Additional codes were produced in relation to different stakeholders in the city and flagship infrastructure projects. Some codes were created before the coding process based on the conceptual framework of this research (i.e. the planning cycle codes) and others were created during the coding process based on trends found in the interviews and documents (i.e. “confusion with other concepts”). The most relevant codes for this paper and their descriptions are shown in Table 3. All coded statements were used as evidence for answering the analytical questions of the EAAC framework as presented below in the analysis of the findings. For example, statements coded under the codes “climate change effects” and “climate change perceptions” provided evidence to answer the question “what is the nature of vulnerability and the perceived risk?”; codes like “adaptation institutional arrangements” or “transport institutional arrangements” provided evidence to understand “who or what adapts?” in the city; and statements coded under codes like “ecosystem-based adaptation” and “adaptation actions” provided evidence on how Bogotá’s transport sector is planning to answer the question “how do they adapt?”. Later, in the Analysis section of this paper, it is described in more detail how the evidence collected in Bogotá provides answers to these and other analytical questions of the EAAC framework.

4. CASE STUDY

Bogotá is the capital of Colombia in South America and is the biggest city in the country with a population of around 8 million people recorded in 2016 [31]. The city is located in the centre of the country on a high plateau in the Andes at an average altitude of 2650 metres above the sea level. The city has an average temperature of 14.3°C all year round and the weather alternates during the year between short periods of intensive rains and dry seasons [31,32].

4.1. Bogotá’s administration

Bogotá has the status of capital district. The district government of the city is led by the city’s mayor and is divided into 15 different sectors. Each sector is directed by one of the district secretaries and is composed of two types of organisations, those in charge of the development of sectoral policies and those in charge of their implementation [33]. Additionally, the city is divided administratively into 20 localities, each one led by a local mayor.

The transport sector of the city is composed of the District Mobility Secretary and other organisations like the Institute for Urban Development (IDU) and the Special Attention Rehabilitation and Road Maintenance Unit (UMV). The District Mobility Secretary oversees the development of the sector’s policies and the maintenance of adequate transit conditions in the city, while the responsibility for the development and maintenance of the transport infrastructure of the city is divided among the other organisations of the sector.

The environmental sector of the city is composed by the District Institute for Risk Management and Climate Change (IDIGER), the Botanical Garden, the District Institute for Animal Protection (IDPYBA) and the District Environment Secretary, the head of the sector.

4.2. Bogotá’s response to climate change

According to the most recent official vulnerability assessment, the effects of climate change will put mainly Bogotá’s food supply, water supply and infrastructure at risk [34]. Because of this, and following the national government’s example and requirements, Bogotá has developed its own climate change policies. Most of these policies have been developed since 2012, after the catastrophic occurrence of La Niña Phenomenon in Colombia in 2010-2011 in which more than 32300 families in Bogotá were affected by flooding produced by the increase in rainfall product of the phenomenon [32]. This demonstrated the need for more climate resilience in the city.

Between 2013 and 2014, IDIGER was created under the administration of Mayor Gustavo Petro to lead the new District Risk Management and Climate Change System and its policies [35,36]. One of the first tasks of IDIGER was to develop the District Management and Climate Change Plan for Bogotá D.C. 2015-2050, which is still in force [32]. However, according to previous reviews by Lombo [37] and Arroyo Narváez [38], the implementation of this plan has been limited. Additionally, some interviewees suggested that the plan's goals are currently being reviewed, thereby delaying its implementation. A further responsibility of IDIGER is to serve as a technical advisor in climate change and risk management to the other agencies of the district government and help them develop their own strategies to tackle climate change.

Several interviewees suggested that IDIGER has provided advice to the District Mobility Secretary in this regard, but the city is still lacking an adaptation strategy for its road network. Nevertheless, the District Mobility Secretary has made some initial steps to understand how to increase the resilience of Bogotá's road network through the establishment of a Vital Road Network (RVV) for disaster risk management in the city. In principle, the infrastructure of the RVV should be able to resist different scenario disasters so adequate mobility in the city can be guaranteed during emergencies. The disaster scenarios that include considerations of climate change are flooding, forest fires and landslides risk scenarios. As a result, some of the interviewees suggest that the RVV will be used in the future as the baseline for the development of the adaptation strategy of the sector.

5. ANALYSIS

The evidence collected suggests that the adaptation planning of Bogotá's road infrastructure lies currently somewhere between the first and second phases of the planning cycle of the EAAC framework. This is evident in the fact that Bogotá has not yet developed an adaptation strategy for its network neither has implemented any clear actions that increase the adaptive capacity of its road network. To provide a more detailed view of how the evidence suggests this, this section is divided following only the first analytical questions of the EAAC framework (Table 2) that the city has approached. This is to show how and to what extent Bogotá's transport sector is answering to each of them. The section then finishes with a description of possible future steps in the adaptation planning process of the sector that may provide answers to the rest of the analytical questions of the framework.

5.1. What is the nature of vulnerability and the perceived risk?

The national and local environmental agencies have made different efforts in recent years to understand the nature of Bogotá's vulnerability to climate change following the technical guidelines of the IPCC. As described before, the most recent effort was done by Colombia's Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) in 2017 [34]. In their assessment of vulnerability to climate change, Bogotá is presented as one of the cities with a higher risk to the effects of climate change in the country. The assessment is multidimensional and presents infrastructure as the third biggest contributor to the city's vulnerability and as an element with low adaptive capacity in the city [34]. However, the infrastructure dimension is presented in this analysis as an aggregated picture of roads, airports and electrical infrastructure. Because of this, the results of IDEAM's assessment can be used only for creating a general understanding of the vulnerability of the city as the particular vulnerability of the city's road infrastructure is not presented.

Due to this gap in knowledge, many interviewees expressed that there is an urgent need to understand better the nature of the specific vulnerability of the city's road network, as this understanding will serve as a necessary baseline for adaptation decision-making in the road sector. Understanding this need, the District Mobility Secretary commissioned in 2017 a technical study to establish what is the RVV of the city. An official from the District Mobility Secretary explains the perceived challenges and importance of the task:

"There is a huge effort there that [the consultants] will need to do and it is that they will need to determine how that Vital Road Network will help to reduce the risk associated with climate change in the city. Both in the mobility system and in the city if possible. Then, I believe that it will be an important input to create a baseline of risk in the city so other things can be done in the future".

The RVV focuses on disaster risk management and emergencies management [39]. By following this focus, the baseline created from the RVV will be limited as it will only provide information to the city on how to deal with one of the two types of risks associated with climate change, those related with extreme weather events. The city will still lack an understanding of the nature of the vulnerability of its road network against risks due to long-term changes in average climatic conditions until a similar study as the RVV is commissioned for this matter.

As the evidence shows, Bogotá has made some initial steps to understand the nature of the vulnerability of its road network, but still needs to fill in some gaps in the comprehension of how the two types of climate change risks will affect the city. Additional to that, the evidence from the interviews suggests that many city officials lack technical capacity regarding climate change and risk management, even officials dedicated to adaptation efforts. For example, an official dedicated to the development of the adaptation strategy of the District Mobility Secretary observes that the concept of adaptation is still *"a bit abstract and ethereal"* for his team and that there is a need to understand better this concept and its practical implications inside different organisations of the transport sector. Therefore, there is also a need to increase the technical capacity of the city professionals in these topics. In summary, until Bogotá's transport sector does not answer more satisfactorily the analytical question presented in this section, it will be difficult for the city to advance effectively to further phases in the adaptation planning cycle.

5.2. Who or what adapts? And, what do they adapt and why?

Complying to the national risk management law (Law 1523 of 2012 [40]), Bogotá's administration created the District Risk Management and Climate Change System in 2014. This system collects all the institutional arrangements for the management of disasters, climate change, emergencies and other risks in the city. IDIGER was created to lead the district system and the policies associated with risk management and climate change. However, this institute has limited execution power as the coordinator of the District Risk Management and Climate Change System in IDIGER explains:

"IDIGER, as it is an institute, it is an organization that should generate more knowledge, guidelines, policies. […] We are not, and we should not be, executors of those projects".

The same interviewee explains then who should be adapting the road network of the city:

"But for that exists a transport sector and there is an Institute for Urban Development and the UMV. So, what do we do with them? We coordinate all actions. So, we are in that right now".

In other words, according to the law and institutional arrangements, the transport sector must oversee the adaptation of its road network. As head of the sector, the District Mobility Secretary is in charge of coordinating with IDIGER the development of the adaptation strategy of the transport sector. Adaptation actions should be divided amongst the different organisations in charge of road infrastructure in the city such as IDU and UMV, but this is still not clear as there is no currently available adaptation strategy. The RVV project tries to assign responsibilities to different organisations over disaster risk management and adaptation, but this will not be legally binding until the city creates a decree to adopt the RVV [39]. Additionally, this level of decentralization of responsibilities will prove to be challenging as problems with the coordination of activities could become a barrier to the adaptation process. Therefore, continuous effective leadership from the District Mobility Secretary and IDIGER will be required.

The RVV project has been also used by the District Mobility Secretary as a first attempt to answer the question “what do they adapt and why?”. The main objective of this project was to determine which is the most important, or vital, road network in the city in which efforts from the whole transport sector should be focused to guarantee resilience of the city against disasters. This network has been established by the consultancy of the project by selecting the assets that simultaneously guarantee the best mobility in the city under different disaster scenarios modelled by IDIGER that include flooding, landslides, forest fires and earthquakes [39].

As the evidence shows, Bogotá’s transport sector presents more advancements in the establishment of responsibilities and in the appreciation of which infrastructure assets require more focus than in understanding the underlying vulnerability of the city’s road network. This can be attributed to the fact that the city has well-established adaptation institutional arrangements at the district level and because the RVV project is helping the District Mobility Secretary to determine what is needed to be adapted in its network. However, without having a comprehensive understanding of the nature of the vulnerability and a baseline, it will remain difficult to answer satisfactorily “why” focus should be given to some roads and not others.

5.3. How do they adapt?

The District Management and Climate Change Plan for Bogotá D.C. 2015-2050 in its conceptual framework establishes that adaptation can be planned and implemented following different approaches that include ecosystem-based adaptation, community-based adaptation and infrastructure-based adaptation. The District Environment Secretary has decided that the city should follow exclusively an ecosystem-based approach to adaptation. This has resulted in a proposed urban planning in the city’s policies focused on eco-urbanism and eco-efficiency in which only “green” infrastructure and sustainable urban drainage systems (SUDS) are presented as possible adaptation measures [31,32,41,42]. Following this approach, the RVV consultancy proposes this kind of measures as the main ones to implement in the RVV project [39].

However, this framing is problematic as it effectively generates tunnel vision of the concept of adaptation for professionals in the city. By conceptually limiting adaptation measures to the betterment of drainage systems, green infrastructure and the protection of crucial ecological systems that provide ecological services to the city, an exclusive ecosystem-based approach creates the illusion that other elements of the city, for example, other structural elements of the road, do not need to be adapted. This critique is shared by some officials of IDIGER as one explains:

“[Ecosystem-based adaptation] is a vision from the District Environment Secretary, but us in IDIGER, as we are the coordinators of the system, we have discussed enough the necessity of [adaptation] not only being ecosystem-based adaptation, yes? But that we rather should incorporate a vision that is a bit more holistic”.

Therefore, Bogotá’s transport sector should reassess the appropriateness of an ecosystem-based approach for future planning. Transport planners could have a look at the other approaches available in the district policies such as infrastructure-based adaptation which could be a better fit for the necessities of the sector and not limit artificially the possible adaptation measures to a handful of them. An infrastructure-based approach is focused in improving the adaptive capacity of infrastructure assets that play a determinant role in economic development, such as transport infrastructure, and considers other adaptation measures such as changes in design processes that include projections of the possible future climate, changes in maintenance operations, changes in road construction standards or changes in other elements of the physical infrastructure like pavements. The different approaches to adaptation are in principle not excluding, so it could be possible to complement the infrastructure-based approach with some of the actions promoted by the ecosystem-based adaptation for better results in the adaptation process.

Additionally, the selection of “green” infrastructure and SUDS is indicative of the scale of adaptation that the city and the transport sector are currently aiming to implement. This kind of measures represent marginal changes to current infrastructure as they are presented in the District Management and Climate Change Plan for Bogotá D.C. 2015-2050 and the RVV project [32,39]. Because of this, they indicate that the city is aiming for a scale of incremental adaptation at the most according to Table 1.

5.4. Future steps

The main future steps for the city are the development of an adaptation strategy for its transport sector and the implementation of the first adaptation measures to increase the resilience of the road system of the city as the evidence shows that both steps have not been yet performed. This would move the adaptation planning of the road sector to the third phase of the planning cycle of the EAAC framework. Bogotá’s transport sector is already thinking about how to advance in the adaptation planning process. For example, some initial answers to the rest of the analytical questions of the EAAC framework have been generated through the commissioning of the RVV project. The report developed by the consultancy presents, for instance, some calculations of the estimated costs of implementing the RVV project in Bogotá, the possible financial sources, a proposal of indicators for evaluating and monitoring the performance of the RVV and the organisations in charge of its elements, and a draft of the decree the city should approve so the RVV can be implemented. If implemented, the RVV has the potential to be an important initial benchmark for adaptation planning in the transport sector of Bogotá, but it must be considered that its scope is limited to only dealing with risks associated with extreme weather events.

In order to develop further its adaptation strategy, Bogotá’s transport sector can use the lessons and products from the RVV as a baseline, as some interviewees indicated, and complement this initial knowledge with similar studies that are aimed to understand how to incorporate other elements of adaptation planning such as dealing with risks associated with the long-term change in average climatic conditions. The District Mobility Secretary and agencies from other cities could use the EAAC framework and the answers to the analytical questions presented in Table 2 as guidelines to develop further their adaptation planning processes and strategies. As shown by the findings presented in Section 5, the framework gives transport planners an opportunity to understand where they are at the present and where they should be moving next in the planning process. Additionally, trying to answer the analytical questions that complement the EAAC framework gives transport planners the chance to understand what their resource needs are (i.e. information, policy support, financial resources, technology, etc.) to achieve effective adaptation planning of their road networks.

6. CONCLUSIONS

This paper has presented a framework called the Expanded Adaptation Action Cycles (EAAC) that further develops the AAC concept presented by Park et al. and aims to support insight into the decision-making processes and the associated resource needs (i.e. information, policy support, financial resources, technology, etc.) of adaptation planning. The paper has demonstrated its utility for urban transport planners, seeking to solve the current need for guidelines to start or continue the adaptation of road infrastructure systems to climate change in their cities.

The EAAC framework is useful as it helps to structure adaptation planning, which is becoming increasingly important, yet organisations find it challenging to meaningfully engage in action. The framework can, first, provide the ability to understand the relative position of a city's approach to adaptation planning within a wider spectrum of possibilities, and second, it can provide insight into future possible planning interventions, their possible impact and the necessary steps to follow in the planning process. The usefulness of the framework has been demonstrated with the analysis of a case study of the transport sector of Bogotá, Colombia. First, the analysis shows that Bogotá's transport sector is currently in between the "Problem structuring and establishing of the arena" and the "Developing the adaptation agenda, vision and pathway" phases of the EAAC framework. By looking at how Bogotá's transport sector has been responding to the first analytical questions of the framework, it is clear that the city has a need to understand better the vulnerability of its road network. But the city has made some progress in giving some initial answers to the questions of who and what needs to adapt and how to adapt mainly through the establishment of the city's Vital Road Network. Additionally, the analysis also provides some insight into possible barriers to the adaptation process, such as the lack in technical capacity from some of the staff of the city regarding adaptation or the selection of ecosystem-based adaptation as the only approach followed by the city. A deeper analysis of these barriers can be performed following other analytical frameworks as the one presented by Lehmann et al. [3]. Second, it is clear that the next steps for Bogotá's transport sector are to develop its adaptation strategy and implement the first adaptation measures. The city has already proposed "green" infrastructure and SUDS as the main adaptation measures to implement in the future suggesting that the city is aiming for a scale of incremental adaptation at the most. In order to continue the planning process into the next steps, Bogotá's transport sector should try to answer the rest of the analytical questions of the EAAC framework and use those answers as a guide for the future. By answering the questions, transport planners will be able to understand the different possible future interventions at hand and the resources needed to implement them.

Finally, the analysis presented in this paper could be used as an example by other urban transport agencies that may want to perform similar analyses with the EAAC framework of their own adaptation planning processes. Its capacity to analyse both the current state of adaptation planning and to provide insight into future steps make it a valuable resource not only for urban transport planners but possibly for decision-makers in other sectors facing the challenge of climate change.

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