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ORIGINAL RESEARCH

Toward Integrated Urban Climate Risk Management: Reflections on a Transdisciplinary Knowledge Approach for the Dutch Delta

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ABSTRACT: Background: Real estate, infrastructure, and related urban systems are increasingly exposed to the physical impacts of climate change, threatening both their durability and societal stability. Today the understanding of urban climate risks and their management is emerging but incomplete, highlighting the need for collaborative, integrated, and transparent approaches. However, existing collaborative approaches do not often lead to practical and actionable solutions, exposing a gap in expertise on how to co-create truly integrative approaches in a landscape of fragmented knowledge. **Method:** This article introduces an integrated approach to transdisciplinary knowledge production on urban climate risk management, using the case of the Red&Blue programme (Real Estate Development and Building in Low Urban Environments). This research-intensive knowledge programme in the low-lying Dutch urban delta was co-created by diverse disciplinary researchers and cross-sectoral practitioners, including financial institutions. Here, the authors reflect on three key "how" questions concerning programme co-creation with stakeholders, the organization of the collaboration process, and capacity development for reflection on insights in transdisciplinary cooperation. **Results:** Preliminary findings over the last two-and-a-half years of the programme highlight key challenges in transdisciplinary cooperation. To address them, the authors stress the need for

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creating safe and open spaces for stakeholder dialogue, where diverse cooperation strategies help build shared vocabularies, enabling stakeholders to jointly define, identify, and analyze multidimensional climate risk issues and potential adaptation solutions. **Conclusion:** The integrated approach presented in this article offers a preliminary model and means to build integrated knowledge on climate risk management and related sustainability transitions in the built environment.

KEYWORDS: climate adaptation; climate risk management; finance; infrastructure; real estate; transdisciplinarity

SUMMARY FOR POLICYMAKERS

- This article introduces an adaptive and integrated approach to transdisciplinary knowledge production on urban climate risk management through the case of Red&Blue, a 5-year knowledge programme with 29 public and private institutional partners focused on the case of the urbanized Dutch delta. The programme is particularly novel in that it brings the financial sector more squarely into highly collaborative discussions about urban climate risk management.
- Highly institutionalized individual and sectoral strategies for addressing urban climate risks hinder transformative approaches, while collaborative and integrated approaches involving public, private, and civic sectors could lead to more effective and equitable outcomes. The study pinpoints seven key focal points of cooperation relevant to the Dutch case, which may inspire practice elsewhere. The approach introduced in this article offers one potential means to produce integrated knowledge on climate risk management solutions.
- Conscious knowledge integration between stakeholders is vital to secure ambitions for integrated urban climate risk management. This study reflects on if and how this can be accomplished through adaptive co-creation and stakeholder engagement processes and what has been learned from doing so over the initial 2.5 years of the Red&Blue programme.
- Generating knowledge for integrated urban climate risk management poses several challenges. These include translating disciplinary languages into a common language, mediating mismatched stakeholder interests and trust issues, and counterbalancing unequal institutional engagement capacities. This article reflects on how adaptive and co-creative approaches to knowledge creation can help address these challenges.

Introduction

Real estate, infrastructure, and other critical urban systems are increasingly exposed to the physical impacts of climate change, ranging from rising seas and

chronic drought to a variety of extreme weather events. Climate risks raise multiple social, economic, and political concerns about the resilience of the built environment and society. In many of the world's delta regions, these risks are amplified due to a combination of flood risks and high densities of urban activity. This is particularly the case in the Netherlands, where more than half of the population and economic activity are concentrated in the low-lying, flood-sensitive delta area, much of it below sea level. The Dutch government projects climate-induced damages to Dutch infrastructure and real estate assets ranging between €33 and €124 billion by 2050 (Delta Commissioner, 2020; Pot et al., 2022). Both existing and planned urban developments in cities like Amsterdam and Rotterdam are significantly exposed to flood risk and other climate change–related risks.

A key challenge here relates to not only the uncertainty of physical risk levels themselves but also ambiguities about how, and by whom these risks should be managed today. For example, the Netherlands is well protected against flooding, with robust climate adaptation efforts primarily organized by national and regional public water management agencies. But this institutional system—and others related to the problem domain—must accommodate significant pressures from multiple directions, including the pace and uncertainty of climate change, tensions between public and private institutional priorities, roles and responsibilities, sustained urbanization pressures in a spatially constrained environment, and growing financial sector anxiety about the climate risk exposure of delta regions more generally. These broader delta-scale transformations also shape, and are shaped by, urban practice. One example, and one of the points of departure for Red&Blue (Real Estate Development and Building in Low Urban Environments), relates to the task of making existing and new urban areas more climate-robust. Tens of thousands of new homes are planned in vulnerable areas, while large segments of existing cities need substantial and potentially extensive retrofitting to become climate adaptative. Even with alignment on physical climate risks and technical strategies to manage them, the legal, financial, and ultimately distributional implications of these strategies will require new and considered multistakeholder approaches.

Siloed approaches to tackling these "climate governance" challenges, from applied science to professional consultancy, have been proven to fall short when climate science is uncertain, values are in dispute, the stakes are high, and decisions are urgent (Funtowicz & Ravetz, 1993). Knowledge and action tend to therefore be fragmented rather than holistic. For example, narrow technical solutions like sea walls offer immediate protection against flood risks but have been shown to fall short in addressing the broader socio-economic and environmental impacts that arise alongside the implementation of these solutions, leaving communities vulnerable to long-term displacement or ecosystem damage (Anderson, 2023; Dugan et al., 2018). Similarly, finance-centric approaches to managing climate risk—for example, through insurance—have been shown to lead to individualized outcomes, leading to socially unequal patchworks of (un)managed adaptation (Taylor & Knuth, 2025).

In addition, while integrated, transdisciplinary approaches are widely regarded as essential to effective climate governance (Daniels et al., 2020; Polk, 2015), many

current efforts offer little more than surface-level engagement, focusing on dialogue rather than action. Jellason et al. (2022) criticize the non-participatory nature of scientific knowledge in climate adaptation, which they believe limit societal adoption of insights. Scherhaufer (2021) advocates for the integration of experts' knowledge to enhance decision-making relevance and practicality. Scholars such as Williams and Hardison (2013), Pearce et al. (2015), and Hosen et al. (2020), among many others, also emphasize the need to incorporate diverse knowledge in the climate adaptation process.

We set out to create an integrated, multidimensional, multistakeholder knowledge programme to connect insights from climate science and technical design to social sciences, and from research to practice. Such an approach calls for collaborative and transdisciplinary research settings, as widely acknowledged in scholarship on climate action (e.g., Daniels et al., 2020; Knapp et al., 2019; Pham & Saner, 2021; Scherhaufer, 2021; Wardani et al., 2023). These settings and the activities that take place within them can illuminate multidimensional, societally relevant insights (Polk, 2015; Ramakrishna et al., 2023), ultimately helping foster societal impact. But what do these knowledge settings look like in the context of urban climate risk management? Today there is a limited understanding of what an effective approach might entail (Döll & Romero-Lankao, 2017), especially in light of the highly institutionalized and internationalized nature of contemporary real estate finance systems (Knuth et al., 2025; Taylor & Aalbers, 2022). Here, a key challenge lies in connecting diverse—and potentially divergent—financial stakeholder interests with place-based, values-driven deliberations about climate adaptation.

Addressing this key challenge requires a deliberate process of knowledge integration—where different and previously unrelated perspectives interact with each other and are assembled into something new (Pohl et al., 2021). When this process accounts for the views of societal stakeholders, scientists, policymakers and practitioners, scholars like Hadorn et al. (2008) refer to it as transdisciplinary integration. However, integration does not automatically take place when creating space for these different actors to interact. Hoffmann et al. (2022) highlight the critical need for leadership in transdisciplinary research, addressing a gap in traditional and mono-disciplinary academic researcher profiles to adequately provide integration expertise. This highlights the need for structured approaches that actively build individual and collective capacity to integrate expertise and foster transdisciplinary cooperation—gaps that the Red&Blue programme seeks to address.

In this article, we introduce an integrated approach to promote transdisciplinary knowledge for collective real estate and infrastructure climate risk management. We present and reflect on the first 2.5 years of the case study of Red&Blue. This 5-year transdisciplinary research and impact programme aims to develop, test, and promote integrated, multiscalar climate risk management strategies for existing and new real estate and infrastructure developments in the urbanized delta region of the Netherlands.[1] The Red&Blue programme is a structured approach to impact research, one that invests in substantial scientific insights on

various dimensions of climate risk management while also building a robust stakeholder network and integrative leadership capacity shared between science and practice. This approach aims to move beyond lip service to integration by creating tangible pathways for stakeholders to address the technical, social, legal, and financial dimensions of urban climate risk management simultaneously (Crowley et al., 2020).

Our aim with this article is to reflect on how to move from problem identification to knowledge for intervention in the domain of urban climate risk management. As such, we focus primarily on "how" questions that have emerged in our work:

> How do we co-create the knowledge and conditions that enable stakeholders to address multi-dimensional urban climate risk management challenges in an effective and equitable manner?

We break this "how" question into three parts, with attendant sub-questions:

1. How do we identify the essential knowledge elements of an integrated strategy for urban climate risk management? Given the diversity of stakeholders involved in this complex and emergent puzzle, who needs to be involved in this process, and what kinds of insights can realistically be drawn based on such a co-creation process?
2. How do we define impact aims and organize our collaboration process accordingly? Who needs to be involved when and in what capacities? What types of stakeholder interactions offer effective and flexible modes of engagement?
3. How do we develop the capacity to reflect on, draw out, and act on deeper insights into transdisciplinary knowledge production? What do we learn about adaptive knowledge programme management, and what insights might apply to other contexts?

The remainder of the article and our contributions are structured as follows: We first elaborate on how Red&Blue programme stakeholders co-identified seven key focal points (FPs), or strategic entry points, into the complex societal challenge of urban climate risk management in the Dutch delta. We then reflect on how we came to practically organize knowledge production on these key FPs. Our findings speak to both process and content. On one hand, we highlight the necessity of developing a shared vocabulary among stakeholders to define, debate, and analyze multidimensional urban climate risk management issues. This shared vocabulary helps stakeholders identify core underlying issues and related assumptions and enable the discovery and prioritization of topics for further iterative analysis and reflection. On the other, the seven FPs offer useful insights into potential thematic avenues around which to structure similar integrated knowledge programmes in other urban contexts. Next, we elaborate on the main challenges in transdisciplinary cooperation that we have observed during the programme's development. The final section presents the conclusions of this study.

Co-creating an integrated approach and process

Finding focus in a complex landscape

The Netherlands has a strong tradition of institutionalized water management, yet climate change presents new challenges, particularly in urban development. Despite the country's expertise, gaps in this knowledge puzzle persist. One key example relates to the interplay between urban-scale climate risk management versus delta system–level action: How should the Dutch multilayer safety system for managing flood risk evolve in light of changing climate conditions, and what does this mean for existing strategies and institutional responsibilities? There is also growing recognition of the need to engage the financial sector in the production of delta-related knowledge, as seen in the launch of the "NLAAA Climate Proof" initiative of the National Delta Program, which expressly connects the financial sector with the Dutch delta management community. These developments suggest a need to extend existing expertise in engineering-centric delta management strategies to new stakeholders, scales, and substantive topics.

Recognizing these gaps, the Red&Blue co-creation process started in 2020 by bringing together multidisciplinary experts to explore the intersection of climate risk and finance in urban development (Janse & Janssen, 2020). The event focused on understanding climate risks at the urban neighbourhood level and reflecting on how they might be addressed by key national- and international public and private institutions. This event and subsequent dialogue sparked the development of a formal consortium-building process, as part of a proposal for research funding under the impact research agenda of the Netherlands Organization for Scientific Research (NWO).

More than 50 stakeholders participated in a series of presentations and open discussions, during which we collectively identified existing scientific and practical knowledge gaps pertaining to climate risk management in the Netherlands. These engagements were further enriched by four subsequent interactive group discussion sessions.[2] We also facilitated extensive one-on-one meetings with scientists and societal stakeholders including real estate financiers, insurers, housing providers, and policymakers.

These intense interactions and knowledge exchanges allowed us to co-define a shared aim—to develop equitable and effective integrated urban climate risk management strategies for the Dutch delta—and seven related FPs, or domains of intervention (see Figure 1). This co-creation process was developed in line with the "impact plan approach" used by the NWO to structure impact research programmes, which call on consortiums to envision long-term societal transformations and to develop knowledge programmes to create the enabling conditions for such changes. The following subsections elaborate on each of the seven FPs, which steer the knowledge programme toward a larger collective aim.

Physical climate risk assessment

Our stakeholders found it crucial to unlock innovative perspectives on state-of-the-art physical climate risk assessment and modelling approaches. Collaboration

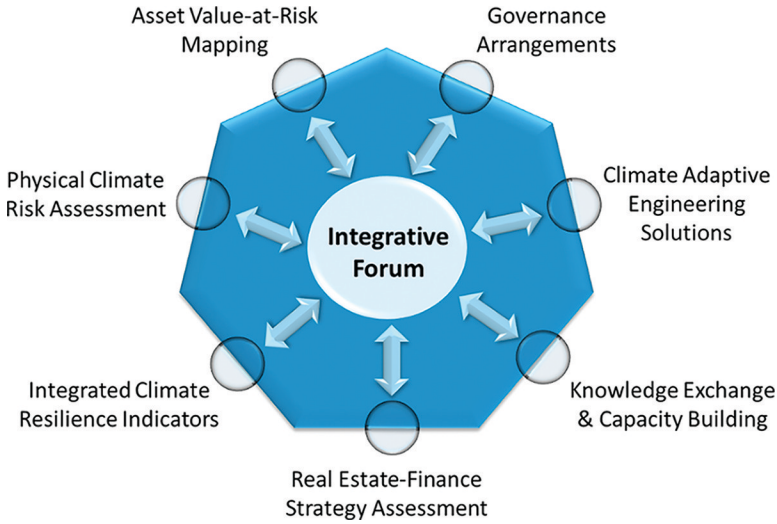

Figure 1: Seven focal points as the focus areas identified from the co-creation process adopted in this study

between climate scientists and practitioners enables a better understanding of individual, compound, and sequential physical climate risks facing the delta. However, there are gaps in the knowledge available on specific hazards (e.g., wind and hail risks), while modelling approaches used in practice often lack consistency, comparability, and transparency (e.g., Hughes et al., 2020; Keenan, 2019). These gaps make it difficult to integrate physical risk assessments with understandings of socio-spatial vulnerabilities and risk exposures at the neighbourhood and urban scales, which we reason to be a necessary precondition for public, private, and civic stakeholder action. These analyses—and their translation into "narratives" for relevant stakeholders can enhance the existing institutional capacity for real estate finance, for example, by building out in-house technical expertise. Public agencies may also utilize these insights in decision-making processes, particularly when assessing suitable climate scenarios or acquiring data to support urban investment plans.

Asset value-at-risk mapping

This FP enables us to gain a deeper understanding of the existing or potential spatial concentration of real estate asset value at risk in the deltas, and to assess the potential socio-spatial effects resulting from shifts in property values (such as a disorderly repricing of housing due to a change in climate risk perception, policy, or private market action). Price effect analysis is one core focus in this line of work, including climate risk mapping and asset valuation in vulnerable areas (e.g., Clayton et al., 2021; Gourevitch et al., 2023). Stakeholders ultimately aim to utilize national-scale and asset-level price data alongside the results of physical risk assessments to identify urban areas where real estate asset values are currently

or may be at greatest risk. The findings can inform further analysis of vulnerable urban areas to climate risks and can facilitate the assessment of potential disruptions to the real estate market, as well as the development of neighbourhood-level adaptation strategies to manage such dislocations. This analysis also invites consideration of the larger distributional effects of asset devaluation and value protection strategies (Taylor & Knuth, 2025).

Real estate finance strategy assessment

This FP hones on the climate risk management practices of real estate finance institutions and examines how they align with emerging urban- and regional-scale adaptation strategies—and with what social and spatial consequences (e.g., Knuth et al., 2025; Taylor & Aalbers, 2022). Using urban use cases within ongoing re/development projects as a point of departure, this research examines how mortgage lenders, insurers, and real estate investors define and address risk through existing or new strategies. The analysis focuses on relating these private strategies to each other and public investments to better understand opportunities and challenges in aligning financing strategies with broader questions of inclusion and equity. Questions of public versus private interest and scale (asset vs. area or neighbourhood level) motivate this work, building on international knowledge of urban climate risk finance. Real estate finance climate risk instruments like "flood risk labels" are leveraged as concrete points of investigation and analysis (see Oerlemans et al., 2025).

Integrated climate resilience indicators

This FP examines the interconnected nature of assets and infrastructure resilience, in line with a "socio-technical-environmental" systems approach (e.g., Mehvar et al., 2021). Climate risks pose limits to effectively managing infrastructure systems using conventional asset-centric approaches and research methodologies (Jones et al., 2021; Pagano et al., 2020). Taking this interdependency into account, this FP aims to identify connections between physical climate risk assessments and pertinent socio-economic–ecological vulnerabilities and societal values. This integration involves leveraging new qualitative and quantitative data to develop resilience indicators and methodologies to facilitate inclusive problem analysis in decision-making across various scales, including asset, portfolio, and urban systems levels. The aim is to promote a more comprehensive integration of social and environmental vulnerability into existing risk management approaches, which often prioritize economic aspects such as asset valuation and corresponding financial risks. Financial institutions, in particular, can leverage these insights to better align their valuation and investment decision-making strategies with integrated area-level needs and opportunities.

Governance arrangements

Stakeholders' interactions revealed the urgent need to assess laws, planning tools, and policymaking procedures to determine how real estate and infrastructure investment strategies can enhance societal climate resilience (e.g., Kim & Olshansky,

2014). Key questions are how risk management standards and roles and responsibilities for various parties are enshrined in existing legislation. Recent policy guidance, such as the new Environmental Act and "water and soil steering" directive of the Dutch government, inject further questions about how both new and ongoing urban re/development projects should address climate risks (Van Karnenbeek & Groothuijse, 2023). In this FP, serious gaming exercises are used to test and evaluate hypothetical governance scenarios and their potential impacts. Through this assessment, the objective is to gain a comprehensive understanding of the distribution of actors' responsibilities in climate risk governance and determine the need for developing new or reformed governance arrangements. The findings of this FP are expected to provide stakeholders with valuable insights into existing and potential challenges and opportunities for actionable policy-related innovations.

Climate adaptive engineering solutions

This FP emphasizes the importance of integrating technical solutions into decision-making processes while considering various factors such as scale, ecology, social equity, and uncertainties related to climate change impacts. While the existing literature extensively examines the impacts of climate change on safety (e.g., Nasr et al., 2021), and on the environment and natural resources (e.g., Mehvar et al., 2019; Weiskopf et al., 2020), research on other aspects remains limited. Specifically, there is relatively less research focused on how technical measures affect decision-making and outcomes regarding resilient built environments (e.g., van den Boomen et al., 2020). By adopting a range of engineering solutions from "hard" to "soft" measures, implemented at a range of scales (from the building to delta-system scales), stakeholders can contemplate and tailor urban climate risk management approaches in specific urban contexts. This integrated approach allows for more resilient and sustainable asset design, planning, and maintenance, ultimately enhancing the adaptive capacity of communities and infrastructure systems in the face of climate change. Stakeholders proposed a variety of engineering solutions to be examined in this line of research such as nature-based solutions, heightening of primary dikes, the provision of sandbags, elevating houses and infrastructures, storing excessive rainfall, and so on.

Knowledge exchange and capacity building

Another FP for stakeholders related to the need for a "soft space" for debates and reflection such as an integrative forum (De Jong et al., 2019). Facilitating knowledge exchange between scientists and practitioners, the forum provides a unique opportunity for advancing research on the institutionalized logics, tactics, and procedures that either hinder or facilitate effective cross-disciplinary collaboration (Crowley et al., 2020). To enhance this research area, artificial intelligence techniques (e.g., natural language processing) are also used to assess the argumentative structures (Lawrence & Reed, 2020), and values (Liscio et al., 2021) held by the researchers and societal partners. This analysis aims to identify the hard rules and soft discursive frames that emerge and evolve over the course of the knowledge

programme. In making these rules and frames more explicit, we aim to foster active reflection before and after stakeholder interactions, accelerating collective learning and iteration along the other FPs' lines.

Knowledge exchange is also centred on urban use-case research, enabling a two-way link between research and relevant societal stakeholders, projects, and community insights. This reflects a commitment to bridging research and real-world applications, fostering collaborative and impactful research through "conscious knowledge integration"—a deliberate process that unites diverse perspectives via interaction, integrative leadership, and iterative collaboration. Cultivating integrative leadership roles—both among participating scientists and societal partners—helps make integration happen through dialogue, seeking alignment between viewpoints, and making collective choices for how to iteratively advance learning in the aforementioned FPs. By navigating institutional and coordination challenges, adaptive leadership drives progress, ensuring transdisciplinary efforts translate into meaningful and scalable solutions.

Operationalizing an integrated and adaptive impact approach

In tandem with the identification of the seven FPs, the co-creation process raised important questions regarding how to organize ourselves to reach our shared impact aims. To facilitate this, we developed a three-layer stakeholder engagement and impact plan strategy rooted in the seven FPs (see Figure 2). We also created venues for dialogues, debates, and exchanges—what we call "Integration Vehicles" (IVs). These venues are targeted at specific stakeholders in the consortium (Layer 1), or between the consortium and broader technical (Layer 2), and general audiences (Layer 3) on an as-needed basis, in keeping with an adaptive and flexible approach to building this emergent knowledge domain in real time. In other words, this approach helps us to "build the ship while we sail it."

IV1 refers to monthly research "lab" meetings that aim to promote peer-to-peer learning among the 14 PhD and postdoctoral researchers directly funded by the programme (Layer 1). During these in-person meetings, researchers share updates on their progress and reflect collectively on opportunities to test, validate, and iterate on their work in collaboration with societal partners working on urban use cases. These internal research meetings occasionally involve experts and practice partners within the consortium and are often extended to other experts outside the programme (Layer 2), to provide opportunities for joint research-practice exchanges. For example, a 2024 lab meeting at Deltares—a Dutch knowledge institute—hosted a two-way knowledge exchange between researchers and experts working on climate risk labels for residential real estate and national delta scenarios. Similarly, a 2023 lab meeting hosted by the municipality of Dordrecht enabled public officials and researchers to jointly share and discuss research updates and reflect on climate risk management approaches within ongoing urban re/development projects.

IV2 refers to various activities that facilitate the exchange of insights, expertise, and best practices either between consortium partners (Layer 1), or between consortium and external experts (Layer 2), which can also be extended to a

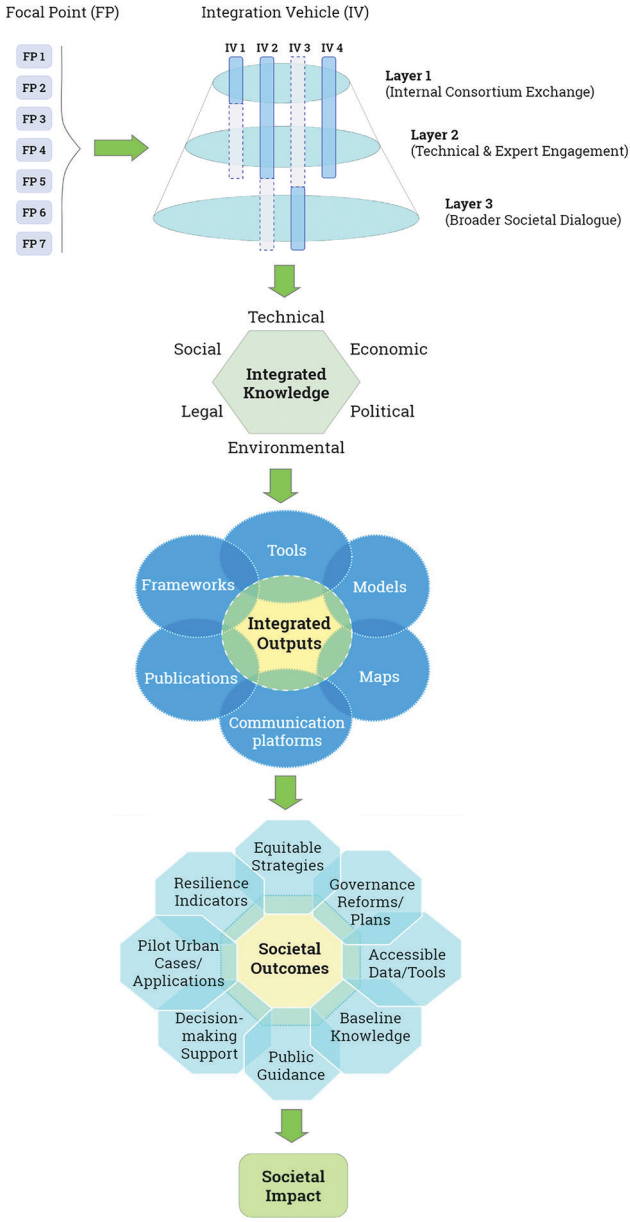

Figure 2: The three-layer stakeholder engagement and impact plan strategy of Red&Blue, with seven focal points (FPs) as the substantive basis for achieving collective aims. Integration Vehicles (IVs), or venues for dialogue and exchange among consortium members, facilitate interaction between stakeholders in the consortium (Layer 1) or between the consortium and broader technical (Layer 2) and general audiences (Layer 3). These processes enable the production of transdisciplinary outputs that promote longer term outcomes aimed toward a broader societal impact, in keeping with the Impact Plan Approach of the Netherlands Organization for Scientific Research.

broader societal audience (Layer 3), such as local communities and residents in the urban use cases. These include, for example, the organization of expert-focused capacity-building workshops at prominent recurrent events for Dutch practice, like the Stichting Kennis Gebiedsontwikkeling (Foundation for Area Development) annual conference. Other examples are the Red&Blue annual symposiums, which serve as key platforms for all programme stakeholders to come together to discuss emerging urban climate risk issues and explore potential solutions.

For example, the 2023 symposium, co-hosted by Vrije Universiteit Amsterdam and the Regional Water Authority of Amstel, Gooi en Vecht, brought together 60 representatives from academia and professional fields such as urban development, flood risk management, climate finance, real estate investment, climate adaptation, and governance. The symposium focused on the theme of "actionability," aiming to foster a shared understanding of the implications of climate science for urban governance and real estate and infrastructure adaptation strategies (see Mehvar, Daamen, & Taylor, 2023).

With respect to IV3, we provide opportunities to promote public awareness and foster reflection about climate risk governance beyond professional audiences at events like Rotterdam Architecture Month. This is achieved through various means, such as co-organizing or contributing perspectives at thematic public events. We also seek to establish stronger connections between the research programme and parallel related debates occurring within Dutch society on key urban transition topics, such as the energy transition, housing crisis, and circular economy by contributing to established public events like the Rotterdam Stadsmakercongress, or City Maker Congress. Continuous feedback, dialogue, and reflection help our team to bring new insights into broader discussions and ensure that our research stays relevant in this fast-moving knowledge landscape.

IV4 refers to the expert-focused exchanges, or "Focal Point Meetings," that enable reflective, "outside-in" dialogue between senior researchers and professional experts either from the consortium or outside. These meetings are designed to address concrete real-world problems and explore potential solution pathways in a safe space. They offer participants the opportunity to engage in dialogue, debate, and discussions about specific issues within the broader realm of real estate and infrastructure climate governance.

For example, during the first, and investor-hosted Focal Point Meeting in 2023, 18 partners from diverse fields of research and practice came together to exchange views with two shared goals: (a) to deepen understanding of the challenges and solutions in developing real estate climate risk assessment models and decision-making processes and (b) to align on priority knowledge questions to advance the field (see Mehvar, Daamen, Taylor, & van Bueren, 2023). The meeting serves as a touchstone for not only prioritizing and delineating research activities within the consortium but also clarifying knowledge needs that can be addressed through parallel activities in the broader stakeholder network. Meetings like this have led to the development of multiple "spin-off" research projects, for example.

Integration vehicles thus seek to catalyze and sustain transdisciplinary knowledge and capacity-building among stakeholders. We envision that the knowledge

generated through these interactions will ultimately land in concrete points of knowledge integration in the final years of the programme. For example, this could involve aligning the technical aspects of potential adaptation strategies in a common urban use-case typology—like un-embanked areas near major waterways—with various questions related to law, finance, participatory decision-making, and inclusion and equity.

By synthesizing insights from diverse fields and perspectives, this integrated knowledge will pave the way for the development of tangible outputs that can support collective action in addressing complex climate challenges. These outputs will likely take various forms on demand—like climate risk maps, analysis tools, decision-making frameworks, visual narratives, and writing beyond traditional scientific outputs.

Both the process and outputs are expected to lead to key interconnected societal outcomes that align with the seven research FPs. These outcomes include, for example, clear public policy guidance and widely accessible climate risk data and analysis tools (FP 1) such as risk maps and technical briefing. Other examples include multiscalar climate risk-governance reform ideas derived from the identified law, planning, and policy mechanisms on climate risks, roles, and responsibilities (FP 5). Ultimately, these intermediate societal outcomes enable broader systemic impact—here, the mainstreaming of integrated urban climate risk management strategies.

Stepping back: Challenges in transdisciplinary cooperation

While the previous section addressed the "how" question, in this section, we reflect on what, after 2.5 years of collaboration with stakeholders, we have learned about facilitating the Red&Blue programme. Five key transdisciplinary challenges emerged through reflections on the successes and shortcomings of our collaborative knowledge exchange activities. While unique to this programme design, we hope these insights are valuable for designing and facilitating future impact-driven knowledge programmes on urban climate risks and related urban transitions.

Language barriers and mismatched interests

We found that miscommunication and language barriers pose enduring challenges to effective transdisciplinary collaboration between science and practice. We see recurrent "translation issues" within scientific and practice stakeholder groups. For example, we observed that stakeholders often have highly variable understandings of concepts like "risk" and "resilience."

We observed that stakeholders also have varying levels of interest in the *types* and *uses* of climate risk information. For example, real estate investors seem to be more in favour of climate risk data and risk maps at the building and asset level, while urban planners reflected their interest in data at a larger spatial scale (e.g., neighbourhood level). This difference is also evident in the scale of action, with

some decisions focusing on the Netherlands or delta scale (e.g., existing policies on flood risk management), while other stakeholders (e.g., Dutch pension funds) may have assets affected by climate risks in different regions (e.g., Florida real estate).

Still other points of discord related to values—some public stakeholders (e.g., municipalities) prioritized questions of socio-economic risks and climate justice, while such concerns tended to be less salient for investors, who tend to position this as a public-sector responsibility. We also see that some stakeholders are not willing or are reluctant to openly share insights or engage in dialogue with other actors, potentially due to underlying trust issues, or individual ambiguities about their positionality as representatives of larger institutions or sectors with relatively undefined positions on the subject matter. In other words, while representatives from large institutions increasingly acknowledge the need for change, they often grapple with their own mandates, constraints, and priorities. This has led to what we call "slow change"—a gradual institutional shift that does not always match the urgency of climate adaptation.

In response to these challenges, we implemented proactive measures aimed at promoting alignment and mutual understanding among stakeholders, such as regular reflective conversations with individual collaborators. During these conversations, stakeholders were guided back to the overarching shared questions, focusing on societal outcomes, shared aims and values, and equity considerations, to realign interests and perspectives toward collective goals. Here, "joint hypothesizing" with small groups of stakeholders has also served as a valuable way to foster a shared agenda, collective ownership, and a pathway for (gradual) shared knowledge production. In other words, modest and tactical approaches have proven vital to making integration workable.

We also encountered disjuncture in the time horizon of traditional research versus the urgent requirements of policymakers and practitioners, many of whom are pressurized to reach decisions on timelines far quicker than academic knowledge production typically allows. We emphasize the importance of securing short-term incremental learning and collaboration in every exchange, when possible—for example, by convening dialogue around topics such as flood risk labels (see Oerlemans et al., 2025). In this case, the programme provides a safe space for joint "sensemaking" and offers a platform for spin-off research projects to take shape, aligning with parallel stakeholder demands, resources, and time horizons for decision-making.

Imbalanced institutional engagement capacity

We also noted imbalances in the institutional capacities of consortium members, with some participating less frequently in collaborative activities. This issue stems from various institutional constraints, such as the financial capacity of neighbourhood groups and non-profit organizations compared to larger financial institutions. We actively seek to platform under-represented groups in activities and support efforts to secure resources to support complementary activities that can enhance participation.

Related to the institutional engagement capacity issue, the research progress within urban use cases in Amsterdam and Rotterdam regions uncovered challenges in establishing potential case studies through collaboration with societal partners, notably with local municipal governments. Cooperation is complicated by the diverse strategies for "doing" climate risk management in participating cities, along with varying levels of institutional buy-in and engagement at different levels or divisions within organizations (e.g., at the political, strategic, and project levels or between various municipal verticals with responsibilities related to climate risk). We found that significant effort is needed by dedicated urban use case coordinators to establish protocols and processes to identify relevant knowledge questions from municipalities and connect them with scientific and practice-based knowledge in the consortium. This two-way translation between grounded complexities, needs, resources, and opportunities makes for a complex collaboration process that can take substantial time and capacity to materialize.

Scientific interdependencies between and within research teams

Our collaborative efforts also revealed two types of interdependencies between research teams that may limit the potential for true integrated co-production. The first relates to the ways that specific research teams rely on each other's findings to progress with their work. For example, physical climate risk insights must be sufficiently well defined before asset value-at-risk mapping research can begin. Similarly, knowledge integration research teams rely on collective time and data sharing from "domain-oriented" researchers who must satisfy the well-entrenched expectations for PhDs and postdoctoral projects in their fields. Domain-oriented research teams find it challenging to meet requests for collective engagement from knowledge integration researchers. This dependency requires conscious, practical workarounds and systemic reflection on incentive structures, funding structures, and recognition and reward systems if impact-oriented integration activities are to succeed.

The second type of interdependence relates to issues with stakeholder management and data accessibility. For instance, urban use case research coordinators working in Rotterdam and Amsterdam encounter challenges with data accessibility, which hinder collaborative efforts to develop a standardized approach for assessing climate risks in specific urban re/development contexts. Similarly, and looking from practice to science, it remains challenging to establish clear and focused joint research questions between municipal practitioners and researchers, for example, in the context of doctoral projects—a point to which we return later. Here, balancing the unique institutional and disciplinary perspectives placed on PhD students against the need for actionable knowledge remains a balancing act that requires careful attention. While these types of challenges are not unusual in action research, they do pose additional challenges in complex collaborations where some degree of early working-level integration between research and practice is important to facilitate authentic two-way cooperation.

To address these challenges proactively, we found organizing regular academic progress meetings involving all academic leads and researchers essential to

discuss their ongoing work, share updates, and identify any challenges or issues they are facing. These touch-base meetings offer an opportunity to collectively brainstorm solutions, leverage expertise from other research teams, and seek advice or guidance from academic leads and peers. Additionally, these interactions enable the management team to gain deeper insights into the unique needs and requirements of each research team, identify areas for additional support or resources, maintain buy-in for collaborative activities, and provide targeted assistance to address obstacles or barriers hindering collaboration.

The challenge of institutionalizing integration expertise

The Red&Blue programme was designed to catalyze public–private engagement in urban climate risk management by fostering structured stakeholder exchange. However, as discussed earlier, differences in terminology, values, and institutional priorities often impede effective collaboration. Likewise, as noted in the previous section, academic researchers face structural constraints that limit their ability to engage in long-term, collective knowledge production. While these challenges highlight the complexity of transdisciplinary work, they also reinforce the need for institutional mechanisms that actively support knowledge integration rather than treating it as an informal by-product of collaboration.

To bridge these gaps, Red&Blue introduced the gluon[3] researcher role as an experiment, an integration expert tasked with facilitating iterative cycles of knowledge exchange between research teams and societal partners. The "gluon" now plays a key role in advancing the three-layer engagement and impact plan by fostering productive interaction between problem analysis and the impact pathway. Working alongside research teams focused on urban use cases, the integrative forum, and knowledge utilization, this collaborative approach fosters inter- and transdisciplinary collaboration by bringing together diverse peer groups, facilitating knowledge exchange, and guiding an iterative learning cycle between academia and practice. By identifying synergies and shared spaces within ongoing research efforts, the gluon role helps define collective (sub)questions, challenges, and adaptation solutions for urban use cases. These shared topics, serving as boundary objects, structure collaboration and shape pathways for addressing societal issues, ultimately leading to intermediate products and integrated outputs (see the section "Operationalizing an integrated and adaptive impact approach").

However, despite the early success of this approach, integration remains highly dependent on individual initiative rather than institutionalized structures, which limits its scalability. One of the primary barriers to deeper integration is the lack of dedicated collective time for transdisciplinary work. As discussed in the previous section, researchers are expected to produce high-quality academic outputs within disciplinary frameworks, often at the expense of collaborative knowledge production. Practitioners, meanwhile, require timely and actionable insights but may lack the resources to sustain long-term engagement. This misalignment of incentives reproduces a fragmented knowledge landscape, where knowledge integration is treated as an extra task rather than a core research function. We see the Red&Blue programme as an opportunity to iterate integrative

approaches and, when possible, celebrate individual and collective successes. However, further discussion about the systemic constraints of integrative and transdisciplinary work—for example, in the design and resourcing of academic research, or traditional recognition and reward systems within universities, is more essential than ever.

The issue of territorial stigmatization

We found it challenging to ensure that our research findings do not unintentionally reinforce territorial stigmatization, enabling processes such as climate redlining or climate gentrification (see also Knuth et al., 2025; Thompson et al., 2023). Framings of climate risks and insights on emergent market responses (e.g., emergent price effects and asset devaluation) can affect perceptions of certain areas, which may harm their reputation or market value. We have taken steps to address this ethical concern by proactively centring the distributional dimensions of climate risk management when selecting use cases or framing research and engagement activities. Concretely, this means drawing sustained attention, and capacity to understand the interconnections between the ecological, technical, financial, and social dimensions of climate risk management at the neighbourhood level, for example. This approach helps us and consortium partners navigate the delicate balance between scientific independence and the potential socio-economic implications of our results.

Conclusion

Urban climate risk management is an emerging and complex domain spanning academic disciplines and policy and practice domains. Integrated and impact-oriented knowledge programmes can help bridge the world between research and action in this urban transition puzzle, connecting diverse stakeholders with new knowledge in novel ways. To effectively build shared knowledge in this domain, employing methodologies that bridge different scientific disciplines and foster collaboration among diverse stakeholders from the public and private sectors is crucial. However, transdisciplinary approaches to defining and "doing" urban climate risk management remain limited to date.

This article presented an adaptive and integrated approach for collective real estate and infrastructure climate risk management in the urbanized and low-lying Dutch delta area, taking up the case of the Red&Blue knowledge programme. We have primarily focused on "how" questions related to co-designing and operationalizing this programme: *How do we co-create knowledge that enables stakeholders to address multidimensional urban climate risk management challenges in an effective and equitable manner?*

Our co-creation process offers a model to engage stakeholders from varying practical and scientific backgrounds to co-define climate risk-related societal challenges, as seen here in the context of real estate finance and infrastructure in the Dutch delta cities. We identified seven FPs to address the multidimensional complexity found in the contemporary Dutch context and developed a transdisciplinary

knowledge programme that fosters learning and action through a three-layer stakeholder engagement and impact plan strategy.

Our approach is not without limitations. Language barriers and mismatched interests, imbalanced institutional capacities, interdependencies between and within teams, and constraints related to collective time and the need for "conscious knowledge integration" are among the key transdisciplinary challenges we have encountered in the process. This has required us to adopt an adaptive approach to managing the knowledge programme—an iterative process of testing and revising collaboration arrangements through multiple stakeholder interactions. This approach follows a dynamic, ongoing, and semi-structured "learning by doing" process. This flexible and dynamic method allows continuous feedback loops and consultation among stakeholders, a continuous testing of our assumptions, and reassessment of adaptation solutions and scenarios in light of new information and knowledge gained through the continuous dialogues and knowledge exchanges.

Reflecting on these challenges, we recognized that transdisciplinary collaboration is inherently difficult. Alongside moments of tangible impact and momentum, there have been moments when collaboration processes have stalled or tensions have arisen. However, our shared impact vision and open commitment to iterative learning and adaptive conscious knowledge integration have propelled the programme forward.

Moving forward, ensuring the long-term viability of transdisciplinary collaboration requires formal institutional recognition of integration efforts. First, the role of integration specialists and integration expertise should be expanded beyond experimental pilots and embedded into funding structures and academic career trajectories. Second, transdisciplinary contributions should be explicitly acknowledged in research evaluation metrics, rewarding activities such as co-authored interdisciplinary outputs (other than papers), leadership in collective knowledge production, and engagement with societal stakeholders. Third, research funding models must allocate specific time and resources for integration activities, ensuring that researchers are not expected to fit this work into already demanding workloads. Finally, stakeholder engagement should be structured for long-term collaboration rather than one-off consultations, allowing for the sustained co-creation of knowledge. The lessons learned from this experience are crucial for others aiming to develop knowledge programmes for urban climate risk management in other cases. Persistence, openness to change, and the ability to adapt to unexpected challenges are essential. While the path to true integration is long and difficult, the benefits of co-creating solutions that are locally relevant, inclusive, and sustainable far outweigh the challenges faced along the way.

Co-design processes, while invaluable for fostering collaboration and integrating diverse perspectives, are resource-intensive and may not be necessary for every transition challenge. However, our ongoing effort suggests that transdisciplinary knowledge programmes have true promise to build substantial collective capacity to understand and "do" urban climate risk management in new ways. Given the enormity and urgency of the challenges ahead of us, finding new ways

to learn and intervene together has never been timelier or more valuable. The key takeaway, then, is that long-term partnerships between universities, research institutions, and public and private actors can ensure ongoing knowledge exchange and informed intervention.

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The authors have nothing to disclose.

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Peer Review

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Notes

1. The integrated approach presented in this article has been developed in collaboration with a diverse range of inter- and multidisciplinary academic, and public and private practice-based experts from 29 institutions. A full list of collaborating institutions is available on the Red&Blue website (see Red&Blue, 2022).
2. Following the initial launch workshop in March 2020, co-creation sessions were held online due to the COVID-19 pandemic.
3. Gluon is a methodological intervention developed by the methodology team of the Resilient Delta Initiative led by Nikki Brand, aiming at testing methods for the integration of insights and approaches in a wide disciplinarity setting. More information can be found in Gluon (2023).

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