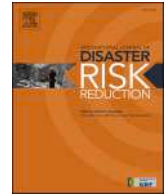
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Interdisciplinarity in practice: Reflections from early-career researchers developing a risk-informed decision support environment for Tomorrow's cities

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ABSTRACT

The concept of disaster risk is cross-disciplinary by nature and reducing disaster risk has become of interest for various disciplines. Yet, moving from a collection of multiple disciplinary perspectives to integrated interdisciplinary disaster risk approaches remains a fundamental challenge. This paper reflects on the experience of a group of early-career researchers spanning physical scientists, engineers and social scientists from different organisations across the global North and global South who came together to lead the refinement, operationalisation and testing of a risk-informed decision support environment for Tomorrow's Cities (TCDSE). Drawing on the notions of subjects and boundary objects, members of the group reflect on their individual and collective journey of transgressing disciplinary boundaries across three case studies between June–December 2021: operationalisation process of the TCDSE; development of a virtual urban testbed as a demonstration case for the implementation of the TCDSE; and consolidation of frequently asked questions about the TCDSE for communication purposes. The paper argues that (1) the production of boundary objects in interdisciplinary research nurtures relations of reciprocal recognition and the emergence of interdisciplinary subjects; (2) the intrinsic characteristics

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of boundary objects define the norms of engagement between disciplinary subjects and constrain the expression of interdisciplinary contradictions; and (3) affects and operations of power explain the contingent settlement of interdisciplinary disagreements and the emergence of new knowledge. Activating the interdisciplinary capacities of early-career researchers across disciplines and geographies is a fundamental step towards transforming siloed research practices to reduce disaster risk.

1. Introduction

The complex, dynamic and uncertain nature of contemporary and future global challenges requires changes in the way of framing and addressing research problems and questions [1–3]. Future urban disaster risk in the context of projected rapid urbanisation in low-to-middle income countries over the next three decades represents one of these intractable challenges [4,5]. Interdisciplinarity has been proposed as a way forward to advancing holistic and integrative ways of thinking and acting towards disaster risk reduction [6,7]; yet, researchers in disaster and risk studies experience a myriad of challenges in ‘doing’ interdisciplinary research [8,9]. Arguably, some of the shortcomings in practicing interdisciplinarity are related to a lack of critical (self-)reflection on what works and how in tandem with in-depth theorisations that make sense of the interdisciplinary process and its core components [10].

There are two main research gaps in the debates on interdisciplinarity in disaster and risk studies that can account for some of the issues facing researchers: (1) a lack of attention to the *subjects* undertaking interdisciplinarity [11], and (2) limited understanding of the *process* of doing interdisciplinarity as an act of generating novel knowledge [12]. In the first place, research on interdisciplinarity has largely focused at the level of communities of practice [13,14] or (small) groups [15], often overlooking how group dynamics shape, and are shaped by, individuals. Secondly, interdisciplinarity is mainly conceived as an end product (i.e., interdisciplinarity as a noun) rather than a relational process of identity formation and belonging in knowledge production (i.e., interdisciplinarity as a verb: *being, belonging, knowing*) [14,16]. The underpinning premise is that the value and authority of knowledge, interdisciplinary or otherwise, cannot be explained without attention to the subject valuing it and the inner changes they undergo throughout the knowledge generation process in which they participate with others [17,18]. This paper proposes to address these two research gaps through the notion of *boundary objects* by responding to an overarching research question: *how can boundary objects contribute to the emergence of interdisciplinary subjects and knowledge?*

Boundary objects are abstract or physical artefacts that reside in the interfaces between disciplines understood as world views [19], communities of practice [14] or cultural groups [15]. They have the capacity to mediate values, norms and aims among these communities and enable cooperation by emerging mutual understanding [12,20,21]. Boundary objects such as agent-based models and scenario development are not new in discussions on interdisciplinarity in disaster and risk research [22,23], but this paper takes a more critical stance and proposes new entry points to their conceptualisation. Specifically, it does so by (1) unpacking the relationships between boundary objects and subjects, and (2) focusing on the dynamic process of producing and managing boundary objects while mediating the production of interdisciplinary knowledge. Ultimately, placing boundary objects in their relations with subjects emphasises the changes which are linked to those interactions.

The empirical basis that informs this paper draws on the individual and collective experiences of members of the Tomorrow’s Cities Early Career Risk Working Group (ECRWG) collated through group autoethnography. Tomorrow’s Cities is the UK Research and Innovation (UKRI) Global Challenges Research Fund (GCRF) Urban Disaster Risk Hub, a five-year global interdisciplinary research programme that aims to catalyse a transition from crisis management to multi-hazard risk-informed and inclusive planning and decision-making for cities in low- and middle-income countries [24]. The ECRWG consisted of seventeen early-career researchers spanning physical scientists, engineers and social scientists, based in different organisations across the global North and global South,¹ whose collaborative work was overseen by two senior researchers. Over the course of seven months (June to December 2021), the ECRWG was tasked with translating the Tomorrow’s Cities Decision Support Environment (TCDSE) concept pioneered by a team primarily composed of senior researchers [25] into a flexible operational framework to be applied in rapidly growing and expanding cities.

The mission of the ECRWG has been threefold. First, to develop a robust methodological approach to risk-informed decision-making, underpinned by the ethos of co-production and engagement with multiple stakeholders, which utilises state-of-the-art scientific modelling and advances an understanding of the socioeconomic flows that characterise cities. Second, to develop a virtual urban testbed known as Tomorrowville to demonstrate the TCDSE concept. Third, to support the communication of the TCDSE

¹ Members of the group identified themselves as urban planners (6 researchers), physical scientists (4), civil or structural engineers (3), human geographer (1), urban political ecologist (1), urban sustainability researcher (1) and interdisciplinary researcher (1). We are based in the UK (9), Nepal (5), Turkey (2) and Kenya (1).

framework for its application in partner cities. Each of these objectives delineates a phase in the ECRWG journey, mediated by a boundary object upon which we interacted and integrated our disciplinary understandings about disaster risk and its reduction. The three boundary objects consisted of (1) a conceptual diagram of the overarching TCDSE framework; (2) a virtual urban testbed (Tomorrowville) developed within a geospatial database; and (3) a frequently asked questions (FAQs) document about various aspects of the TCDSE.

The paper begins with a review of the literature in Section 2, enriching discussions on interdisciplinarity in disaster and risk studies with the notions of *subject* from feminist scholars (2.1) and *boundary objects* from Science and Technology Studies (2.2) which are then brought together in a novel analytical framework (2.3). A description of the methodological approach that oriented the paper follows in Section 3. Section 4 continues with an introduction of the three case studies that delineated our interdisciplinary journey, each of them characterised by a specific boundary object. The analysis of the ECRWG journey in Section 5 is organised in two subsections, specifically developing the notions of emergent interdisciplinary subject (5.1) and boundary objects as objects of relational mediation (5.2). The last section discusses the implications of our findings in the context of existing scholarship and practice and suggests future avenues of research and recommendations for forthcoming interdisciplinary efforts in disaster and risk studies (Section 6).

2. Subjects and boundary objects in interdisciplinary disaster and risk research

Historically, hazards and disaster research has assembled multiple disciplines and professions [26]. Cross-disciplinary fertilisation of perspectives has been encouraged by the multidimensional nature of disasters, the subsequent need for holistic approaches to their understanding, and the strong applied focus that has characterised the field [27,28]. However, much of the discussion about interdisciplinarity has centred on hazards and disasters, with an emphasis on disaster response to avoid societal disruption [29]. Shifting our attention to the future and the delineation of prospective approaches instead compels us to focus on the integration of knowledge (s) towards a comprehensive and inclusive understanding of (disaster) risk and proactive strategies for its management [6,7,30]. Our interdisciplinary engagement as members of the ECRWG contributes to this line of thinking and action, spearheaded by the forward-looking approach that underpins the TCDSE.

Interdisciplinarity in disaster and risk research is increasingly defined vis-à-vis (uni)disciplinary, multidisciplinary and transdisciplinary research, depending on who is involved and the degree of knowledge integration [30,31]. Yet, the main challenge remains not the identification of the various disciplines for a cross-disciplinary endeavour as much as how to bring multiple disciplinary viewpoints into dialogue, mutual understanding and delineation of shared research objectives, questions and methods [32]. While some are starting to acknowledge that this requires reconciling ontological and epistemological differences across the various disciplines and professions that conceptualise and manage disaster risk [18,33,34], the interdisciplinary production process is still undertheorized in disaster and risk research.

Two fundamental shortcomings are identified in terms of theoretical gaps. In the first place, composition of research teams has rarely focused on the subject, taking cognate disciplines as the unit of analysis. While there is some recognition of the micro-level, including emotions and attitudes of researchers, these are not problematised and often taken for granted [31,35]. Similarly, there is increasing acknowledgement of power imbalances within a team, often associated with disciplinary status but also gender, age and geography of researchers, among other identity axes [27]. Recognition of emotional, attitudinal and power relation issues significantly advances the understanding of the interdisciplinary process, but disaster and risk scholarship has fallen short in unpacking the subjective, relational and political nature of interdisciplinary knowledge production (i.e., *being, belonging, knowing*) [11,14,16].

The second research gap pertains to integration. Interdisciplinarity is often defined as integration across ‘academic research fields’, ‘areas of science’ or ‘research domains’ [35]. Boundary objects, often conceived as static and separate entities, are pinpointed by some as a way of enhancing integration [22,23]. However, disaster and risk research has rarely questioned what integration means and how it unfolds as a process of change. Broader literature on interdisciplinarity problematises the notion of integration [12,36,37], highlighting that there is a fine line between ‘integration as synthesis of existing knowledge’ and ‘integration as generation of new knowledge’. The latter brings to the fore the idea of emergence, under the assumption that the interaction between perspectives and researchers has generative or productive potential [38–40]. In this context, the conceptualisation of boundary objects requires further attention, reframing them as dynamic entities that are intertwined with the subjects producing and managing them [21,41]. Thus, the interdisciplinary production process (i.e., emergence), pertains not only to knowledge but also subjects.

There are no formal recipes on how to undertake interdisciplinary disaster and risk research, but this paper argues that a focus on subjects and boundary objects provides entry points to actionize strategies within the sphere of influence of researchers and the teams of which they are part. This differs from macro-level factors (e.g., funding, reward system, publication rules, organisational norms), which are beyond the immediate scope of individual researchers and might take longer to modify [23]. Drawing on feminist scholarship and science and technology studies (STS), the following subsections elaborate on the notions of subject (2.1) and boundary objects (2.2), respectively, to then propose an analytical framework to understand the emergence of interdisciplinary subjects and

knowledge (2.3).

2.1. On subjectivity and knowledge

The relationship between the subject and knowledge has been interrogated by different schools of thought, from the Althusserian tradition, through post-structuralist approaches to feminist scholarship [42–46]. Building on the advancements of each of these traditions, four analytical elements are identified to better understand how interdisciplinary subjects emerge and change overtime: (1) self-identification and reciprocal recognition, (2) dispersed operations of power and internalisation, (3) embodied practice and (4) intersectionality.

An Althusserian reading of subjectivity defines it as the positionality of an individual in a social field, let it be its citizenship, gender, ethnicity or disciplinary background, and argues that this positionality determines the actions available to them, that is, their power to act and influence the collective [47]. This tradition highlights a dual dimension of subjectivity. On the one hand, an individual is hailed by the members of a social field as a particular subject, for instance a white male. On the other hand, the individual self-identifies with that position and acts accordingly, claiming its associated rights. Knowledge, here, can be understood as the identity traits that define the positionality of an individual, whether their place of origin, sex, colour of their skin or disciplinary belonging. This, in turn, has consequences on their authority to speak about certain scientific matters or exercise their civil and political rights.

The Althusserian approach to subjectivity is helpful to highlight the relationship between knowledge and influence capacity, and the role of self-identification and recognition in establishing this relationship. However, Althusser [47] considers the subject “always already there”, always constituted and stable, and there is no attention to the process of subjectification (i.e., how the positions with which an individual self-identifies come to be conceived in the first place). This implies that the social fields and their constitutive knowledge(s) are frozen, precluding the possibility of change. This represents a limitation to explain how interdisciplinary knowledge becomes valued and authoritative, and a procedural dimension is required to account for the process of becoming.

Post-structuralists responded to this limitation by arguing that the behaviour of individuals, or subjects, results from operations of power [42,43,48–50]. Operations of power shape the will and desires of subjects, orienting them to behave in certain ways. Thus, power is taken as the analytical entry point to understand how subjects are produced. Examples of operations of power may be taxes or work promotion schemes to (dis)incentivise consumption or production patterns; or narratives that appeal to fears of socio-economic collapse to justify austerity policies. These examples highlight the ways in which both material and discursive incentives exert pressure on the individual and shape their behaviour. Ultimately, operations of power produce subjects as they become internalised. Consequently, the subject is not static but in the making.

According to post-structuralists, power is deployed in a strategic manner through programmes or projects aimed at resolving problems such as the impending risk of climate change. This begs the question of how these problems are identified and rationalised. The concept of knowledge helps to answer this question. Here, knowledge is read as a historically contingent understanding of the world, belonging to a particular tradition of thought. Different knowledges rationalise different problems and inform the ways in which they are tackled. Therefore, the emphasis is not on how well knowledge represents reality, but instead how knowledge allows for a specific rationalisation of a certain problem.

The post-structuralist approach is well suited to explain how hegemonic regimes of knowledge, or disciplines, perpetuate and expand over time. Power operates through a network of subjects, or disciplinary scientists, always on the making, whose behaviour cannot be explained separate from the network with which they self-identify and by which they are recognised. However, this approach falls short in explaining unexpected processes of change [39], such as the emergence of interdisciplinary knowledge. By focusing on how particular knowledges justify a problem and its resolution, post-structuralists leave unattended how multiple rationalisations of the world, or multiple (scientific) knowledges, interact on relatively equal terms and open the possibility of new understandings.

Aiming to respond to this limitation, feminist scholars have moved the focus to the everyday, or routinary praxis, where subjects internalise power as norms and expectations attached to identity traits [43,51,52]. In so doing, they highlight how mundane sites where people live, work and socialise, performing everyday activities, become the sites of their own constitution [43,53–56]. By focusing on everyday sites, feminist literature advances the concept of embodied practice when explaining the production of the subject [57–61].

Internalisation of identity traits, and of the norms and expectations attached to them, is an “ambivalent” process; that is, while it orients individuals to behave in certain ways, it also opens modes of resistance [43]. Transgression of norms and expectations, through embodied practice, has shown to encourage the emergence of new subjectivities [62,63]. Furthermore, multiple and intersectional identities such as gender, class, age and ethnicity offer a way to understand how embodied practice can challenge and transform normative expectations on a subject [63]. Intersectionality suggests that the options available to an individual are delimited by the multiple identity axes defining their subjectivity, being disciplinary orientation one of them. By virtue of adherence and compliance to the expectations determined by one of the axes, a subject remains recognised by others in that social field; yet, the subject is

simultaneously able to challenge the expectations stemming from other axes.

Feminist approaches with a focus on the everyday invite us to think about embodied practice in the procedural engagement of disciplinary researchers through boundary objects. Occasionally tense and conflictual, as it expresses contradictions between disciplines, this engagement illuminates how disciplinary subjects transform and emerge as interdisciplinary scientists. The next subsection elaborates on the concept of boundary objects, further emphasising how subject and boundary object are mutually constituted.

2.2. On boundary objects in interdisciplinary research

There is growing attention on the role of boundary objects in facilitating dialogue across disciplines and contributing to the emergence of shared perspectives [12,64]. Star and Griesemer [19] pioneered the conceptualisation of boundary objects around their ethnographic research at the Berkeley's Museum of Vertebrate Biology while trying to understand how heterogeneity and cooperation could coexist between individuals from different social worlds and with divergent viewpoints. Their definition of boundary objects remains highly relevant for contemporary analyses:

“This is an analytic concept of those scientific objects which both inhabit several intersecting social worlds (...) and satisfy the informational requirements of each of them. Boundary objects are objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use, and become strongly structured in individual-site use. These objects may be abstract or concrete. They have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable, a means of translation” (Star and Griesemer, 1989, p.393).

Drawing on this pioneering work, different typologies have been proposed in the literature to characterise and illustrate boundary objects. Star and Griesemer [19] began by distinguishing four types of boundary objects: (i) repositories (e.g., libraries and museums); (ii) ideal types (e.g., drawings and models); (iii) terrain with coincident boundaries (e.g., office building); and (iv) standardised forms (e.g., standard procedures). An alternative typology has been then suggested by Wenger [14], organising boundary according to (i) artefacts (e.g., shared tools, documents and models); (ii) discourses (e.g., a common language); and (iii) processes (e.g., shared procedures and routines). Finally, Carlile [65,66] advances a typology that articulates boundary objects with specific types of knowledge boundaries: (i) repositories, for crossing syntactic knowledge boundaries (differences in language); (ii) standardised forms and methods, for semantic knowledge boundaries (differences in meaning); and (iii) objects, models and maps, for pragmatic knowledge boundaries (differences in practice). The evolution of these typologies, which are synthesised in Table 1, is underpinned by changes in the ways of conceiving boundary objects.

The first typology [19] focuses on boundary objects as finalised and static products, while the second one [14,16] also emphasises what boundary objects do (e.g., they provide a ‘shared’ language, tools or procedures). The third typology [65,66] expands on the role of boundary objects ‘in the making’, that is, how they operate while being produced. In this regard, there are two important points to highlight. In the first place, an exclusive focus on boundary object *types* has tended to obscure the process of their constitution. While the original work of Star and Griesemer [19] already called attention to the process of creating and managing boundary objects, few scholars have explicitly elaborated on the dynamic and procedural nature of boundary objects [14,21,65,66]. Secondly, an understanding of boundary objects as end products has often overlooked the ways in which they operate, that is, the role that they play in interfacing world views and mediating relations between different social worlds. Here, the work of Wenger [14,16] on dimensions of boundary objects becomes relevant to move from *types* to the *intrinsic characteristics* that account for their mediating capacity. Specifically, Wenger [16] delineates four dimensions of boundary objects:

Table 1
Boundary object typologies in the literature.

Scholars	Type 1	Type 2	Type 3	Type 4
Star & Griesemer [19]	Repositories (e.g., libraries and museums)	Ideal types (e.g., drawings and models)	Terrain with coincident boundaries (e.g., office building)	Standardised forms (e.g., standardised procedures)
Wenger [14,16]	Discourses (e.g., a shared language)	Artefacts (e.g., shared tools, documents and models)		Processes (e.g., shared procedures and routines)
Carlile [65,66]	Repositories, for crossing syntactic knowledge boundaries (differences in language)	Objects, models and maps, for crossing pragmatic knowledge boundaries (differences in practice)		Standardised forms and methods, for crossing semantic knowledge boundaries (differences in meaning)

- i. **Abstraction:** the general character of the object leads to a certain level of abstraction and conceptual vagueness, facilitating dialogue between different ‘worlds’;
- ii. **Accommodation:** the object can be used for several activities and practices, such that different people can implement the concept in their own way;
- iii. **Modularity:** the object consists of several parts that can be mobilised in various situations according to actors’ needs and interests;
- iv. **Standardisation:** the information contained in a boundary object is in a pre-specified form and directly interpretable, so that it can be used locally.

A dynamic understanding of boundary objects grounded on the dimensions or intrinsic characteristics that explicate their mediating potential contributes to better understand their relevance in interdisciplinary research. In the first place, the process of creating and managing boundary objects unpacks the mutually constitutive nature between objects and subjects² [21], which is often overlooked in interdisciplinary literature. Some scholars acknowledge the political nature of boundary objects and their capacity to catalyse change or rather stabilise the status quo in terms of existing power relations, including hierarchies in disciplines [67,68]. Less explored, though, is the extent to which boundary-object-mediated relations between disciplinary subjects can trigger inner transformation [10,11,69], including the emergence of interdisciplinary subjects.

Secondly, the processual view of boundary objects echoes an understanding of ‘interdisciplinarity as a verb rather than a noun’ [12] and a relational approach to knowledge production grounded on the relevance of social relations. In this context, interdisciplinarity results from ‘knowing as an act of participation’ and ‘knowing as an act of belonging’ [14,16], where boundary objects mediate the emergence of an interdisciplinary identity, a shared sense of belonging across yet disciplinary subjects [21]. Thus, cooperation does not necessarily entail consensus nor surrendering individual positions [19,70]. Instead, individuals subordinate strong disciplinary commitments, identities and repertoires to a collective goal [12]. In short, boundary objects do not erase disciplinary differences but circumscribe them and expose their contradictions.

Much of the literature on boundary objects has fallen short of exploring the dynamic process(es) of mutual constitution between boundary objects, subjects and the ‘social worlds’, ‘communities of practice’ or ‘disciplines’ with which they identify. The conceptual and empirical contributions of this paper aim to start filling these gaps by better connecting subjects and boundary objects in processes of interdisciplinary knowledge production in disaster and risk research.

2.3. A framework to understand the emergence of interdisciplinary subjects and knowledge

Bringing together understandings of the subject from feminist literature [42–46] and boundary objects in science and technology studies [12,13,19,21], Fig. 1 proposes an analytical framework that contributes to critically unpack the emergence of interdisciplinary subjects and knowledge.

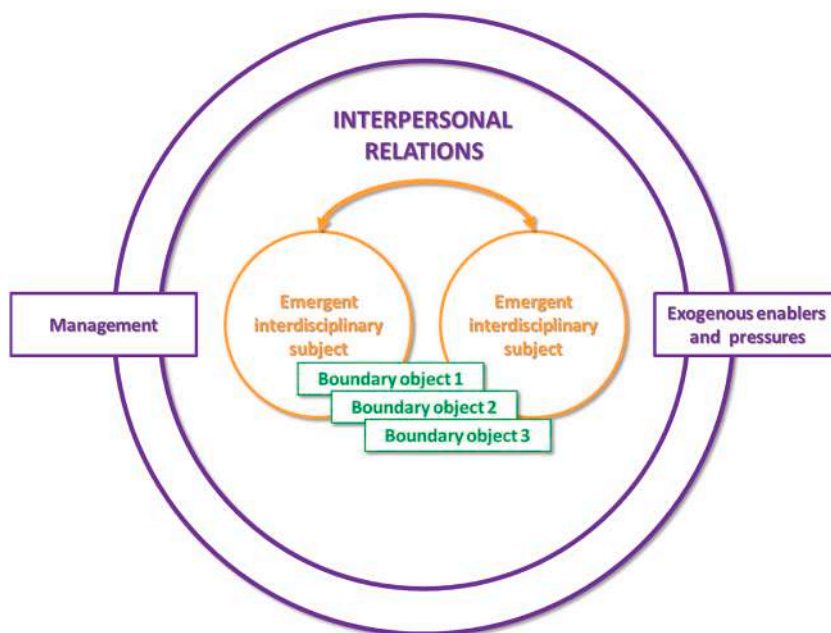


Fig. 1. Analytical framework to understand the emergence of interdisciplinary subjects and knowledge.

² Boundary objects simultaneously enable and are enabled by the ongoing interactions between the communities of practice that share them [21].

The analytical framework places the emergence of the interdisciplinary subject, one that confers an authoritative value to interdisciplinarity, at the centre of the knowledge production process. Relations of reciprocal recognition, mediated by multiple and diverse boundary objects, explain the emergence of interdisciplinary subjects. These relations are further conditioned by exogenous (i.e., contextual) enablers and pressures as well as by the authority and resources flowing down the management line.

3. Methodological approach: group autoethnography

This paper draws on the individual and collective experiences of members of the ECRWG, collated through a process of reflexive thinking about who we are as interdisciplinary subjects, how we worked together as a group and what we achieved during a seven-month working period. Markham depicts reflexivity as “a continuous self-interrogation of our positionality in research practice” ([71], 3 min 27). Autoethnography encourages researchers to externalise this self-directed scrutiny of motivation, emotions, values, beliefs and schema about the world and how they influence our research by means of writing, narrating, visualising or other forms of representation, individually or with others [72,73]. Collective, collaborative or group autoethnography has been proposed and used by others as an approach to research and writing [10,74] and it becomes important for evaluation and learning purposes within an interdisciplinary project given the difficulties in observing and analysing the process from an ‘outsider’ perspective [64].

Two reflexive exercises were used to generate data for this paper:

- i. An individual reflexive exercise through an online questionnaire, which consisted of a mix of open-ended and semi-structured questions. An open-ended question was set at the outset about the respondent’s understanding of interdisciplinarity. This was followed by the same two questions about each of the three boundary objects (TCDSE conceptual diagram, Tomorrowville virtual urban testbed and FAQs document). The questionnaire concluded with three open-ended questions on the hindering and enabling factors of interdisciplinary work. All members of the ECRWG (17 respondents) completed the questionnaire.
- ii. A collective reflexive exercise during a 2-h online focus group discussion. This discussion was attended by most of the ECRWG (14 participants) and involved a series of breakout group sessions that were organised around three themes cutting across each boundary object: 1) value of boundary objects; 2) tracing relations through boundary objects; 3) emotions and perceptions of others attached to the creation and management of boundary objects. Three breakout groups were defined in advance to secure a balanced distribution between disciplinary background, gender and geographic location. We used Padlet to input, map and visualise our reflections.

The qualitative analysis of the reflexive exercises followed a grounded theory approach, where theory is constructed from data themselves and the central activity is a coding exercise which starts from participants’ lay accounts [75,76]. We used a range of qualitative techniques, ranging from open and axial coding, through categorisation or classification, to making connections between categories [77]. The initial coding, development of categories and the sketching of emerging connections between these categories were performed in NVivo, after individual survey responses and posts on Padlet were transcribed.

4. Boundary objects in context

The configuration of the ECRWG unfolded in the context of a series of processes that are worthy of consideration. The UK Official Development Assistance (ODA) cuts announced in April 2021 due to the COVID-19 pandemic catalysed a restructuring of the work plan of Tomorrow’s Cities and the internal reconfiguration of its teams³ [78]. This included a transition from a pioneering Risk Working Group (RWG) formed mainly by senior researchers in June 2020 to the ECRWG that was brought together in June 2021. A second contextual process was the funder reporting cycle in June–July 2021, known as Stage Gate Review, to which the ECRWG contributed a case study. Finally, the participation of Tomorrow’s Cities in the United Nations Climate Change Conference of the Parties (COP26) in Glasgow, UK concentrated the efforts of the ECRWG in the design of a short video to showcase the relevance of our research to climate change adaptation⁴. These macro-level processes meant that the ECRWG research was undertaken in a fast-paced environment and under significant pressure, against a backdrop of ECRWG members making efforts to secure their job stability in the mid-term.

The abovementioned is a reminder of the relevance of context in interdisciplinary research [37,79] and that the creation and management of boundary objects is context specific [67]. Notably, boundary objects have been often conceptualised in relatively stable environments [21], which significantly differs from our volatile circumstances that were marked by multiple contextual changes. This provides a unique opportunity for our experience to enhance our understanding of the dynamic interactions between subjects and boundary objects in interdisciplinary research which are permeated by contextual pressures and enablers.

Our interdisciplinary journey was defined by three phases in which we interacted from our various disciplines through boundary objects to generate new knowledge on disaster risk. These three phases, (1) operationalisation of the TCDSE; (2) development of a virtual urban testbed (Tomorrowville) as a demonstration of the TCDSE; and (3) consolidation of a frequently asked questions document to better communicate the TCDSE concept, represent the case studies of our analysis. Each of these phases is characterised by specific boundary objects created and managed at particular moments in time (see Fig. 2).

The temporal dimension is important to trace the process of learning to work as a group of researchers with different perspectives

³ The cuts represented a reduction from 0.7% to 0.5% of the gross national income that the UK has committed by law since 2015 and impacted the funding of several research projects focusing on low- and middle-income countries.

⁴ The video was completed over the course of one month (October 2021) and is available at <https://www.youtube.com/watch?v=2LMXxaR7bJY>.

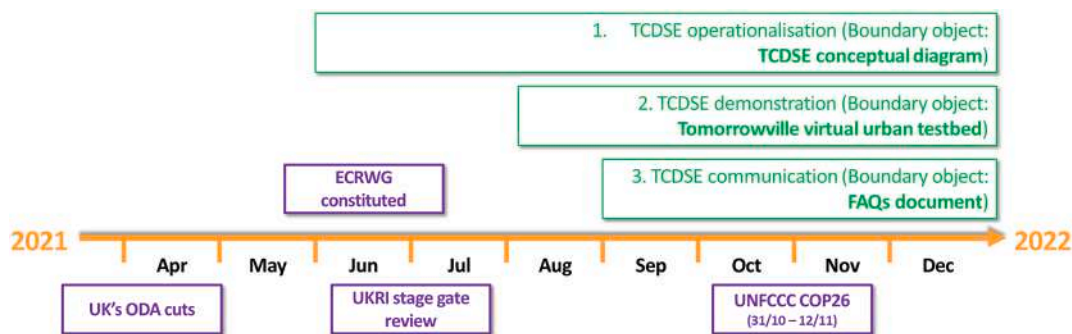


Fig. 2. Context of the ECRWG, interdisciplinary phases and boundary objects.

on disaster risk. In addition, the multiplicity and diversity of boundary objects provides an interesting background to reflect on whether certain objects are more conducive to interdisciplinarity [65,67]. The rest of the section introduces each case study, including a description of its corresponding boundary object.

4.1. Case study 1: TCDSE operationalisation (June–December 2021)

Tomorrow's Cities Decision Support Environment (TCDSE) advances beyond conventional risk modelling approaches and simplistic decision-making tools. The TCDSE first facilitates multi-stakeholder future visioning in a given urban context, realises technical scenarios embodying these visions, exposes these scenarios to multi-hazard events to estimate physical and social impacts associated with potential disasters, and democratises the concept of risk by ensuring the voices of marginalised groups are included throughout the process. The TCDSE framework is underpinned by state-of-the-art physics-based simulations of multiple hazards [80], physical vulnerability models [81], innovative methods for harmonising data generation and analysis across the physical and social sciences [82] and rigorous capacity-strengthening strategies. For a detailed description of the TCDSE framework, see Cremen *et al.* [83].

In June 2021, the ECRWG was tasked with refining the TCDSE pioneering concept (Version #0, see [25]) and first attempt at its operationalisation by a team comprised exclusively of earthquake-focused scientists and engineers (Version #1, see [84]) to facilitate its practical implementation across partner cities. Presentation of Version #1 by its developers to the wider ECRWG marked the first instance when we gathered together as a group, and it was mediated by the TCDSE conceptual diagram as a boundary object constituted of modules and feedback loops. After an introduction to the rationale underpinning Version #1, a convening space was established for providing feedback, suggesting changes and questioning some of the core assumptions of the flowchart. This space, which was facilitated by online oral discussions and collective writing sessions, led to significant improvements of Version #1 and the creation of Version #2 as an updated operational version of the TCDSE (see Fig. 3).

Together with the TCDSE conceptual diagram, we collectively, interactively and iteratively co-produced an online document containing the definition and characterisation of each of the modules and their relations, which was transformed into a journal publication [83].

4.2. Case study 2: TCDSE demonstration (August–December 2021)

Alongside the operationalisation of the TCDSE concept, the ECRWG was charged with demonstrating how the TCDSE could be implemented in practice. Accordingly, a virtual urban testbed known as Tomorrowville was created and used to develop several scenarios to be tested throughout the TCDSE. The conceptualisation of Tomorrowville and multiple scenarios of its future development represents the boundary object of our second case. For a detailed discussion of this process, see Menteşe *et al.* [82].

Tomorrowville is a virtual 500-ha urban extent prone to earthquake, flood and debris flow hazards which was developed by combining synthetic and empirical data from Kathmandu and Nairobi to broadly reflect a global South urban context. The virtual urban testbed is underpinned by a geospatial database consisting of four main layers (1. land-use, 2. buildings, 3. households and 4. individuals), which are designed to flexibly accommodate different scenarios of its urban development. An initial version of Tomorrowville (TV0), representing the current state of the area to be developed, was produced as the baseline scenario. Then, two additional versions were created to represent potential scenarios in 50 years' time (TV50): 1. an urban development scheme that does not account for possible inundation of new buildings within the floodplain (hazard-insensitive; TV50_b1); 2. an urban development scheme that prevents or minimises new development within the floodplain (hazard-sensitive; TV50_b2) (see Fig. 4). ECRWG members from different disciplines generated data for the different layers: social scientists characterised the land-use layer, while engineers spearheaded development of the buildings layer, relying on social science expertise for building occupancy and household information. The processing of data was coordinated and executed by GIS and computational experts within our interdisciplinary team. Thus, the scenario development process was mediated by a geospatial database that integrated different types of data from various disciplines.

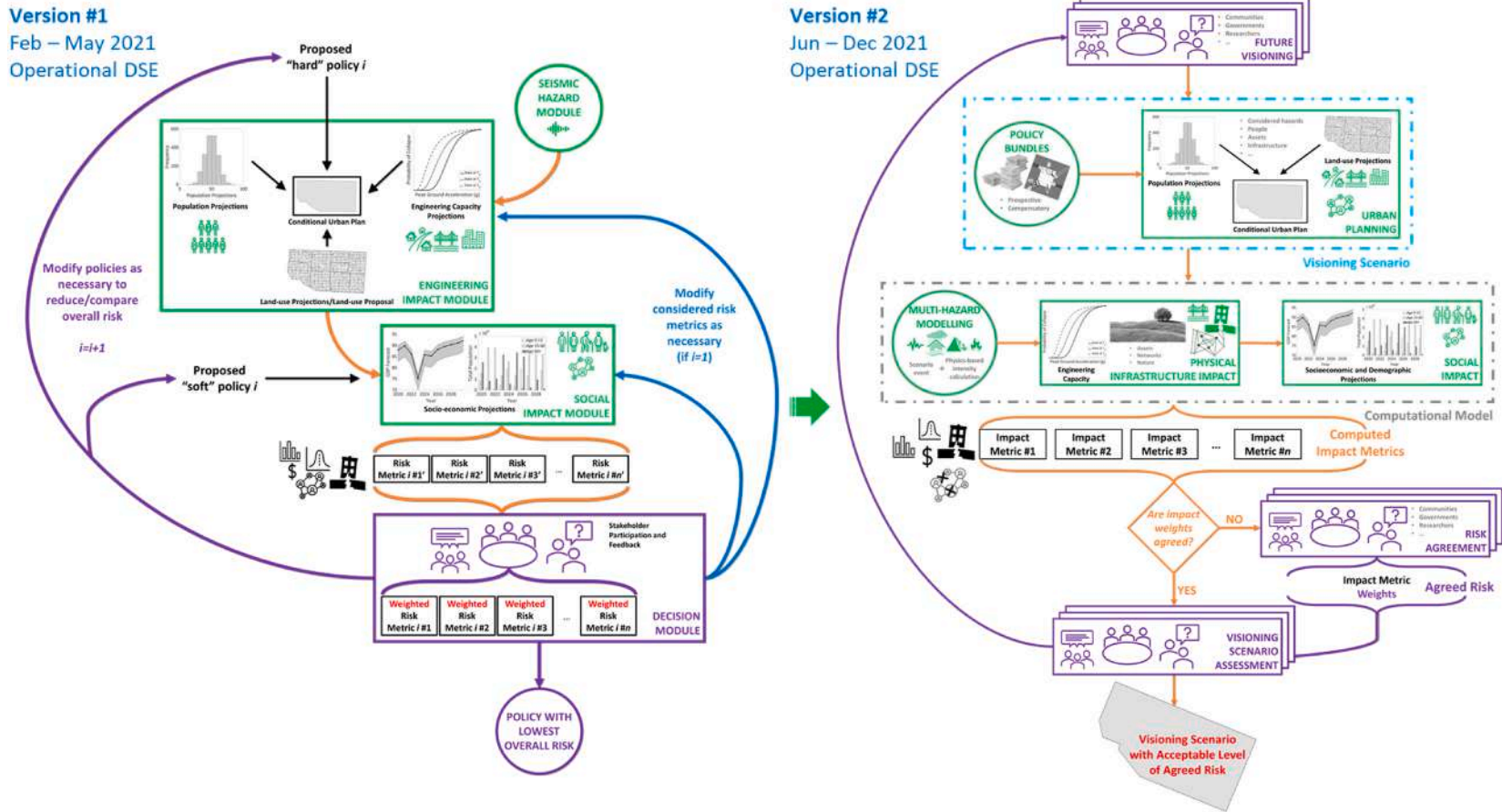


Fig. 3. Interdisciplinary refinement of TCDSE operationalisation. Sources: Version #1 [84]; Version #2 [83].

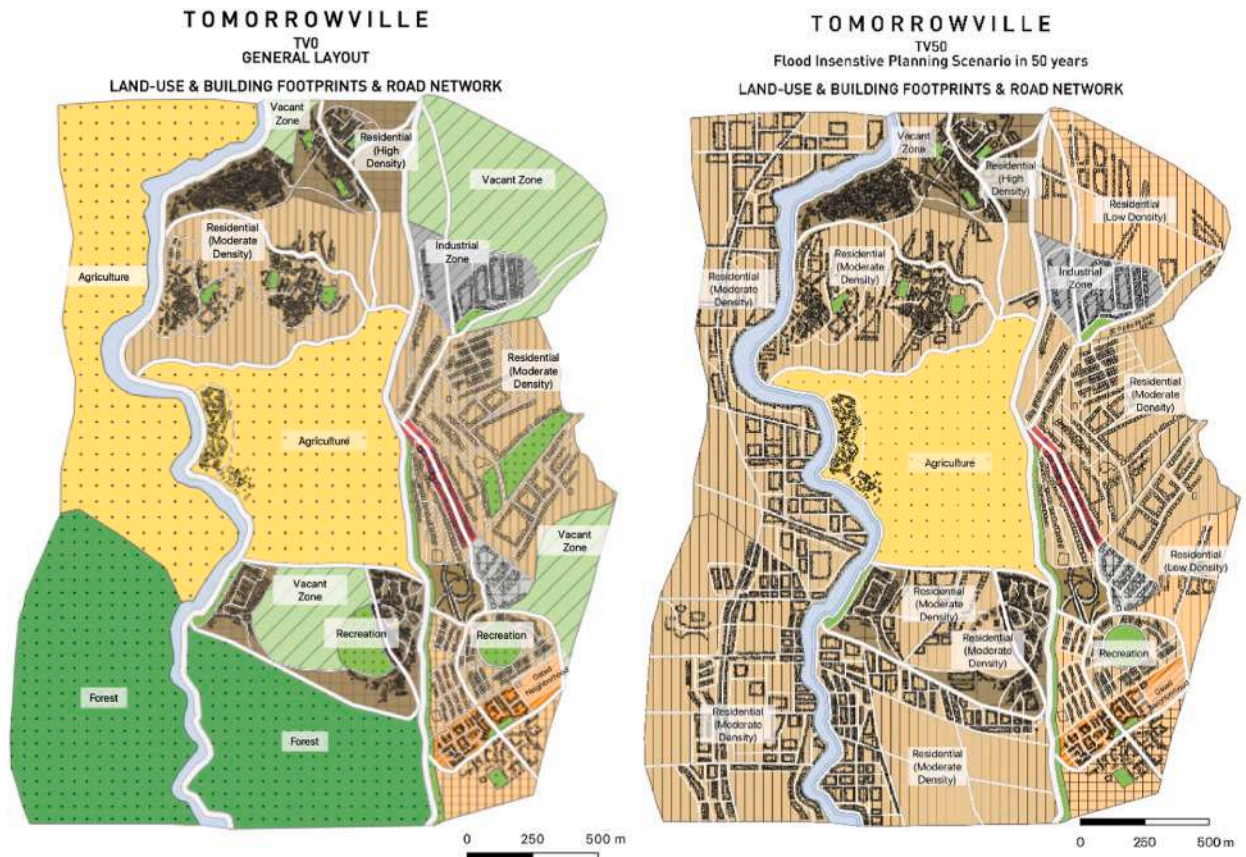


Fig. 4. Layout of Tomorrowville: TV0 baseline scenario (left) and TV50_b1 (“hazard-insensitive”) scenario (right). Source: Mentese et al. [82].

4.3. Case study 3: TCDSE communication (September–December 2021)

Boundary objects mediated relationships within the ECRWG as well as between the ECRWG and other members of Tomorrow’s Cities Hub. This became clear as we started to disseminate progress on the TCDSE operationalisation and demonstration across the wider Hub membership (100 members by September 2021). During various internal meetings⁵, the ECRWG received multiple and repeated questions about the TCDSE. Collecting, categorising and co-producing answers to these questions generated a convening space for the ECRWG to refine our mutual understanding and shared terminology as well as to smooth our interactions with the rest of the Hub by means of concise communication on the TCDSE. The result of this process was the TCDSE Frequently Asked Questions (FAQs) document.

The FAQs document was co-produced following a bottom-up approach facilitated by two ECRWG members (i.e., a social scientist and an engineer). The process started in September 2021 and concluded with a first version by the end of December. The initial step was for the ECRWG researchers to review minutes and video recordings of internal meetings to identify TCDSE-related questions that were asked by other members of the Hub. These questions were then collated in a shared online document and ECRWG researchers were asked to provide individual short answers (100 words or bullet points) to all or some of the questions, depending on their knowledge. The answers were tracked in ‘reviewing’ mode, which allowed us to trace the diversity of responses according to expertise. As a second step, the two facilitators of this exercise jointly reviewed the document to (1) categorise the questions; and (2) synthesise the multiple responses to each question into a single answer. Multiple possible answers were proposed for questions where a single answer could not be agreed. Finally, the preliminary version of the FAQs document was released to the entire ECRWG for feedback, using the same methodology of online, simultaneous reviewing.

The FAQs document contains 28 questions organised under four categories: (1) purpose of the TCDSE; (2) defining the TCDSE; (3) testing the TCDSE; and (4) using the TCDSE.

⁵ Between August and December, the ECRWG delivered biweekly online progress reporting meetings to the entire Hub community. These meetings were recorded, stored in an online shared platform and made accessible to all members of the Hub for further consultation.

5. The ECRWG interdisciplinary journey

Following the introduction of the phases of our interdisciplinary journey and related boundary objects, this section unpacks the process of creating and managing these boundary objects to shed light on the emergence of interdisciplinary subjects (5.1) and the understanding of interdisciplinarity as a relational process of knowledge production (5.2). The framework presented in Section 2.3 orients the analysis and discussion of the main findings.

5.1. The emergent interdisciplinary subject

This subsection confirms that interdisciplinary research stimulates an emergent process among researchers, including changes in their disciplinary assumptions. This is significant as the legitimacy of knowledge cannot be understood in isolation from the individuals valuing it, that is, from the social fields that determine what constitutes valid knowledge [17,69,85]. Thus, the production of legitimate interdisciplinary knowledge is underpinned by the emergence of interdisciplinary subjects. The analysis of our interdisciplinary journey reveals three interwoven dimensions of this emergent process: (1) internalisation of relations of reciprocal recognition, (2) intersectional identity axes and (3) affective forces.

In the first place, while engaging in the operationalisation, demonstration and communication of the TCDSE we developed relations of reciprocal recognition that cut across our disciplines. Recognition was articulated around an appreciation of the “dedication”,⁶ “effort” and “depth of knowledge” of colleagues working in other disciplines and attending to similar research questions. Consequently, we experienced a growing awareness of the assumptions and analytical deficits of our own discipline. Furthermore, a desire to protect group relationships encouraged openness and willingness to compromise ontological and epistemological commitments. With the thickening of relations and reflexivity, our ability to influence and be influenced by others accentuated. We loosened our sense of superiority over what at first were identified as disciplinary turfs. We experienced a growing openness towards concepts and approaches from other disciplines. This signalled the internalisation of a group identity, with consequences for how we oriented ourselves towards other disciplinary researchers.

The internalisation of relations of reciprocal recognition while producing boundary objects reveals the procedural and embodied nature of our own transformation and how we came to value interdisciplinary knowledge. The interdisciplinary research process involved cycles of interaction between researchers of varying frequencies. The TCDSE conceptual diagram was produced through a series of short cycles of online discussion and synchronous collective writing. Similarly, Tomorrowville was developed during iterative online discussions that contributed to incremental improvements of its various layers. This contrasted with a less frequent, asynchronous and individual writing when elaborating the FAQs document. Varying frequencies and degrees of collective engagement in the production of boundary objects steered the internalisation of a group identity in distinct ways. On the one hand, we felt that our appreciation of the contributions of other disciplines was better when gained through shorter cycles of focused interaction. We also attributed a greater value to boundary objects that were produced in this way. On the other hand, asynchronous work, through online written platforms such as the FAQs document, offered a repository of incremental agreements. This served as a reference point for researchers, like a social norm, tempering our inclination to re-open longstanding discussions. Thus, the act of writing stabilised these agreements, although contingently so.

Secondly, further unpacking of this internalisation process calls for an examination of intersectionality and how our positionality on various identity axes played a key role in this transformation process. A number of identity traits were found to offer sites for both interdisciplinary recognition and alienation. Ontological and epistemological differences, stemming from distinct scientific traditions, represented the main identity boundary that we had to overcome. These differences were expressed, for example, through issues such as preferences towards quantification versus qualification and semantic variations around core terminology. This situation imposed initial obstacles to define shared research objectives and communicate between us. As confirmed by other scholars, this is one of the main challenges to interdisciplinarity in disaster and risk research [18,33].

However, other identity axes offered sites of resonance to bridge across disciplines and build reciprocal recognition [63,86–89]. On the one hand, we connected with others through shared identity traits such as place of origin and cultural references. On the other hand, we self-identified with the research process, highlighting some of the attributes that resonated with our value systems. For example, some engineers defined the research process as “coherent and systematic”, increasing its efficiency. This contrasted with the perceptions of other researchers who saw it as “organic” and “messy”, opening creative research avenues. Members of the ECRWG with prior interdisciplinary experience helped to translate disciplinary differences. This highlights the dispersed and networked nature of interdisciplinary research and how, as a praxis, incrementally and progressively sediments a new identity that allows for mediation between disciplines.

Despite recognition across some of our multiple identity axes, researchers struggled with “compromising” and “negotiating” disciplinary epistemological demands and ontological commitments. Here, a sense of self-efficacy stemming from the ability of the group to accomplish goals helped reducing these contradictions. Specifically, career ambitions of ECRWG members and the ability to conduct impactful research by participating in the group facilitated the process of alignment. In some cases, researchers valued the process as beneficial to produce a more “holistic” perspective when compared to their narrower disciplinary research. In the case of others, it was about enhanced political impact and the possibilities of our collective ability to influence audiences beyond academic circles, spanning policymakers at local, national and global scales.

Finally, we experienced a variety of affects that both signified our coming together as an interdisciplinary group and contributed to

⁶ In Section 5, words or phrases in “ ” represent direct quotes from members of the ECRWG extracted from the individual surveys or focus group discussion.

our inner transformation. Affects were felt as a field of forces that, while not fully determining our behaviour, encouraged an orientation towards the group. Two distinct types of forces are discussed here. On the one hand, a set of affects pushed researchers to transgress the boundaries of their respective disciplines towards a creative endeavour. “Inspiration”, “passion”, “excitement”, “motivation” and “hope” oriented us positively towards an exploration which at times felt beyond our comfort zone. Some of us felt a resonance of the group’s “enthusiasm”, signalling the relational nature of affects. This helped overcoming the initial confusion concerning the objectives of the group and direction of exploration. While felt individually, affects pushed the research in a direction that transcended individual objectives. Indeed, boundary objects produced by the ECRWG could not have been imagined or created by any single discipline.

On the other hand, a set of affects stemming from a sense of security within the group oriented us to sustain our engagement. “Camaraderie” and “lack of hierarchy” among group members were seen to make the work enjoyable and “fun”. Having the skills to respond to the needs of other group members was felt by some as a sense of belonging and safety that motivated the continuation of our engagement. Contrastingly, other researchers felt “anxiety” and “fear” because of tight deadlines and high expectations from the broader membership of the project. In the context of funding cuts, the work of the ECRWG was interpreted as the measure of the funder’s “value for money”. The success of the group was articulated as the single factor with the highest impact on the probability of further continuation of the project. Some of us felt “overwhelmed”, describing the group’s objective as “mission impossible”. Many researchers within the ECRWG sought alternative job arrangements as a way to protect their financial security. With the success of some of them, the group lost some members with consequences for the research trajectory. These findings echo what affective geographies have taught us about the ontological priority of affects in knowledge production [39,90–93].

5.2. Boundary objects: objects of relational mediation

This subsection illustrates how boundary objects mediate relations and foster alignment between disciplinary researchers. Defined by a set of intrinsic characteristics [14,16], boundary objects constrain the expression of contradictions between disciplines and delimit the space of possibilities from where interdisciplinary knowledge emerges.

Modularity and modular interdependence, two intrinsic characteristics of boundary objects, mediated the relations between members of the ECRWG. The TCDSE conceptual diagram consisted of various modules (see Fig. 3, Version #2). While the overarching conceptual diagram was developed through an interdisciplinary process, each of the modules retained a distinct disciplinary orientation. For instance, the multi-hazard modelling module was strongly influenced by physical scientists, while the physical infrastructure impact module was structured around engineering expertise. Disciplinary dominance at module level black-boxed some disciplinary assumptions, leaving them beyond the interdisciplinary deliberation. However, modules were connected through data flows, each module processing the outputs of the preceding ones and adding analytical categories. Thus, the multi-hazard modelling module would simulate natural hazard scenarios at the scale of urban planning that the physical infrastructure impact module would translate into quantifiable impacts on the built environment. These, in turn, would be interpreted through the social impact module as disruptions of socio-economic processes in a given city that affect disaggregated social groups differentially.

Modular interdependence in the TCDSE conceptual diagram exposed interdisciplinary contradictions as data flows and analytical categories had to connect different scientific traditions. Some disciplines were inclined towards (risk) quantification, generalisability and abstraction, while others privileged qualitative information, contextual specificity and attention to social difference. Contrasting ways of understanding the urban were also exposed. Some disciplines saw the urban as a material landscape whose characteristics determined physical vulnerability, including risk of basic service discontinuity. Other disciplines considered the urban as the materialisation of power-laden socio-environmental relations, including labour-capital, gender, ethnic and caste relations. Noteworthy, these contradictions became the site of interdisciplinary emergence.

Modularity of the TCDSE conceptual diagram allowed us to “play” with (e.g., move, change, rename) analytical categories and data flows as a way to find space for our disciplinary contributions. Thus, modularity was linked to another intrinsic characteristic of boundary objects, creative accommodation, which favoured the entanglement of analytical approaches and contingent settlement of contradictions. For instance, the decision of where to locate the originally labelled ‘decision module’ (see Fig. 3, Version #1) underwent various design iterations and rounds of deliberation between researchers with different disciplinary backgrounds. While this might seem trivial, the location of this module in the TCDSE conceptual diagram would have critical implications on how different knowledges and knowledge holders (i.e., expert knowledge from scientists and local knowledge from city stakeholders) could open or foreclose possibilities for risk-informed decision-making in urban policy and planning.

Another illustration of creative accommodation corresponded to the various understandings of the urban and how the expression of contradictions was creatively resolved in the concept of the ‘city of flows’ [94,95]. Framing the city as a space of socio-material flows challenged the analytical priority that is often ascribed to physical assets (e.g., buildings and roads) in engineering-oriented risk quantification approaches. Instead, we turned our attention to how damage to these assets can affect the flows of people, workers and commodities that animate urbanisation processes. Furthermore, a sensitivity towards social difference encouraged us to conceive the disruption of socio-material flows through an intersectional lens of class, gender, age and other forms of social differentiation.

Modularity and accommodation were also intrinsic to the other two boundary objects, namely, Tomorrowville and the FAQs document. Tomorrowville was designed on the basis of a modular geospatial database, accommodating various layers of disciplinary data. The geospatial database then facilitated the interaction between disciplines when combining multiple layers to derive scenarios to identify and reduce disaster risk. However, generating data to the required granularity and quality standards of different disciplines exposed contradictions in the interdisciplinary development of scenarios. Similarly, the organisation of the FAQs document in four core sections and subsequent individual questions allowed for the breakdown of the boundary object into segments to which each disciplinary expertise could contribute. Multiple responses to the same question accommodated various perspectives to address the

same interrogation, exposing interdisciplinary contradictions in the production of the document.

Standardisation, another intrinsic characteristic of boundary objects, was represented in pre-defined format requirements that mediated the relations between members of the ERCWG. The elaboration of the FAQs document provides a clear example of standardisation through the word count limitation (max 500 words) to the answers to each question. By limiting the visibility of disciplinary assumptions, word count requirements bypassed interdisciplinary contradictions that could have been revealed otherwise. Since interdisciplinarity emerges from these contradictory junctures, word counts (and other format requirements) set limits to its occurrence.

A closer examination of the resolution of contradictions reveals how various operations of power permeated the procedural and embodied practices of our everyday interdisciplinary engagements. In the first place, authority derived from academic seniority was deployed in a number of occasions to close discussions and focus the direction of the research. For instance, the ECRWG was asked by senior researchers to produce the FAQs document. The elaboration of this boundary object help consolidating agreements between members of the ECRWG group, while simultaneously “fencing off” questions and critiques from the wider Hub membership. Thus, the FAQs document can be read as a boundary object which purpose was to foreclose discussions rather than opening them up. Ultimately, it was aimed at focusing the energy of the group and increasing its efficiency.

Secondly, our interdisciplinary journey can be divided into two phases, attending to their degree of exploratory openness and creativity. The transition from one phase to the other was marked by operations of power linked to the political economy of research funding. An initial phase, characterised by limited consensus on research objectives and direction, permitted the questioning of disciplinary assumptions more openly. Corresponding to the development of the TCDSE conceptual diagram, this phase was underpinned by flatter power relations and “messy” interactions, and was depicted as “creative”, “exploratory” and “inefficient”. A second research phase ensued, when funder’s demands for delivery tightened up. As a result, the group hierarchy became more structured and research energy became tightly focused, leading to an increase in efficiency and a reduction in creative exploration.

Members of the ECRWG also joined the group at different phases. Some latecomers felt that many questions were foreclosed at the time they integrated the group. When examining the differences between the role played by each of us, one can see that latecomers were mainly involved in the refinement and implementation of earlier conceptual developments, which enshrined a more creative interdisciplinary engagement. The internalisation of agreements between researchers, as discussed in the production of the FAQs document, made early members of the ECRWG group more rigid and less open to discussions as they moved along the research trajectory. This shows the historical dependency of research trajectories and highlights the relational nature of operations of power.

The ECRWG journey confirms that interdisciplinarity is a process of ongoing (re)alignment in the face of contradictions that challenge our positionalities, including disciplinary premises, *in relation to* others and others’ worldviews. The creation and management of boundary objects mediate this process of simultaneously surfacing contradictions and stimulating creativity. Crucially, this mediation role calls for attention to the intrinsic characteristics of boundary objects that circumscribe the expression of interdisciplinary contradictions from where new knowledge emerges. Resolution of contradictions can be spontaneous, but in many cases responds to operations of power.

6. Conclusion and moving forward

In this paper, we aimed to critically reflect on the intricacies of doing interdisciplinary disaster and risk research by proposing core concepts and an analytical framework for an in-depth theorisation of the process. We began by identifying two main research gaps in discussions on interdisciplinarity in disaster and risk studies: (1) a lack of attention to the subject and (2) a prevailing focus on interdisciplinarity as an outcome rather than a process. By drawing on the contributions from feminist scholars on subjectivity and from science and technology studies on boundary objects, we developed an analytical framework that proposes entry points to put interdisciplinarity to work. Specifically, we argue that the emergence of interdisciplinary knowledge is intrinsically entangled with the emergence of interdisciplinary subjects and that boundary objects play a key role in mediating this generative process.

Unpacking the interdisciplinary process through the lens of subjects and boundary objects brings to the fore two important dynamics. In the first place, the mutually constitutive nature between subject-object, synthesised under the notion of embodied and procedural practices. In the production of boundary objects, the subject interpellates themselves and their disciplinary assumptions. Secondly, the intrinsic characteristics of boundary objects explain their mediating role and how they delineate the norms of engagement between disciplinary subjects. Boundary objects constrain the possibilities of interactions and, in so doing, the expression of disciplinary contradictions. Affects and operations of power orient the ways in which subjects resolve these contradictions, although with unexpected results. Ultimately, resolution of contradictions requires transformation of the subject, including the knowledge they considered to be valuable. Both dynamics, simultaneously, account for the emergence of interdisciplinary subjects and knowledge.

Moving forward, there are at least two areas of future investigation that we would like to propose. In the first place, interdisciplinarity in disaster and risk research has tended to focus on individual boundary objects [22]. Our paper emphasises the relevance of considering the production of multiple and diverse boundary objects over time [65,67] and invites us to further explore the extent to which certain boundary objects might be more conducive to interdisciplinarity, at what stages and for what reasons. Secondly, more radical perspectives advocate for the dismantling of disciplinary boundaries under the notion of post-disciplinarity or post-disciplinary forms of science [1,96], and this debate needs to be brought into the research agenda of disaster and risk studies. In this regard, we should ask ourselves: does it make sense to keep structuring disaster and risk research around circumscribed disciplines and professions?

Practising interdisciplinarity will vary depending on the focus of the research (i.e., the specific problem, issue or question being addressed) and context, but we would like to highlight three key processes conducive to interdisciplinarity: (1) the production of

boundary objects nurtures relations of reciprocal recognition and the emergence of interdisciplinary subjects; (2) the intrinsic characteristics of boundary objects define the norms of engagement between disciplinary subjects and constrain the expression of interdisciplinary contradictions; and (3) affects and operations of power explain the contingent settlement of interdisciplinary disagreements and the emergence of new knowledge. The insights derived from our reflections are not intended to deter interdisciplinarity in disaster and risk research; on the contrary, they are aimed at unpacking the complexity of interdisciplinary undertakings to delineate potential pathways to unleash their full potential. We encourage others to join us in this critical exploration and practice of interdisciplinarity for reducing disaster risk in tomorrow's cities.

Credit authorship statement

María Evangelina Filippi: conceptualisation, methodology, analysis, writing – original draft; Alejandro Barcena: conceptualisation, methodology, analysis, writing – original draft; Robert Šakić Trogrlić: conceptualisation, methodology, writing – reviewing and editing; Gemma Cremen: writing – case study; comments and feedback to the original draft; Emin Yahya Mentese: writing – case study; comments and feedback to the original draft; Roberto Gentile: writing – case study; comments and feedback to the original draft.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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