Infrastructuring to support multi-discipline, multi-stakeholder research: Co-designing synergy through a systems lens

Dr Eli Hatleskog
e.hatleskog@arts.ac.uk

Central Saint Martins: University of the Arts London, Granary Building, 1 Granary Square, London N1C 4AA (Previously, University of Bristol)

Funder

"This work was supported by the UK Prevention Research Partnership (award reference: MR/S037586/1), which is funded by the British Heart Foundation, Cancer Research UK, Chief Scientist Office of the Scottish Government Health and Social Care Directorates, Engineering and Physical Sciences Research Council, Economic and Social Research Council, Health and Social Care Research and Development Division (Welsh Government), Medical Research Council, National Institute for Health Research, Natural Environment Research Council, Public Health Agency (Northern Ireland), The Health Foundation and Wellcome."

Declaration of interests

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.

Ethics

Ref: 99963 - University of Bristol Faculty of Engineering Research Ethics Committee (FREC)

Data Access Statement

The data supporting the findings reported in this paper comprises primary interview data and secondary existing data. A redacted and anonymised version of all primary interview data used in this paper will be made available via the University of Bristol Research Data Repository data.bris two years after the completion of the project, Tackling the Root causes Upstream of Unhealthy Urban Development (TRUUD). All secondary existing data used in this paper is openly available at locations cited in the 'References' section of this paper.

Dr Eli Hatleskog, Environmental Science and Policy

Infrastructuring to support multi-discipline, multi-stakeholder research: Co-designing synergy through a systems lens

Abstract

This paper explores how systems informed collaborative design practice can help multi-discipline, multi-stakeholder research to integrate knowledge and think in aligned ways. Whilst there is growing appreciation for the need to do joined-up complex research and move beyond one-way research processes, there is less consensus on how researchers can practically work together to integrate their skills, expertise, and knowledge. Through working closely with an ongoing research consortium, participatory design approaches were developed that can benefit complex research projects, leading towards better collaboration across disciplines sectors and publics.

Learning from interviews with researchers on a large-scale multi-discipline multi-sector consortium, who came from different backgrounds, with varying perspectives and expectations, collaborative design methods were developed to support researchers in taking self-determined steps toward more productive research infrastructures. The consortium aimed to employ systems approaches to help researchers to understand and address complex urban challenges. Taking a starting point in different understandings of systems approaches on the project, the design research was influenced by contemporary approaches to community involvement in the urban planning system.

The activities described in this paper sought to build capacity towards a responsive infrastructure of shared connections, interests, and needs, with the overarching aims of supporting future discussions about dynamics, interactions, alignments, and synergies; and making a process contribution to the improved integration of the consortium.

Keywords: research integration; co-design; equitable collaboration; transdisciplinary research; systems approaches.

Infrastructuring to support multi-discipline, multi-stakeholder research: Co-designing synergy through a systems lens

Highlights

- Develops arenas for cross-disciplinary research collaboration through design infrastructuring
- Frames conversations across a multi-discipline mission-orientated research consortium using participatory design approaches
- Enables readers to take self-determined steps toward more productive research interactions through collaborative design methods
- Builds capacity for a responsive research infrastructure that fosters shared connections, interests, and needs
- Shows how to better integrate the consortium by contributing to the process through co-design activities

1. Introduction

As researchers navigate into evermore complex territories and collaborations, with the aspiration of addressing some of the most pressing challenges faced by society today, it is supposed that diverse research traditions can unite towards shared common goals, or missions (Hadorn et al. 2008). Complex 'real-world' challenges, such as health and well-being and the climate crisis, are embedded culturally, socially, and institutionally and shaped by cultural biases, power dynamics, and inequality (Van Kerkhoff and Lebel 2006). There are entrenched interests and conflicting logics, which place pressure on collaborations (Rayner 2006; Helms, Oliver, and Webb 2012). These forces do not remain external to large scale research projects but can play out across different scales as researchers, stakeholders and other actors learn to work together. Researchers doing collaborative research bring with them expertise and expectations shaped by their disciplines, outlook, and previous interactions. Institutional pressures and knowledge hierarchies can emerge, which privilege some forms of research to the detriment of other ways of knowing and doing. This paper explores how collaborative design practices can help researchers to navigate this complexity and achieve more equitable collaborations.

Readers of this journal engage inherently interdisciplinary fields, requiring effective collaboration across diverse expertise, sectors, and groups. However, conventional research structures often struggle to facilitate meaningful interactions that span disciplinary silos and differing perspectives and expectations. This paper argues that design research, particularly participatory design and infrastructuring, offers an approach that can foster integrative and synergistic collaborations. Design research emphasises iterative, co-creative processes that actively engage diverse actors in shaping research infrastructures. Participatory design methods provide structured yet

adaptive frameworks that allow researchers, policymakers, and practitioners to co-develop shared understandings, identify synergies, and generate actionable insights. This approach is especially critical in mission-oriented, multi-disciplinary research consortia, where the ability to coordinate diverse perspectives can significantly impact the effectiveness of decision-making and implementation. By embedding participatory design principles within research collaborations, we can create more responsive, equitable, and solution-oriented infrastructures that enhance knowledge exchange, policy relevance, and stakeholder engagement. This paper explores how research infrastructuring can be leveraged to cultivate these cross-disciplinary interactions, offering insights into its application for others seeking to navigate complex challenges.

Problem-driven/solution-orientated approaches aim to address complex societal challenges, 'wicked' problems (Rittel and Webber 1973), which are 'open, complex, dynamic and networked' (Dorst 2015, 1). A growing appreciation of the challenges of doing research in complex situations, has resulted in systems approaches being adopted by large-scale research programmes, with the aim of developing joined-up solutions and better understandings of complex societal challenges (Black et al. 2021; EDSI, 2021). One of the benefits of thinking in systems is that a degree of systems knowledge and understanding is latent in everyone. This common potential may help researchers to collaborate, however, given the different expertise, expectations, biases, and dynamics researchers bring to each collaboration, views on the application, capacity and usefulness of systems approaches can misalign to the detriment of productive research interactions.

One domain where systems approaches have gained significant traction is urban research. Cities, as complex and dynamic environments, are prime examples of interconnected systems where multiple actors, infrastructures, and socio-economic

forces interact. Indeed, cities are situations where people live, work, and socialise, which have been likened to living organisms. In ‘Cities for a Small Planet’ (1998) the eminent British architect Sir Richard Rogers considered the unsustainability of linear system mega-cities as opposed to the potential environmental benefits of circular urban systems which reuse, recycle, and metabolise to improve sustainability (Liaros, 2019; Liaros and De Silva, 2022). Today, much urban research takes a systems view, linking research, practice, and high-levels goals, such as the UN Sustainable Development Goals (UN_General_Assembly 2015) This is done in the understanding that the city is a ‘system of systems’ (Worldwatch_Institute 2016, 27) where things interconnect, interact, and there can be both intended and unintended outcomes.

In the UK, there is an expectation of community involvement in the urban planning system (Healey, 1996; Healey, 2006). Moving beyond surveys about, and public exhibitions of near complete designs, some architects and designers have developed collaborative practices which seek to be egalitarian and empowering. These range from the activation of space through community gardening or making, citizen science, asset and value mapping, and strategic networks of small-scale interventions called urban acupuncture, to approaches developed through design for social innovation, such as ‘infrastructuring’(Petrescu, Petcou, and Baibarac 2016; Thorpe, Kaszynska, and Mitchell 2022; Beebeejaun 2016; Hatleskog., 2020; Fredericks, J., et al., 2019; Björgvinsson, Ehn, and Hillgren 2012).

Infrastructuring, as discussed in Section 2.2, refers to the ongoing, participatory process of assembling and maintaining socio-technical and material conditions that enable long-term collaboration and collective action. Rather than viewing infrastructure as a static entity, infrastructuring is concerned with the dynamic and iterative ways in which structures of support, governance, and participation are co-developed over time.

In this sense, it is a crucial methodological approach in design for social innovation, fostering open-ended systems that allow diverse actors to engage with and shape shared urban futures.

Each of these collaborative approaches, including infrastructuring, has evolved to amplify the voices of people who feel marginalised, with the aspiration of achieving more inclusive and fairer cities. These types of design practice support collaboration in complex situations, where there are many powerful actors with different agendas. Design methods can enable disparate actors to navigate complex terrains. Whilst typically employed in real-world contexts, the research described in this paper explores how complex academic collaborations can benefit from participatory design methods. It will discuss how different perspectives and expectations relating to systems approaches amongst researchers on a large-scale research project, fed into feelings of frustration, and how collaborative design methods, including personas and mapping, supported researchers to take self-determined steps toward more productive research interactions.

The co-design activities described in this paper were developed in response to Tackling Root Causes Upstream of Unhealthy Urban Development (TRUUD), a five-year multi-discipline, multi-stakeholder UK research consortium, involving over forty researchers across five different universities and two pilot cities.The consortium had the overarching aim of reducing health inequalities and non-communicable diseases, such as diabetes and obesity, through co-produced, systems-aware interventions in the urban development system (Black et al. 2021). Consortium researchers identified with multiple disciplines. These broadly converged around a core concern of health and included: health economics; public health; environmental health; social science; urban studies; public involvement; and systems. The consortium acknowledged that decision-making in urban development is complex, involving multiple stakeholders and systems.

While decision-making responsibility lies with local authorities in the UK, underlying motivations often stem from distant private sector interests, propelled by political and economic frameworks that prioritise short-term gains and growth driven by consumption. Thus, the consortium's activities were shaped in response to a broader decision-making landscape. It developed a mixed-methods approach, structured into six interconnected work streams, with the aim of multi-action interventions in two urban locations: one focusing on large-scale mixed-use development and the other on transport initiatives. At the heart of the interventions was a desire for collaborative engagement with key stakeholders to produce evidence.

Concurrent with the intervention workstreams, a separate yet interconnected participatory activity of design research was established with the aims of supporting collaborative self-direction of the project and studying approaches to and methods for conducting complex research across multiple disciplines, partners, stakeholders, and publics (Matthews, et al., 2022). This activity was informed by moves in participatory design towards: long-term involvements; the scaffolding and development of new skills and practices; and co-designing mutual scoping, processes and possible directions (Smith and Iversen 2018, 9).

Researchers from different backgrounds and institutions can have different ways of collaborating developed through their previous experiences with different organisational and epistemic contexts (Montuori, 2013). There can be different levels of significance given to collaborative research and the types and timings of interactions with others. These differences can, in turn, lead to misunderstandings and frustration. In response to this, the study explored some of the challenges of complex large scale research collaboration through design. The approach was developed with reference to 'infrastructuring' (Björgvinsson et al., 2010, 2012; Star & Ruhleder, 1996) and sought

to promote empathy and diversity. Infrastructuring is a methodology employed by designers to co-create enabling conditions for collaboration, such as through design for social innovation (Hillgren et al., 2011).

The research described in this paper developed through interactions with the project team of researchers, who initially described the overt systems framing of the project as an inspiring and unifying structure to collaborations. Over time however, scepticism developed in certain quarters as to the application and usefulness of systems to the research. The project benefitted from researchers with expertise in systems approaches, however, at times, those same researchers same felt that others in the project had unrealistic expectations of what was included in their scope of their work. In turn, these expectations were influencing how researchers were communicating. The consortium was managed by a top-down leadership structure that encouraged researchers to collaborate in the traditional way, through joint publications, but that was also open to demonstrations of new approaches. In response to concerns about unrealistic expectations of systems approaches, the design research began by focusing on different perspectives of system approaches across the project, to explore whether these systems lenses could reveal biases, power dynamics and inequalities relating to different research traditions, epistemologies, and expectations, and learn whether design methods could support more empathetic and diverse alignments across the research team.

Following a literature review that situates the need for this study, the methodology section describes design infrastructuring and how the research followed a double diamond structure. The research approach describes the steps of discover, define, develop, and deliver, in relation to the challenges faced, the methods used and their usefulness. The synthesis interprets these materials in the context of broader

research aims, before the conclusion outlines the implications for future research and practice in collaborative design and research.

2. Literature Review

2.1 Types of Research Collaborations

Contingency and uncertainty in science have led to a growing understanding that scientific knowledge is not enough to generate positive change. Knowledge production today transcends traditional disciplinary boundaries (Oxman, 2016). This means that one-way research processes do not typically achieve the required traction needed to bring about change. In response to this, there is increasing pressure for researchers to collaborate across traditional boundaries in order to demonstrate that their research can address critical societal challenges, such as society's health and well-being, and contribute to positive change. There is a need not only to possess a depth and breadth of skills, but also to adapt and integrate new competencies as urban environments and technologies evolve (Foth, 2018). Whilst there are challenges working across disciplines, an enriching friction can emerge in these interactions which underscores the complexity and value of collaborations (Jensenius, 2012). These have resulted in forms of solution-orientated research which involve multiple disciplines and aim to engage with diverse sectors, stakeholders and research users (Nowotny, Scott, and Gibbons 2001; Hadorn et al. 2006). However, researchers navigating unconventional methods must strategically blend traditional and new approaches to gain acceptance and mitigate career risks, highlighting the need for interdisciplinary identity and institutional support (Koppman & Leahey, 2019).

Problem-driven/solution-orientated approaches aim to address complex societal challenges, 'wicked' problems (Rittel and Webber 1973), which are 'open, complex,

dynamic and networked' (Dorst 2015, 1). There are different names for these types of research including: mode 2 research (Gibbons 1994); mission-orientated research (Mazzucato 2018); post-normal science ((Funtowicz and Ravetz 1993; Ravetz 1999); sustainability science (Brandt et al. 2013; Clark and Dickson 2003; Kates et al. 2001; Roux et al. 2017); team science (Stokols et al. 2008); transdisciplinary research (Carew and Wickson 2010; Jahn, Bergmann, and Keil 2012; Klein 2006; Pohl 2010; Walter et al. 2007; Wolf et al. 2013); and Quadruple Helix Innovation, also known as Open Innovation 2.0, which aims to integrate the skills, resources, expertise and interests of government, higher education institutions, industry and publics/citizens (Carayannis and Campbell 2009; Yawson 2009). A key objective of these new approaches is to co-create different forms of knowledge in collaboration with stakeholders and research users (Clark and Dickson 2003; Holling 1993; Holling and Gunderson 2002).

Whilst consensus regarding the theoretical problem-focused framing of problem-driven/solution-orientated approaches is emerging (Cash et al. 2003; Pohl and Hadorn 2007; Jahn, Bergmann, and Keil 2012; Lang et al. 2012), there is less agreement about how these work in practice. As Felt et al. (2016) state 'although there seems to be agreement that these approaches might nurture innovation of a new kind, we know little regarding research practices.' (p. 732) Researchers from different institutions may have different ways of collaborating developed through their experiences in different organisational and epistemic contexts (Lengwiler 2006). There can be different levels of significance given to collaborations and the types and timings of engagements with others (Bieluch et al. 2017). Challenges arise relating to: knowledge integration (Bammer et al. 2020); the time/expertise needed to build relationships and functional research teams (Stokols 2006); equally legitimate, but differing, sources of knowledge and evidence (Lidskog 2008; Collins and Weinel 2011); and contrasting attitudes

towards collaboration, which are shaped by individual cultural contexts and personal experience (Montuori 2013). Academics are not homogenous groups who have shared understandings and ways of communicating. However, in many discussions, disciplines are still treated uncritically as monolithic constructs (Klein 2008).

Disciplinary norms and silos can create barriers to collaboration. One advantage design-driven research has in complex multi-disciplinary multi-sector environments is that a design approach, 'does not describe a single set of ideas about research. Its meaning varies with discipline, location and person and it varies with the questions that are investigated.' (Rust, Mottram, and Till 2007, 10) With an emphasis on process, 'The claim […] is not one of attainment, but rather of a work in progress' (Fry 2011, 20). The knowledge developed through participatory design methods, seeks to explore relationships across a broad field. It relates to a practical understanding of connections and relationships.

With awareness that diverse expertise is needed to tackle complex challenges, the role of communication tools to bridge gaps, clarify research questions and system boundaries, and expose underlying assumptions, has been recognised alongside the need for philosophical tools and toolboxes to explore differences in scientific values and assumptions (Winowiecki et al. 2011). Within these toolboxes there is scope for a range of approaches, conceptual models can act as communication tools to bridge gaps, clarifying research questions and expose underlying assumptions, thus aiding decision-making (Heemskerk, Wilson and Pavao-Zuckerman 2003). Mapping methods, such as mind mapping for stakeholder analysis or transect mapping for understanding the physical experience of flooding (Hemström et al. 2021) can prove useful, as can constellation analysis which visualises and assesses complex relationships between elements within a social-ecological system enhancing project outcomes in complex

inter- and transdisciplinary research settings (Schafer and Kroger 2016). Indeed, there is growing recognition that transdisciplinary research toolkits can help communities and researchers to address global challenges by providing accessible, adaptable methods and tools for collaborative knowledge creation (Studer and Pohl 2023). Indeed, Schnapp et al. 2012) explored the tacit nature of expertise (Rust, 2004) and the ways in which it manifests in different communities through a toolbox dialogue method which built mutual understanding by enabling structured dialogue. The Integrated Research Toolkit (Landcare Research 2021) includes tools as resources as part of their curated kit which includes timeline and influence and interest mapping. The MSP Tool Guide (Brouwer and Brouwers 2017) offers 60 tools for facilitating effective multi-stakeholder partnerships in sustainable development, covering all aspects from initiation to commitment. Of these, Net-Map is a tool that allows users to be more strategic about how they act in these complex situations; It combines social network analysis with power mapping, utilising a participatory approach where both interviewees and interviewers collaboratively draw a network map of the actors involved in a policy arena (Net-Map 2007). The series 'Toolkits for Transdisciplinarity,' (Bammer 2017) serves as a resource of methods and approaches including: co-production, policy engagement, dialogue methods, change management, research integration, systems thinking, and integration methods. It includes how-to guides for understanding dynamic systems, such as matrixes to map stakeholders and the 'Wheel of Multiple Perspectives' tool, to map different perceptions of reality within a team. The Shape ID toolkit (2021) aims to enhance interdisciplinary and transdisciplinary research by improving integration and providing guidance to foster better decisions in policymaking, funding, and education. The td-net toolbox (2018), developed by the Swiss Academies of Arts and Sciences Research, is a collection of methods tools for various aspects of

knowledge co-production, including soft systems and design approaches. It aims to bridge different thought styles with low-tech, everyday language methods to develop shared understandings and facilitate knowledge exchange. Further to this, Sturder and Paulsen (2023) discuss 'ideal' applications of the td-net toolkit and need for researchers to share their experiences to develop greater understanding of the toolkit in practice.

In response to this interest in toolkits of practical methods and approaches, this study developed an approach that learns from urban design and community mapping practices. The practice-based approach is situated, emergent and relational. The stages of the design process can be adapted to different contexts and concerns. It understands maps to be inherently political (Harley 2011), a form of navigating or wayfinding (Ingold 2016), with the ability to solve relational problems (Kitchin and Dodge 2007). In this sense, mapping makes space for exploration and interactions which reveal both visible and invisible conditions and surface hidden potential (Corner 1999).

2.2 Infrastructuring as a Methodology

Multi-discipline, multi-stakeholder research can face challenges relating to developing capacity to integrate knowledge and think in complex and interlinked ways (Godemann 2008). Collaborations require an ability to locate and work with pertinent information, compare and contrast different methods and approaches, and clarify how differences and similarities relate to a designated task (Klein 2008). As such, it can be useful to learn more about the diversity of the participants' perspectives and exploring and clarifying their differences, so that dialogue and collaborative integration can take place within a group or a team (Hadorn et al. 2008). An infrastructuring approach can help to build capacity towards integration and thinking in complex ways through making connections and responding to shared needs and interests as they arise. Infrastructuring,

which is a participatory design methodology (Star and Ruhleder 1996; Björgvinsson, Ehn, and Hillgren 2012, 2010), seeks to co-create enabling conditions for collaboration. It is a process-based approach typically developed in response to marginalised communities. It legitimises, organises and amplifies diverse viewpoints (Björgvinsson, Ehn, and Hillgren 2012, 143). It can be described as a matchmaking process which takes place within an open-ended design structure without predefined goals or fixed timelines. It aims to 'intentionally enable adoption and appropriation beyond the initial scope of the design, a process that might include participants not present during the initial design' (Dantec and DiSalvo 2013, 247) making it potentially useful to multi-discipline, multi-stakeholder research partnerships where new researchers join at different points over the lifetime of a project.

Infrastructuring is broadly understood as an ongoing, evolving process that supports long-term engagement and stakeholder collaboration across various domains. Karasti (2014) emphasises its unfinished nature, highlighting the need for sustained co-creation and a sociotechnical perspective that integrates both technical and social dimensions. Pipek and Wulf (2009) extend this view to organisational IT, framing it as a dynamic work infrastructure that requires continuous adaptation, methodological integration, and stakeholder-driven improvements. Seravalli (2018) relates infrastructuring to urban commons, describing it as an iterative process of exploring, solidifying, and reconfiguring collaborative arrangements while ensuring adaptability, accountability, institutional alignment, and governance. Frauenberger et al. (2018) call for leaving behind repertoires for the future in participatory design, emphasising the need to create lasting resources, practices, and infrastructures that enable future adaptation and growth. This approach ensures that participatory efforts extend beyond

their immediate context, fostering sustainability, ongoing engagement, and the evolution of design outcomes over time.

Key aims of an infrastructuring approach are to:

- Build arenas of heterogeneous participants
- Maintain network constellations
- Leave behind repertoires for the future

  (Björgvinsson, Ehn, and Hillgren 2012, 2010)

3. Research Approach

The following section of this paper describes the co-design process of infrastructuring that took place over the spring and summer of 2022. It follows the UK Design Council's Double Diamond, a 'universally accepted depiction of the design process.' (Design Council, 2005) The Double Diamond is divided into four distinct phases: Discover, Define, Develop, and Deliver. It supports an iterative process of exploration, consolidation, ideation, and implementation, which can be the basis for addressing complex challenges within design contexts. In respect to this paper the diamonds were applied as follows:

Discover: Interviews and Conversations

The discovery phase involved conducting 44 semi-structured interviews with the research team, uncovering common challenges such as the clarity of the project mission and effective collaboration methods. This stage revealed the team's ambitions, priorities, and expertise.

Define: Research Personas

Utilising the data from interviews, the define phase saw the development of eight research personas, which embodied different systems perspectives within the project. This stage concentrated on building empathy and understanding diversity, aiding in locating the primary issues researchers encountered.

Develop: Empathy Mapping

In the development phase, empathy mapping was used to explore the personas' perspectives, thoughts, emotions, and actions. This approach enabled a deeper understanding of different perspectives, accentuating the necessity for integrated approaches.

Deliver: Collaborative System Mapping – A Shared Perspective

The delivery phase saw the team co-design a system map to represent the complex research terrain they were navigating. This activity worked towards a common perspective to inform action and decision-making by visualising and combining their perspectives on the system and showing where research might have most influence.

4. Analysis

4.1 Discover: Interviews and conversations

A key challenge for the discovery phase was to gain a deep understanding of ambitions, assets, priorities, and expertise across individuals in the research consortium. This phase sought to uncover common challenges, such as individual relationships to the project mission, decision-making processes, time management, biases, and assumptions.

To address this, 44 semi-structured interviews were conducted with the research team. These took place over two rounds which were spaced a year and a half apart. Anonymised transcripts of interviews formed the basis of five online collaborative analysis and sense-making workshops. These revealed common challenges. Across the two rounds of interviews, there was a degree of consistency whereby concerns relating to: the clarity of the project mission; decision making; time management; the assumptions of others; bias; and how to collaborate, remained common. Over time, however, there was a change in how systems approaches were discussed. Initially systems were cited as a unifying concept and the reason some researchers signed up to join the project. However, by the second round of interviews, questions were being raised about different understandings, and expectations, of systems approaches. This shift provided an opportunity to explore the perceived role(s) of systems in the project, as a lens through which to consider different attitudes and expectations.

Targeted conversations were arranged with members of the research team who had different positions on systems: neutral, ambivalent, positive, and sceptical. They took place online and explored how systems had been used by the research team to date and their hopes for the future. These, in turn, fed into the development of research personas and subsequent group empathy mapping, to help define key issues faced by researchers, explore different understandings of the usefulness of systems approaches, and co-produce innovations that could benefit research collaborations.

The approach taken to the discovery phase helped to gain understanding through interviews and subsequent conversations. However, it was time and resource intensive. The two rounds of interviews allowed identification of consistent challenges as well as shifts in thinking, particularly in regard to systems approaches. The collaborative nature of the analysis allowed the group to identify and discuss issues leading potentially to

more cohesive team dynamics. However, at the collaborative events and during the interviews, it should be noted that some early career researchers kept quiet or deferred to their line managers/professors' opinions. This led to challenges in maintaining balance, with some voices being louder and stronger than others.

4.2 Define: Research personas – understanding diversity and empathy building

Following concerns that early-stage researchers did not engage as openly as more experienced researchers during the discovery phase, the define stage began with informal conversations with early-stage researchers in the consortium. These revealed a belief that there was a general lack of empathy across the consortium, exemplified by entrenched views and loud strong voices. There was a fear of speaking up due, in part, to a perceived lack of openness to alternate perspectives. The early-stage researchers asked for something to help bring empathy and more respectful interactions to the consortium, which could in turn build confidence.

In response to this, eight research 'personas' were created, who typified different perspectives on one contested issue: the role of systems in the project. In design research, personas are used to help empathise with the motivations, needs and expectations of the people we are designing for. Personas are, 'fictious, specific, concrete representations of target users' (Pruitt and Grudin 2003, 11). They are a method used to drive people-centred design processes, which can challenge long held, and often incorrect, assumptions (Miaskiewicz and Kozar 2011). A persona is a fictional person who represents a body of people with similar characteristics. The persona is given a name, likeness and story, which brings them to life (Cooper 1999). The persona method aims to promote empathy (Nielsen 2019). For the purposes of this research, personas were employed as a method to develop more empathetic

conversations amongst the research team, which could support them to focus and prioritise discussions around the issue of systems approaches on the project.

Each persona was given a name, photo portrait, disciplinary background and role in the project. The personas then described, in the first person, their: incentive for getting involved in the project; background; view of collaboration; frustrations with collaboration; successes of systems; challenges of systems; and mission. The group of personas included researchers, activity leaders, and champions from: public health; interdisciplinary research; health economics; mixed health focus; urban related research; public engagement; and engineering disciplines. They were representative of the spectrum of research experience on the project. By editing and combining data into personas these rich and nuanced views were in an accessible format made available for collective analysis, which followed ethics protocol, and could be shared and discussed openly.

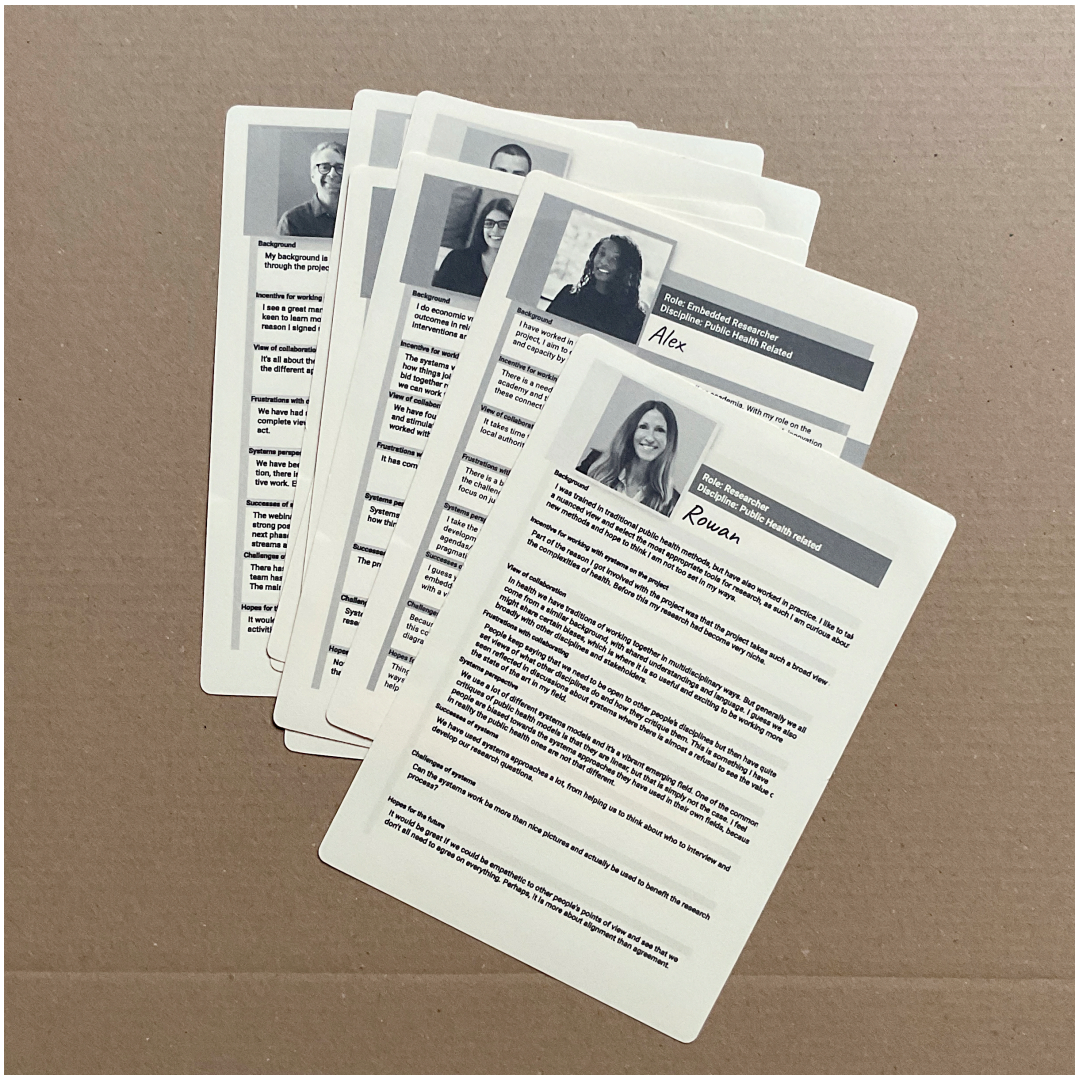

Figure 1, Research personas

The research personas (Fig 1) provided an overview of different perspectives on the project. They revealed that the overt systems framing of the research project had been a reason for some members wanting to join the team. A systems approach acted as an incentive as: it supported a broad view of the complexities of health; it facilitated new ways of seeing things; it provided opportunities to explore systems parallels in relation to other forms of research; it was a novel methodological addition to some disciplines; and it had the power to locate and combine the different strands of work. (Table 1).

Part of the reason I got involved with the project was that the project takes such a broad view of the complexities of health. Before this my research had become very niche – Rowan

The conversations I had with the systems people when we were putting the bid together really opened my eyes to looking at thing in new ways – Nitya
I see a great many parallels between the systems approach and my own research. I am very keen to learn more through collaborating with the systems team and others. It was part of the reason I signed up for the project – Kiran
I got involved with the project because I felt that the systems approach of the project was full of potential and hadn't really been explored in my field before – Dana
I can see the value of knowing who is where in the system. It can provide a spine to all of the Different strands of work – Jaimie

Table 1 – Persona Highlights, systems as a perceived incentive to collaboration.

The personas also began to reveal some of the different disciplinary perspectives of the value of systems approaches. Broadly speaking, the expertise, interests and skills researchers brought to the consortium coloured the advantages they saw to adopting a systems approach. As such, researchers developing an economic model of health impacts in the built environment appreciated how systems could help them to know how things were linked and where they could affect change. Researchers with interdisciplinary expertise, saw value in the process of making connections through non-static, responsive, systems maps. And, researchers with an interest in public engagement saw systems approaches as being able to provide tools to help them to better know their publics. There was also an awareness of the breadth of systems approaches, critiques of linear models, reflections on systems thinking versus system mapping, and an awareness that the urban development system is not necessarily based on valuing things like health (Table 2).

Systems are absolutely essential in this type of work. We need to have a better appreciation of how things are linked and where we can affect change. (Nitya – Health Economics)
I don't really see great value in static systems maps, mainly because these are simple snapshots of a moment in time or perspective, the system we are working with is not static. (Mischa – Interdisciplinary scholar)
We need a systems map of the planning system, which can be explained to everybody, so we all know the system we working with and who sits where. Jaimie- Public Engagement
We use a lot of different systems models and it's a vibrant emerging field. One of the common critiques of public health models is that they are linear, but that is simply not the case. (Rowan - Public Health)
We have been using systems mappings, rather than systems thinking. Everything is a negotiation, there is no pure systems work on the project in the same way as there is no pure qualitative work. (Kiran – Qualitative with a health focus)
The function of the urban development system is, essentially, to make money, not to be altruistic. (Laura - Urban Planning)

Table 2 – Persona Highlights, disciplinary perspectives on systems.

Overly complex systems diagrams were critiqued for being confusing and illegible,

simply highlighting that things were, indeed, complex. In response to this, the research personas revealed suggestions for how systems approaches could help them to collaboratively find ways through the complex research terrain. The personas were keen for: images that could be useful to the research process; greater openness and transparency across the project; systems approaches that could support improved integration; shared methods; dynamic and integrated ways to make connections across academic, public and private sectors; tools to help researchers know when and where to act and make decisions; and systems diagrams that were nuanced but legible, which could help them to navigate pathways through their research (Table 3).

How can systems approaches help us to navigate complex research collaborations?
Can the systems work be more than nice pictures and actually be used to benefit the research process? (Rowan)
I would like there to be greater openness and transparency across the different work streams, so that we don't miss the key issues and potential solutions. (Mischa)
It would be great if systems mappings could support not only further integration across activities, but also collaboration and integration in our teams. (Kiran)
systems thinking could be key to unlocking the project and our collaborations. We need an agreed method/approach. (Dana)
There is a need for us to make better connections between the research going on in the academy and the private and public sectors. Systems approaches can support us to develop these connections in a dynamic and integrated way. (Laura)
We need tools to make it easier for us to communicate and make decisions. We need systems diagrams that are easily understandable across disciplines and publics, however these need to take into account nuance and be sure to be representative. (Jaime)

Table 3 – Persona Highlights, how can systems approaches help us to navigate complex research collaborations?

The development of research personas provided a tool for to share information gathered through interviews, workshops and research conversations in an accessible format. They were the first step towards addressing an initial challenge of early-stage researchers feeling hesitant to engage, due to a perceived lack of openness. The personas represented a broad spectrum of disciplinary backgrounds, with the aim of encouraging open dialogue. However, the success of the method relied upon buy in from across the consortium. If they were seen to be irrelevant or trivial, then they would not result in greater empathy and openness.

4.3 Develop: Empathy mapping

The primary challenge addressed by the research personas related to communication and collaboration within the research team, specifically miscommunication and a lack of empathy for differing viewpoints within the consortium. This challenge was explored in more depth through empathy mapping, which supported collective reflection upon learning from the research personas and the development of practical steps towards improvement.

The research personas were sense-checked by sharing them with the entire consortium, some of whom took park in a co-analysis and ideation workshop, which employed group empathy mapping and scenario building to reflect on what the research personas 'do, think, feel, and want' to develop collaborative activities in response to the perspectives and challenges raised by the research personas.

Empathy mapping is a design thinking method. It is a way of developing insight into personas through reflecting on their perspectives, thoughts, emotions, and actions. Empathy mapping was initially conceived as a way of overcoming miscommunication and misunderstandings about the target audiences, or users, of design processes. It can also be used to reveal gaps in knowledge which are worth further study. An empathy map has four quadrants representing what the persona/user: says, thinks, does, and feels. Participants are asked to populate these with sticky notes. The approach provides lenses through which to reflect on the complexity and nuance of different people/personas and to collaboratively discuss the thoughts and feelings of others, with a view to designing inclusive responses.

The research personas formed the basis of an in-person group empathy mapping activity, as those present were asked to consider what each persona: does; thinks; feels; and wants. Each participant was given sticky notes and pens and to add notes directly to

a central sheet of paper which had a persona stuck to it. Putting the persona in the centre of the table allowed a group conversation to take place at the same time as notes were added to the sheet. This co-analysis activity generated comments and reflections about how some of the research personas were feeling defensive, disappointed, frustrated, and undervalued. The activity allowed the group to discuss these concerns, which had also been raised during the interviews, in a neutral way.

Figure 2, Group empathy mapping

The group empathy mapping showed a common interest in how to practically do research, how to interact with others to evolve and learn, with a focus on results. The activity revealed: consensus on the perceived value of systems approaches; frustrations exacerbated by a lack of certainty and trust; willingness to compromise and work together towards common outcomes; and desires for systems approaches to support more joined-up approaches and help the researchers to navigate complexity (Table 4).

Thinks
Consensus around the perceived value of systems to the project, but a sense that systems approaches were being underutilised
Feels
Frustrations relating to: perceived bias; theorists; value judgements; uncertainty; and a lack of common understanding. As well as feelings of hope, confidence, and openness to new ideas and collaboration in the future.
Does
Individuals learning how to do research together through making compromises towards a common mission. Application of methods and writing of publications facilitating steps towards outputs and outcomes.
Wants
More acceptance of systems; reasonable expectations of systems; a more holistic and open approach; for systems to reach full potential; to be more confident with systems; discussions/ clarification on mapping and thinking; and, to have a better view of the system and systems methods.

Table 4 – Empathy mapping, what the research personas think, feel, do, and want.

One point of interest raised through the empathy mapping relates to 'missing' personas: *Who was missing?* Through discussion it became clear that there was a 'missing' theorist persona, who was putting pressure on how the other personas were thinking. Whether this persona represented individual ambitions or external forces, such as institutional or disciplinary pressures is worth further investigation. The issue of leadership was also raised through a missing leader persona, this links to expectations of others, feelings of powerlessness, and the group desire for a complete view of the system.

Empathy mapping addressed the challenge of communication and collaboration within the consortium, faced with a lack of empathy for differing viewpoints. The team participating in the activity gained deeper insights into different perspectives, thoughts, emotions, and actions, fostering a more empathetic and inclusive environment. The

outcomes from the group empathy mapping included: a consensus on the value of systems approaches; acknowledgement of frustrations due to uncertainty and trust issues; a readiness to compromise; and a desire for more cohesive strategies. In response to this, five proposed steps towards a co-developed infrastructure for research collaborations were made:

- To collaboratively design a view of the system they hoped to influence.
- To integrate knowledge, think in a complex and interlinked manner.
- To make space for emergence.
- To achieve closer alignment.
- And, to move towards real world impact.

Whilst each of these was of interest to the group, researchers were keen to start making a complete systems view, immediately. The aim of designing a map to help them make decisions and act, resonated, and a small working team began collaborating on the subject.

Empathy mapping offered a structured yet adaptable way to navigate and improve interpersonal dynamics within the team. However, there was limited uptake across the broader consortium of researchers and managers. This led to questions amongst the participating group, based in one of the pilot cities, as to whether this work was representative of intentions across the whole project and a desire to zoom in to their specific city scale, in the hope that the demonstration of a local infrastructure of successful collaborations could influence or inspire the broader consortium structure and hierarchy.

4.4 Deliver: Collaborative system mapping – a shared perspective

With a focus on one pilot city, the team collaborating, comprised largely of early and mid -stage researchers, proposed that the key issue they faced was a lack of a comprehensive and clear understanding of the local urban planning and development system that they hoped to impact through research interventions. This challenge was compounded by an abundance of pre-existing diagrams which they felt did not capture the full range and nuance of the specific context. To address this, a collaborative mapping effort was initiated by the group, with a focus on visualising the system in a way that was accessible enough to enable future engagement and strategy making. The map aimed to identify key interactions, gaps, and potential intervention areas and research impact.

Multi-discipline, multi-stakeholder research requires a holistic understanding of pertinent information, methods and approaches and the problems being addressed (Klein 2008). Through the research personas and empathy mapping it was apparent that the research team were struggling to gain a joined-up view of the complex research terrain that they were hoping to intervene in. They discussed the need to collaboratively design a view of the system, which was representative of the evidence they had gathered to date. This view of the system could help them to know where to act. It was proposed to make a map which was abstract/complex enough to be useful, and in a visual language that was accessible across disciplines, sectors, and publics.

The process of collaborative mapping was facilitated by the author, a researcher with expertise in participatory design methods and the mapping of intangible assets and values (Hatleskog, 2020). The activity started with the intention of exploring potential arenas of capacity building and knowledge exchange, visualising and encouraging conversations across the research project field, and to provide a tool to help participants

to locate themselves and navigate towards their desired outputs and outcomes. It sought to make the hidden system visible and make space for strategies and interventions.

The mapping was developed through a series of three workshops with the small working group who had expressed a need for, and interest in, mapping the system, or research terrain. There had been some resistance across the larger research project, to generating a full system mapping, this was, in part, due to the complexity of the system and the pre-existence of other diagrams and mappings of the UK's urban planning and development system. In response to this, the working group was clear that they wanted to map the specific terrain relating to their research interactions not the whole urban development system.

The first action towards the mapping was gathering a database of existing diagrams and mappings of the urban planning and development system to see if any of these were sufficient. The first workshop session provided an opportunity to gather and discuss these existing mappings, before collaboratively refining the purpose and scope of the mapping activities. The existing system maps, sourced and discussed by the group, focused largely on the planning system, rather than including stages pre and post planning, or were felt to be too abstract to help researchers visualise where their expertise and evidence could engage meaningfully. However, they did help the working group to develop a framing of the scope of the mapping, which was to include: planning policy; local plan; regeneration framework; planning applications; and post planning. They were keen to map pathways along this framework, as well as potential missed connections and interdependencies, with the aim of revealing where and how their research activities might have the most impact. This required a view that was specific, situated and provided local context. As such, the working group decided to focus the mapping onto one pilot city, Bristol.

The mapping activity began with the framing the group had developed through studying existing mappings. A long sheet of paper was rolled out across two tables and dotted lines drawn to mark the divides between: national planning policy; Bristol's Local Plan; Froome Gateway Regeneration Framework; Planning Applications; and Post Planning. The working group was encouraged to tell their narratives and describe pathways through the system they had experienced in their research to date. Content was added as people spoke as sticky notes were placed onto the paper which described: process, stakeholders, dutyholders, decisionmakers, influence, evidence, and activities.

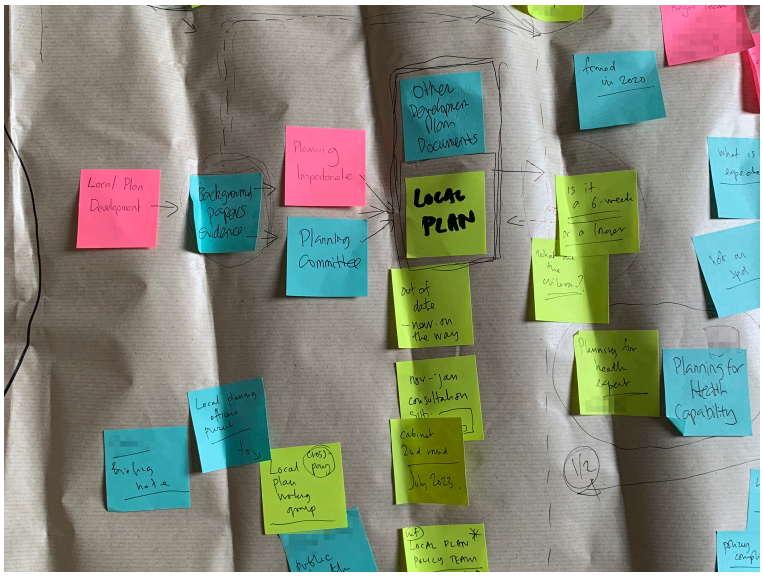

Figure 3, Close-up view of the paper mapping activity.

The activity took a responsive structure, without too many rules, which aimed to get as much as possible onto one sheet of paper. As the team described their perspectives of the system, they decided to colour code sticky notes and discuss potentials and interdependencies across the mapping. Following the workshop, the paper mapping was digitised and placed onto an online collaborative whiteboard. This was shared with participants and discussed with others, who had expressed an interest in the mapping, who added their perspectives through workshopped discussions and

individual conversations. These iterating activities refined and developed the content of the mapping. The result was a busy board full of data in the form of virtual sticky notes, clusters, lines, and connectors, that had been collaboratively discussed and sense checked.

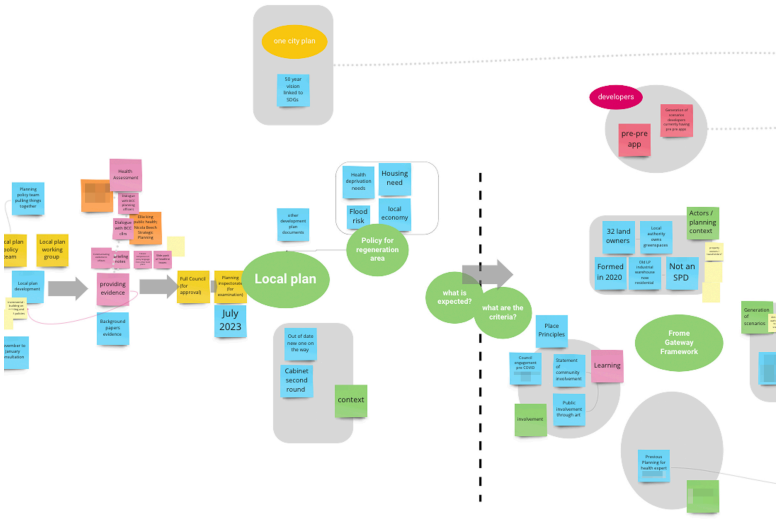

Figure 4, Close-up view of the digitised mapping content.

Once there was broad agreement regarding what was to be included, the content was studied with the intention of designing a visual that was fully representative of the data. One that could support future discussions about: power structures and intentions; how researchers interact and influence; ways through the local system as well; as potential alignments and synergies.

The colour coding of sticky notes which evolved through the workshop revealed that there was perceived significance to representing- public, research, government, and industry, each as distinct colour classifications or streams. This links with a quadruple helix approach to innovation (Carayannis and Campbell 2009). The framing, colours and co-produced map content formed the basis of a design exercise to visualise the research terrain with greater clarity. Through discussions with the working group, the

structure provided by government policy seen as was central. As such, this became the spine of the mapping, which the other streams, or layers, interacted with.

The core structure provided by government policy and actors was represented in blue and placed centrally to the system interactions, as a spine to the mapping. This spine linked planning policy to the city's local plan through the evidence provided at a national scale. The local plan then fed directly into the planning and development of a local regeneration framework, which in turn linked to planning pre-applications, applications and decisions before ending post planning in conditions and building regulations. The prominence given by the working group to the structure provided by the urban planning and development system, suggested that they felt influencing decisionmakers was critical to achieving real world impact, as opposed to disruptive citizen- or industry-led actions, such as activism or developing innovation beyond regulations.

To the right of the blue governmental policy and planning spine, the interactions private developers had with the planning system were mapped in yellow. These focused formally on the planning stages, with less structured interactions and influence at earlier stages of policy and planning, the specifics of which were unclear to the working group. The mapping revealed scope to explore this gap in knowledge further through including perspectives of industry, something which other researchers on the project, who were not involved with the mapping, had investigated through expert interviews. This revealed an internal lack of interaction and communication between the different research workstreams and the opportunity for inclusion of other project researchers and also external stakeholders in the mapping process.

Public involvement in the city's urban planning and development system was mapped to the very left of the central spine in pink. It comprised of specific moments of

consultation, engagement, involvement, and communication. It was largely linked to gaining public input to support design and decision making. The public stream was furthest away from industry on the mapping, with connections between the two only happening formally at planning through 'Statements of Community Involvement'. This revealed opportunities for researchers to reflect on how their activities could bridge interactions between the public and industry.

The 'research' stream, mapped in green, lay between public interactions and the central policy and planning spine. It showed moments where evidence could interact with the planning and development system as well as where research could combine with and galvanise public interactions with the system.

The mapping was shared with the working group for comment before being shared with the research project at a consortium meeting, where it was printed out at a large scale, two meters long, for discussion and feedback. The next stage of the mapping process, beyond the remit of this study, would be to open it up to discussions with other researchers, public, governmental, and industry actors to gain fuller understanding not whether it is representative of the system as they perceive it before further refinement and iterations. This could support a process contribution towards better collaboration and more productive exchange across silos.

The mapping sought to visualise where interactions happened in relation to the urban planning and development system in Bristol. It highlighted key moments, gaps, and where evidence, or evaluation, might have most impact. From the mapping activities, the value of linking research and public interactions in relation to the urban planning and development system was revealed as an opportunity and lack of connections to industry was revealed as a gap. By developing a joined-up map of the city's urban planning and development system, researchers could see where they were

opportunities to influence and improve the system as well as observing what parts were underrepresented by the research group. None of whom, for example, had experience of national planning policy this was a gap for future collaborative activities with the broader research team, who had significant expertise and knowledge of policy, but who had chosen not to input to the mapping, revealing certain divides and dynamics across the research workstreams.

A collaborative mapping process helped the team to gain a comprehensive view of the research landscape they intended to influence. By engaging in the process, they were able to generate a representation of the system that was reflective of the evidence they had gathered, making it more accessible and navigable. The workshop structure was responsive to the researchers' understandings of the local urban development system. Different streams of interaction within the system (public, research, government, and industry) were colour coded, allowing for a more nuanced discussion about structures, influences, and potential alignments and synergies. The process revealed opportunities to link research more effectively to existing public engagement initiatives and provided a shared reference for collective action, which could adapt with ongoing engagement, refinement, and adaptation. It provided a joined-up view of the research terrain but also laid the groundwork for a more inclusive, responsive, and effective collaboration among diverse stakeholders.

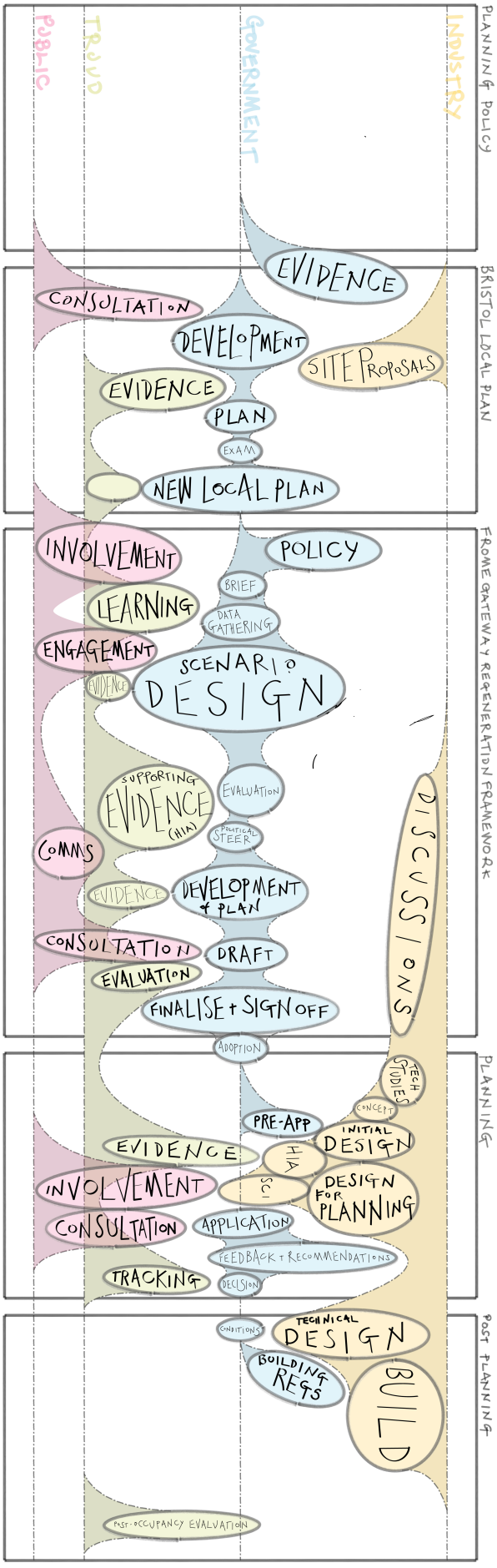

Figure 5, Mapping

5. Synthesis

The research described in this paper developed in response to a diverse group of researchers who were united around the common project mission of reducing urban health inequality. Whilst the research group agreed broadly on the project mission, the breadth of disciplines and interests represented by the group led to different levels of significance being given to collaborative research, the types and timings of interactions, and different ways of collaborating developed through experiences with different organisational and epistemic contexts. These resulted in frustrations related to perceived: assumptions, bias, and lack of decision making. Rather than expect this heterogeneous group to converge around a core mission, the design research sought to develop arenas where different attitudes to and expectations of collaboration could be explored, with a view to infrastructuring an approach which could accept and amplify these different perspectives and make connections to support better future research interactions and collaborations.

The approach evolved in response to some emerging tensions relating to overly optimistic expectations of what other parts of the consortium could practically achieve. The issue of projecting expectations onto others reflected dynamics which applied at different scales and instances across the project. Consequently, systems approaches, consortium leadership, and also this design research, were each faced with assumptions and frustrations from the research team. This suggests that the consortium could have benefitted from clearer discussions about the expectations and scope of the individual work streams at an early stage.

The development of research personas provided a tool to share information gathered through interviews, workshops and research conversations in an accessible format, which introduced different perspectives and supported group empathy building.

By collaboratively mapping a complete view of the research system, steps were taken towards a co-developed infrastructure for research collaborations. This infrastructure built on the skills, needs, and experiences of the group, such as that of systems engineers, and responded to frustrations voiced by researchers, in a way that could support future negotiations, alignment and integration.

The co-design activities sought to identify some of the challenges faced by researchers collaborating across disciplines and provide practical examples of how research integration can be facilitated through participatory design methods. By supporting conversations about different understandings of systems approaches in complex research projects, the study sought to responsively co-develop enabling conditions for research collaboration. The approach was process based and aimed to legitimise, organise, and amplify diversity. The process highlighted challenges relating to the integration of knowledge and understanding on large scale research projects. Through reflecting on difference, researchers in the working group were able to develop greater empathy for other participants' perspectives. This led to a group-initiated mapping process which helped participants reflect upon their research activities relationally, with the aspiration of developing greater agency through seeing a joined up view of structures, alignments and opportunities. The resultant mapping visualised the research terrain, including potential moments of influence, however it also revealed internal gaps in coordination and exchange across the consortium. In particular, a divide between early-stage researchers, some of whom lacked a willingness to speak up in formal research spaces, and more established researchers and project managers, who did not join the co-design activities.

The co-design process emerged from specific needs expressed in particular by early-stage researchers and evolved in response to their inputs. However, disciplinary

norms, institutional and time pressures, alongside established knowledge hierarchies, may have hindered the process, as there was not capacity or willingness across the entire consortium to engage with a slow, soft, emergent process. As such the bottom-up co-design process did not link succinctly with the top-down management of the project. There is often a leap to be made to communicate effectively across the top-down and the bottom-up in both the 'real world' and academia. This is where infrastructuring can play a vital role in scaffolding together small-scale actions, initiatives, and ideas, into productive structures that make space for confidence to grow and synergies to evolve. This study took some first steps towards a co-developed infrastructure for research collaborations. The process, which can be replicated elsewhere, demonstrates an approach and set of methods to build on the skills, needs, and experiences of a group, and respond to frustrations, in a generative way that can support future negotiations, alignment and integration.

6. Conclusions

This paper explored how participatory design approaches could benefit complex research projects, which strive towards collaboration across disciplines sectors and publics. The activities aimed to support equitable interactions which could benefit a multi-discipline multi-stakeholder consortium. Taking a starting point in different understandings of systems approaches, co-design activities were influenced by contemporary approaches to community involvement in the urban planning system.

The activities described in this paper demonstrate how participatory design and infrastructuring can serve as powerful integration tools. By applying these methodologies to a mission-oriented, multi-stakeholder consortium, this paper illustrates how research infrastructures can be intentionally designed to support more

equitable, inclusive, and synergistic interactions. Findings suggest that participatory design offers a practical pathway for addressing the persistent challenges of siloed expertise and fragmented communication. The application of infrastructuring in this context helps to create spaces where researchers, policymakers, and practitioners can co-construct shared problem framings, align on research priorities, and develop more adaptive, solution-focused strategies

Whilst there is growing appreciation for the need to do joined-up complex research and move beyond one-way research process is, there is less consensus on how researchers can practically work together to integrate their skills, expertise, and knowledge. The activities sought to build capacity towards a responsive infrastructure of shared connections, interests, and needs. Learning from interviews with members of the consortium, personas were developed to facilitate empathetic conversations about the different roles of systems on the project, and expectations and understandings of 'good' collaboration. From these, frustrations were raised, alongside some common interests in developing practical ways to build trust and share knowledge together.

A working group of researchers felt that they did not have sufficient understanding of the system that they were hoping to influence, so they were supported in a collaborative mapping activity. The mapping brought researchers together to discuss their pathways through the urban development system. It provided space and time for participants to reflect on the complexity of the project and share their perspectives on challenges and opportunities. The results maps sought to support future discussions about dynamics, interactions, alignments, and synergies; a potential process contribution to the future integration of the consortium.

The mapping highlighted the perceived significance of policy to researchers and their aspirations to work within the existing power structures. It also revealed gaps in

knowledge, with the potential to include the perspectives of non-researchers (industry, public, policy) and the need to develop closer integration across the different workstreams of the consortium. The mapping showed moments where researchers could influence the larger system through providing evidence or collaborating with publics to amplify their voices. Whilst the co-design activities sought to facilitate integration in responsive way, the emergent nature of the process did not marry well with the structure and management of the larger consortium.

The study understood diversity of perspectives and expectations as both a challenge and an asset. However, the deliberate nature of participatory design, which only goes as fast as its slowest participant, met with constraints relating to time, institutional pressures, and top-down management. These challenges underscore the need for more flexible, responsive research infrastructures, that can scaffold the gaps between on-the-ground research and project management and objectives.

References

Bammer, Gabriele, Michael O'Rourke, Deborah O'Connell, Linda Neuhauser, Gerald Midgley, Julie Thompson Klein, Nicola J Grigg, Howard Gadlin, Ian R Elsum, and Marcel Bursztyn. 2020. "Expertise in research integration and implementation for tackling complex problems: when is it needed, where can it be found and how can it be strengthened?" Palgrave Communications 6 (1):1-16.

Bammer, Gabrielle, 2017. "Toolkits for Transdisciplinarity" GAIA – Ecological Perspectives in Science and Society. https://www.oekom.de/_uploads_media/files/gaia_flyer_toolkits_032911.pdf

Beebeejaun, Y. 2016. The Participatory City: Jovis.

Bieluch, Karen Hutchins, Kathleen P Bell, Mario F Teisl, Laura A Lindenfeld, Jessica Leahy, and Linda Silka. 2017. "Transdisciplinary research partnerships in sustainability science: an examination of stakeholder participation preferences." Sustainability Science 12:87-104.

Björgvinsson, Erling, Pelle Ehn, and Per-Anders Hillgren. 2010. Participatory design and" democratizing innovation". Paper presented at the Proceedings of the 11th Biennial participatory design conference.

Björgvinsson, Erling, Pelle Ehn, and Per-Anders Hillgren.. 2012. "Agonistic participatory design: working with marginalised social movements." CoDesign 8 (2-3):127-44.

Black, Daniel, Sarah Ayres, Krista Bondy, Rachel Brierley, Rona Campbell, Neil Carhart, John Coggon, Eleanor Eaton, Eleonora Fichera, Andy Gibson, Eli Hatleskog, Matthew Hickman, Ben Hicks, Alistair Hunt, Kathy Pain, Nick Pearce, Paul Pilkington, Ges Rosenberg, and Gabriel Scally. 2021. "Tackling Root Causes Upstream of Unhealthy Urban Development (TRUUD): Protocol of a five-year prevention research consortium." Wellcome Open Research 6:30

Brandt, Patric, Anna Ernst, Fabienne Gralla, Christopher Luederitz, Daniel J Lang, Jens Newig, Florian Reinert, David J Abson, and Henrik Von Wehrden. 2013. "A review of transdisciplinary research in sustainability science." Ecological economics 92:1-15.

Brouwer, H., & Brouwers, J. 2017. "The MSP Tool Guide: Sixty tools to facilitate multi-stakeholder partnerships. Companion to The MSP Guide. Wageningen University and Research & Center for Development and Research."

Carayannis, Elias G, and David FJ Campbell. 2009. "'Mode 3'and'Quadruple Helix': toward a 21st century fractal innovation ecosystem." International journal of technology management 46 (3-4):201-34.

Carew, Anna L, and Fern Wickson. 2010. "The TD wheel: a heuristic to shape, support and evaluate transdisciplinary research." Futures 42 (10):1146-55.

Cash, David W, William C Clark, Frank Alcock, Nancy M Dickson, Noelle Eckley, David H Guston, Jill Jäger, and Ronald B Mitchell. 2003. "Knowledge systems for sustainable development." Proceedings of the national academy of sciences 100 (14):8086-91.

Clark, William C, and Nancy M Dickson. 2003. "Sustainability science: the emerging research program." Proceedings of the national academy of sciences 100 (14):8059-61.

Collins, Harry, and Martin Weinel. 2011. "Transmuted expertise: How technical non-experts can assess experts and expertise." Argumentation 25 (3):401-13.

Cooper, Alan. 1999. "The inmates are running the asylum." In Software-Ergonomie'99, 17-. Springer.

Corner, James. 1999. The agency of mapping: Speculation, critique and invention: na.

Dantec, C. A. L., & DiSalvo, C. (2013). Infrastructuring and the formation of publics in participatory design. Social Studies of Science, 43(2), 241-264. https://doi.org/10.1177/0306312712471581

Design Council. (2005). The Double Diamond: A universally accepted depiction of the design process. Design Council. Retrieved from https://www.designcouncil.org.uk/our-work/news-opinion/double-diamond-universally-accepted-depiction-design-process

Dorst, Kees. 2015. Frame innovation: Create new thinking by design: MIT press.

EDSI. 2021. "Urban ID (Integrated Diagnostics)". https://esdi.ac.uk/projects/urban-id-integrated-diagnostics/.

Felt, Ulrike, Judith Igelsböck, Andrea Schikowitz, and Thomas Völker. 2016. "Transdisciplinary sustainability research in practice: between imaginaries of collective experimentation and entrenched academic value orders." Science, Technology, & Human Values 41 (4):732-61.

Foth, M. (2018). Participatory urban informatics: towards citizen-ability. Smart and Sustainable Built Environment, 7(1), 4-19. https://doi.org/10.1108/SASBE-10-2017-0051

Fredericks, J., et al. (2019). The city as perpetual beta: Fostering systemic urban acupuncture. In M. de Waal & M. de Lange (Eds.), The hackable city: Digital media and collaborative city-making in the network society (pp. 67-92). Springer. https://doi.org/10.1007/978-981-13-2694-3_4

Fry, Tony. 2011. "Getting over architecture: Thinking, surmounting and redirecting." In Transdisciplinary knowledge production in architecture and urbanism, 15-32. Springer.

Funtowicz, Silvio O, and Jerome R Ravetz. 1993. "Science for the post-normal age." Futures 25 (7):739-55.

Gibbons, Michael. 1994. The new production of knowledge : the dynamics of science and research in contemporary societies. London ;: SAGE Publications.

Godemann, Jasmin. 2008. "Knowledge integration: A key challenge for transdisciplinary cooperation." Environmental Education Research 14 (6):625-41.

Hadorn, Gertrude Hirsch, David Bradley, Christian Pohl, Stephan Rist, and Urs Wiesmann. 2006. "Implications of transdisciplinarity for sustainability research." Ecological economics 60 (1):119-28.

Hadorn, Gertrude Hirsch, Holger Hoffmann-Riem, Susette Biber-Klemm, Walter Grossenbacher-Mansuy, Dominique Joye, Christian Pohl, Urs Wiesmann, and Elisabeth Zemp. 2008. Handbook of transdisciplinary research. Vol. 10: Springer.

Harley, J.B. 2011. “Deconstructing the Map.” Cartographica The International Journal for Geographic Information and Geovisualization 26(2):271 – 294.

Hatleskog, Eli. 2020. “Mapping Eco-social Assets” *Architectural Design,* 90(4), (2020), 52-59.

Healey, P. (1996). The Communicative Turn in Planning Theory and its Implications for Spatial Strategy Formation. Environment and Planning. B, Planning & Design, 23(2), 217-234. https://doi.org/10.1068/b230217

Healey, P. (2006). Collaborative Planning: Shaping Places in Fragmented Societies (2nd ed.). Palgrave Macmillan.

Heemskerk, M., Wilson, K., & Pavao-Zuckerman, M. 2003. “Conceptual models as tools for communication across disciplines.” Conservation Ecology, 7(3). ://WOS:000223963100011

Helms, Wesley S, Christine Oliver, and Kernaghan Webb. 2012. "Antecedents of settlement on a new institutional practice: Negotiation of the ISO 26000 standard on social responsibility." Academy of Management Journal 55 (5):1120-45.

Hemström, Kerstin, David Simon, Henrietta Palmer, Beth Perry and Merritt Polk. 2021. Transdisciplinary knowledge co-production: a guide for sustainable cities. Practical Action Publishing. https://practicalactionpublishing.com/book/2544/transdisciplinary-knowledge-co-production-for-sustainable-cities

Holling, Carl S. 1993. "Investing in research for sustainability." Ecological applications:552-5.

Holling, Crawford S, and Lance H Gunderson. 2002. "Resilience and adaptive cycles." In: Panarchy: Understanding Transformations in Human and Natural Systems, 25-62.

Ingold, T. 2016. Lines: A Brief History: Routledge.

Jahn, Thomas, Matthias Bergmann, and Florian Keil. 2012. "Transdisciplinarity: Between mainstreaming and marginalization." Ecological economics 79:1-10.
Jensenius, A. R. (2012, March 12). Disciplinarities: intra, cross, multi, inter, trans. https://www.arj.no/2012/03/12/disciplinarities-2/
Karasti, H. (2014). Infrastructuring in participatory design. Proceedings of the 13th Participatory Design Conference: Research Papers - Volume 1, 141-150. https://doi.org/10.1145/2661435.2661450
Kates, Robert W, William C Clark, Robert Corell, J Michael Hall, Carlo C Jaeger, Ian Lowe, James J McCarthy, Hans Joachim Schellnhuber, Bert Bolin, and Nancy M Dickson. 2001. "Sustainability science." Science 292 (5517):641-2.
Kitchin, Rob, and Martin Dodge. 2007. "Rethinking maps." Progress in human geography 31 (3):331-44.
Klein, Julie T. 2008. "Evaluation of interdisciplinary and transdisciplinary research: a literature review." American journal of preventive medicine 35 (2):S116-S23.
Klein, Julie Thompson. 2006. "Afterword: the emergent literature on interdisciplinary and transdisciplinary research evaluation." Research Evaluation 15 (1):75-80.
Koppman, S., & Leahey, E. (2019). Who moves to the methodological edge? Factors that encourage scientists to use unconventional methods. Research Policy, 48(9), 103807. https://doi.org/10.1016/j.respol.2019.103807
Landcare Research. 2021. “Integrated Research Toolkit.” https://integrated.landcareresearch.co.nz
Lang, Daniel J, Arnim Wiek, Matthias Bergmann, Michael Stauffacher, Pim Martens, Peter Moll, Mark Swilling, and Christopher J Thomas. 2012. "Transdisciplinary research in sustainability science: practice, principles, and challenges." Sustainability Science 7:25-43.
Lengwiler, Martin. 2006. "Between charisma and heuristics: four styles of interdisciplinarity." Science and Public Policy 33 (6):423-34.
Liaros, S. (2019). Implementing a new human settlement theory: Strategic planning for a network of regenerative villages. Smart and Sustainable Built Environment, 9(3), 258-271. https://doi.org/10.1108/SASBE-01-2019-0004
Liaros, S., & De Silva, N. (2022). Human settlements arranged as networks of regenerative villages with nature-based infrastructure ecosystems. Civil Engineering and Environmental Systems, 39(4), 328-346. https://doi.org/10.1080/10286608.2022.2128341
Lidskog, Rolf. 2008. "Scientised citizens and democratised science. Re-assessing the expert-lay divide." Journal of risk research 11 (1-2):69-86.
Matthews, B., et al. (2022). The publics of design: Challenges for design research and practice. Design Studies, 80, 101106. https://doi.org/10.1016/j.destud.2022.101106
Mazzucato, Mariana. 2018. "Mission-oriented innovation policies: challenges and opportunities." Industrial and Corporate Change 27 (5):803-15.
Miaskiewicz, Tomasz, and Kenneth A Kozar. 2011. "Personas and user-centered design: How can personas benefit product design processes?" Design studies 32 (5):417-30.
Montuori, Alfonso. 2013. "Complexity and transdisciplinarity: Reflections on theory and practice." World Futures 69 (4-6):200-30.
Net-Map. 2007. “Net-Map Toolbox Influence Mapping of Social Networks.” https://netmap.wordpress.com/about/
Nielsen, Lene. 2019. "Persona writing." In Personas-User Focused Design, 55-81. Springer.

Nowotny, Helga, Peter Scott, and Michael Gibbons. 2001. Re-thinking science: Knowledge and the public in an age of uncertainty: SciELO Argentina.
Oxman, N. (2016). Age of entanglement. Journal of Design and Science. https://doi.org/10.21428/7e0583ad
Petrescu, Doina, Constantin Petcou, and Corelia Baibarac. 2016. "Co-producing commons-based resilience: lessons from R-Urban." Building Research & Information 44 (7):717-36.
Pipek, V., & Wulf, V. (2009). Infrastructuring: Toward an integrated perspective on the design and use of information technology. Journal of the Association for Information Systems. https://aisel.aisnet.org/cgi/viewcontent.cgi?article=1503&context=jais
Pohl, Christian, and Gabriela Wuelser. 2019. "Methods for Co-Production of Knowledge among Diverse Disciplines and Stakeholders." In K. L. Hall, A. L. Vogel, & K. Crowston (Eds.), Strategies for Team Science Success: Handbook of Evidence-based Principles for Cross-Disciplinary Science and Practical Lessons Learned from Health Researchers (pp. 115-121). Springer. https://link.springer.com/chapter/10.1007/978-3-030-20992-6_8
Pohl, Christian, and Gertrude Hirsch Hadorn. 2007. Principles for designing transdisciplinary research: oekom Munich.
Pohl, Christian. 2010. "From transdisciplinarity to transdisciplinary research." Transdisciplinary Journal of Engineering & Science 1.
Pruitt, John, and Jonathan Grudin. 2003. Personas: practice and theory. Paper presented at the Proceedings of the 2003 conference on Designing for user experiences.
Ravetz, IR. 1999. "What is post-normal science." Futures-the Journal of Forecasting Planning and Policy 31 (7):647-54.
Rayner, Steve. 2006. "Wicked problems: clumsy solutions–diagnoses and prescriptions for environmental ills." Jack Beale memorial lecture on global environment:1-12.
Rittel, Horst WJ, and Melvin M Webber. 1973. "Dilemmas in a general theory of planning." Policy sciences 4 (2):155-69.
Rogers, R., and P. Gumuchdjian. 1998. Cities For A Small Planet: Basic Books.
Roux, Dirk J, Jeanne L Nel, Georgina Cundill, Patrick O'farrell, and Christo Fabricius. 2017. "Transdisciplinary research for systemic change: who to learn with, what to learn about and how to learn." Sustainability Science 12 (5):711-26.
Rust, Chris. 2004. Design Enquiry: Tacit Knowledge and Invention in Science. Design Issues, 20(4), 76-85. https://doi.org/10.1162/0747936042311959
Rust, Chris, Judith Mottram, and Jeremy Till. 2007. "Review of practice-led research in art, design & architecture."
Schafer, Martina, and Melanie Kröger. 2016. "Joint problem framing in sustainable land use research Experience with Constellation Analysis as a method for inter- and transdisciplinary knowledge integration." Land Use Policy, 57, 526-539. https://doi.org/10.1016/j.landusepol.2016.06.013
Schnapp, Lynn, M., Liela Rotschy, Troy Hall, Stephen Crowley, and Michael O'Rourke. 2012. "How to talk to strangers: facilitating knowledge sharing within translational health teams with the Toolbox dialogue method." Translational Behavioral Medicine, 2(4), 469-479. https://doi.org/10.1007/s13142-012-0171-2
Seravalli, A. (2018). Infrastructuring urban commons over time: learnings from two cases. Proceedings of the 15th Participatory Design Conference: Full Papers - Volume 1, 4. https://doi.org/10.1145/3210586.3210593

SHAPE-ID. 2021. “Pathways to Interdisciplinary and Transdisciplinary Research: the SHAPE-ID Toolkit.” https://www.shapeidtoolkit.eu

Smith, Rachel Charlotte, and Ole Sejer Iversen. 2018. "Participatory design for sustainable social change." Design studies 59:9-36.

Star, Susan Leigh, and Karen Ruhleder. 1996. "Steps Toward an Ecology of Infrastructure: Design and Access for Large Information Spaces." Information Systems Research 7 (1):111-34. doi: 10.1287/isre.7.1.111.

Stokols, Daniel, Kara L Hall, Brandie K Taylor, and Richard P Moser. 2008. "The science of team science: overview of the field and introduction to the supplement." American journal of preventive medicine 35 (2):S77-S89.

Stokols, Daniel. 2006. "Toward a science of transdisciplinary action research." American journal of community psychology 38 (1):63-77.

Studer, Sibylle, and Theres Paulsen. 2023. “Co-producing knowledge: Phases, issues and the td-net toolbox.” Integration and Implementation Insights. https://i2insights.org/2023/10/10/co-producing-knowledge-td-net-toolbox/

Sturder, Sibylle, and Christian Pohl. 2023. “Toolkits for transdisciplinary research: state of the art, challenges, and potentials for further developments.” In R. Lawrence (Ed.), Handbook of Transdisciplinarity: Global Perspectives (pp. 536-546). Edward Elgar Publishing. https://doi.org/10.4337/9781802207835.00044

td-net. 2018. “Methods and tools for co-producing knowledge.” Swiss Academies of Arts and Sciences. https://naturalsciences.ch/co-producing-knowledge-explained

Thorpe, Adam, Patrycja Kaszynska, and Samuel Mitchell. 2022. "MAKE (e) valuation Report."

UN_General_Assembly. A/RES/70/1. "Transforming our world : the 2030 Agenda for Sustainable Development." https://www.refworld.org/docid/57b6e3e44.html

Van Kerkhoff, Lorrae, and Louis Lebel. 2006. "Linking knowledge and action for sustainable development."

Walter, Alexander I, Sebastian Helgenberger, Arnim Wiek, and Roland W Scholz. 2007. "Measuring societal effects of transdisciplinary research projects: design and application of an evaluation method." Evaluation and program planning 30 (4):325-38.

Winowiecki, Leigh, Sean Smukler, Kenneth Shirley, Roseline Remans, Gretchen Peltier, Erin Lothes, Elisabeth King, Liza Comita, Sandra Baptista, and Leontine Alkema. 2011. “Tools for enhancing interdisciplinary communication.” Sustainability: Science, Practice, & Policy, 7(1), 74-80. https://doi.org/10.1080/15487733.2011.11908067

Wolf, Birge, Thomas Lindenthal, Manfred Szerencsits, J Britt Holbrook, and Jürgen Heß. 2013. "Evaluating research beyond scientific impacthow to include criteria for productive interactions and impact on practice and society." GAIA-Ecological Perspectives for Science and Society 22 (2):104-14.

Worldwatch_Institute. 2016. Can a City Be Sustainable? (State of the World): Island Press.

Yawson, Robert M. 2009. "The ecological system of innovation: A new architectural framework for a functional evidence-based platform for science and innovation policy." Munich Personal RePEc Archive MPRA Paper No. 33179.