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Briefing: Embedding transdisciplinarity in engineering approaches to infrastructure and cities

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Many of the specialisms on which infrastructure and cities rely for their effective design, construction, operation, governance, management and maintenance are underpinned by the principles of certainty, accuracy, precision and prediction. Not least of these is civil engineering. Yet infrastructures and cities are characterised by complexity and emergence. In recent decades, understandings of infrastructures and cities have begun to reflect these properties, and in particular, transdisciplinarity is promoted as critical to advancing these new understandings. However, this presents conceptual and operational challenges for civil engineering, as there is a fundamental mismatch between the certainty, accuracy and precision required by engineers and the complexity and emergence of transdisciplinary research approaches. The forms of value arising from these research approaches are themselves contentious, leaving engineers exposed to competing claims and making them ill prepared to exploit new insights to full advantage. This briefing explores these mismatches and contentions and proposes a set of four principles that underpin successful transdisciplinary research, laying the foundation for transforming research in infrastructure and cities by leveraging emergent, transdisciplinary approaches.

1. Introduction

Paul Jowitt (2004), a past president of the Institution of Civil Engineers, reflected that since its inception, civil engineering has been largely concerned with technical rationality: narrow technical approaches to problem solving that have not taken into account wider social and environmental impacts. ‘No one foresaw that Henry Ford’s production line of black Model Ts would lead inexorably to changes in urban form, large-scale urban congestion, air pollution (and its linkage to the higher incidence on [*sic*] child asthma), CO₂ emissions or global warming and climate change’ (Jowitt, 2004: p. 82). Now, however, engineers are increasingly asked to grapple with wicked problems such as sustainability, resilience, liveability, urbanisation, climate change and smartness (noting that smartness is truly smart only if it delivers on all of these allied agendas (Cavada *et al.*, 2017)). Wicked problems – those problems that are intractable and often unsolvable (Rittel and Webber, 1973) – require system-level solutions and the twenty-first century marks the point at which civil engineering started to move away from short-term ‘technical rationality’ and towards a future-looking ‘systems/holistic viewpoint’ (Jowitt, 2004). This change in mindset, however, is no small task, and it propels engineers into non-engineering domains, including those of complexity science, big data and the Internet of things.

Head and Xiang (2016) argue that wicked problems favour adaptive, participatory and transdisciplinary approaches. There is no agreed definition of transdisciplinarity, but one of the most comprehensive definitions is that provided by Jahn *et al.* (2012: pp. 8–9): ‘a critical and self-reflexive research approach that relates societal with scientific problems; it produces new

knowledge by integrating different scientific and extra-scientific insights; its aim is to contribute to both societal and scientific progress; integration is the cognitive operation of establishing a novel, hitherto non-existent connection between the distinct epistemic, social-organizational and communicative entities that make up the given problem context’.

Three characteristics of transdisciplinarity distinguish it from the closely related concepts of interdisciplinarity and multidisciplinary. First, transdisciplinarity addresses societal problems. Second, it engages beyond science and academia. Third, it creates transformation through synthesis. Transdisciplinarity is, therefore, essential if civil engineers are to respond effectively to societal challenges and to shape future research agendas.

This study seeks to answer two questions: (a) how are transdisciplinary approaches suited to the engineering of infrastructure and cities and (b) how is the engineering of infrastructure and cities suited to transdisciplinary approaches? It was undertaken for UKCRIC – the UK Collaboratorium for Research on Infrastructure and Cities (see UKCRIC, 2020a). Through its four missions (see UKCRIC, 2020b), UKCRIC is supporting the renewal, sustainment and improvement of infrastructure and cities in the UK and elsewhere by creating a paradigm shift in how and by whom infrastructure and cities research is conducted (for UKCRIC’s research capability in cities, see UKCRIC Coordination Node (2019)). The authors conducted a review of the literature on transdisciplinarity (and its closely related terms and concepts) alongside a review of the evolution of civil engineering approaches to infrastructure and cities. The

outcome is a set of principles for enabling transdisciplinary civil engineering research into infrastructure and cities. Two workshops were held in 2019 to pressure-test the principles, after which the principles were refined. The workshops were attended by practicing civil engineers, urban designers, government think tanks, municipalities, and academics.

This section has introduced the problem space being addressed. Section 2 explores how engineering approaches to infrastructure and cities have evolved. Section 3 surfaces tensions around the intrinsic positive value of transdisciplinarity. Section 4 introduces the outcomes of this study – four principles for encouraging transdisciplinarity in engineering. Finally, Section 5 discusses the implications for UKCRIC.

2. Engineering approaches to infrastructure and cities

‘In the early 21st Century, it is clear that a radical shift in metaphor is taking place to thinking of cities and societies as organisms, as biological rather than physical systems.... This is also a switch from thinking of cities as being artefacts to be designed to thinking of them as systems that evolve, that grow and change in ways that might be steered and managed but rarely designed from the top down. This also reveals a shift from an emphasis on structure and form to one of behaviour and process and it mirrors the slow march from the physicalism which dominated city planning a generation or more ago to a serious concern for social process’ (Batty, 2010: p. 100).

Complementing this is a growing realisation that engineering infrastructures, and in particular urban infrastructures, need to be conducted in ways that question perceptions of them as neutral or passive underlying material structures. ‘Infrastructure is not identical to system or structure, as we currently see them, because infrastructure is defined by the movement or patterning of social form. It is the living mediation of what organizes life: the lifeworld of structure. Roads, bridges, schools, food chains, finance systems, prisons, families, districts, norms all the systems that link ongoing proximity to being in a world-sustaining relation’ (Berlant, 2016: p. 393).

Berlant (2016: p. 394) also reflects on the relationship between infrastructure and politics: ‘Given newly intensified tensions, anxieties, and antipathies at all levels of intimate abstraction, the question of politics becomes identical with the reinvention of infrastructures for managing the unevenness, ambivalence, violence, and ordinary contingency of contemporary existence’.

McCormack (2014) observed how physical infrastructures can be more than material objects and how their value (positive and negative) develops through their design, construction and use in, sometimes, unpredictable and emergent ways. He provides as one example accounts of the construction of the Brooklyn Bridge (Figure 1), which, once completed, provided physical connectivity, social mobility and social identity. It inspires poetry,

prose, photography, paintings and movies; as well as providing a location for public demonstrations and events. He describes how, during its construction, there was political controversy when the contract for producing the steel cables was won by a local organisation that then supplied under-strength wire (luckily, the bridge had been over-engineered and it did not matter). Despite being so well engineered, the crucial role of Emily Roebling was purposefully diminished in order not to undermine faith in the construction of the bridge (because she was a woman).

In broadening the purview of civil engineers, there is a recognised tension with regard to rigour and scale. ‘Engineers are not comfortable – and rightly so – with the idea of a profession which eschews rigour’ (Jowitt, 2004: p. 79). Care must be taken not to conflate rigour and precision (an accusation that can reasonably be levelled at the swamp allegory by Schön (1987)). Wicked problems are often so complicated (displaying emergent properties and encompassing multiple technical and non-technical disciplines) that precision in addressing them is close to impossible. It does not follow, however, that the ways of addressing them lack rigour. This argument is particularly pertinent when dealing with complex systems thinking and digital technologies, whose relevance to infrastructure and cities is widely discussed but which are, themselves, emerging approaches (see Batty, 2012; Faithfull-Wright, 2018; Kitchin, 2014; Rathore *et al.*, 2016; Samet, 2013). With regard to scale, ‘A worldwide survey of engineering students ... confirms that they have difficulty making links between general sustainability theory and the detail of engineering practice’ (Keirstead, 2014: p. 138), a difficulty that it would not be hard to imagine extends to other wicked problems.

3. The intrinsic positive value of transdisciplinarity

There is an assumption within transdisciplinarity that ‘if transdisciplinary research is done under the “right” conditions and

Figure 1. Brooklyn Bridge c. 1915

with the “correct” procedures for engaging different types of stakeholders, it will generate relevant knowledge’, yet this is far from a *fait accompli* (Klenk and Meehan, 2017: p. 28). Synthesis, a cornerstone of transdisciplinary research, is assumed to be both possible and desirable (Donaldson *et al.*, 2010). However, too great a focus on the ‘integration imperative’ can, in fact, reduce the implementation of experimental methods and transformative ways of understanding (Klenk and Meehan, 2015). Although integration and synthesis can lead to new forms of knowledge, it is not guaranteed and it is possible for transdisciplinarity to lead to convergence and closure (Barry *et al.*, 2008: p. 28).

It may be that certain areas of investigation are particularly conducive to transdisciplinarity. In fact, challenges that require the engagement of multiple disciplines have spurred, and continue to spur, the evolution of disciplines (Barry *et al.*, 2008). Transdisciplinary approaches are rarely applied to simple problems because they are, simply, not necessary – the answers to simple problems often lie within the knowledge and expertise of a single discipline. The challenges posed by infrastructure and cities are neither simple nor singular. Such challenges appear messy ‘because they are multiply determined and partially connected’ (Donaldson *et al.*, 2010: p. 1534).

Jessop and Sum (2001) describe the origin of scientific disciplines as pre-disciplinary, when academics were polymaths (or deep generalists (Tank, 2018)), and the future of scientific disciplines as post-disciplinary, when academics become polymaths once again. However, there is a crucial difference between the past and the future that they describe: the polymaths of the future exist within a scientific world of vastly expanded knowledge and an improved understanding of how individuals best work and work together. The days of the true polymath are in the past. Its counterpart, the

transdisciplinary, needs to be familiar with many disciplines, as well as with ways of bringing them productively together and innovatively interpreting the outcomes.

4. Principles for encouraging transdisciplinarity in engineering

Despite lacking certainty of positive outcomes, it seems that transdisciplinarity has something to offer in engineering. The question remains as to how to embed transdisciplinarity into engineering research and practice. In response, this briefing introduces a set of four ‘principles of transdisciplinarity’ that have been compiled from the literature reviews and refined through the workshops. The principles are positioned as the first step in fostering transdisciplinary approaches to the opportunities and challenges posed by infrastructure and cities. They underpin the enabling, facilitating and embedding of transdisciplinary thinking and practices into engineering. The applicability and importance of each principle depends on the context to which it is being applied (e.g. an organisation, a research project, an individual). Each principle opens the door to abundant complementary literatures and the opportunity to tailor transdisciplinarity to a given context. The four principles follow, with references found in Table 1:

- multidimensional problem framing – prioritising innovative and experimental problem framings and methodologies that ensure engagement across disciplines and domains and encourage systems thinking
- talented human resource – supporting an enabling mix of personal attributes and skill sets within individuals and teams; encouraging diversity of disciplines, domains, functions, disability, culture, race, religion, age, gender and sexual orientation

Table 1. Principles for encouraging transdisciplinarity in engineering

Principle	References
■ Multidimensional problem framing: prioritising innovative and experimental problem framings and methodologies that ensure engagement across disciplines and domains and encourage systems thinking	Bammer (2015, 2017), Barry <i>et al.</i> (2008), Brandt <i>et al.</i> (2013), Carew and Wickson (2010), Harris <i>et al.</i> (2008), Jahn and Keil (2015), Lang <i>et al.</i> (2012), Wickson <i>et al.</i> (2006)
■ Talented human resource: supporting an enabling mix of personal attributes and skill sets within individuals and teams; encouraging diversity of disciplines, domains, functions, disability, culture, race, religion, age, gender and sexual orientation	Bammer (2015), Boyko <i>et al.</i> (2015), Brandt <i>et al.</i> (2013), Graff (2015), Harris <i>et al.</i> (2008), Klenk and Meehan (2015), Thompson <i>et al.</i> (2017), Wickson <i>et al.</i> (2006)
■ Collaboration not competition: making collaboration the default position no matter what the geographical scale, disciplinary scope, domain span or societal impact of the issues being investigated (and the response to them)	Balsiger (2004), Bammer (2015), Barry <i>et al.</i> (2008), Bozhkova (2016), Brandt <i>et al.</i> , 2013), Carew and Wickson (2010), Donaldson <i>et al.</i> (2010), Harris <i>et al.</i> (2008), Jahn and Keil (2015), Klenk and Meehan (2015), Lang <i>et al.</i> (2012), Ledford (2015), Petts <i>et al.</i> (2008), Ramadier (2004), Thompson <i>et al.</i> (2017), Wickson <i>et al.</i> (2006), workshop held on 10 September, workshop held on 20 September
■ Supportive governance, structures and processes: ensuring that governance, structures and processes are democratic, flexible, integrative and motivational; that they promote continuity, collaboration and interaction; that they reward interdisciplinarity and support transdisciplinarity; that they are reflexive and recursive; and that they do these things at the appropriate scales and magnitudes for the issues under investigation	Brandt <i>et al.</i> (2013), Carew and Wickson (2010), Harris <i>et al.</i> (2008), Jahn and Keil (2015), Klenk and Meehan (2015), Lang <i>et al.</i> (2012), Nowotny <i>et al.</i> (2001), Thompson <i>et al.</i> (2017)

- collaboration not competition – making collaboration the default position no matter what the geographical scale, disciplinary scope, domain span or societal impact of the issues being investigated (and the response to them)
- supportive governance, structures and processes – ensuring that governance, structures and processes are democratic, flexible, integrative and motivational; that they promote continuity, collaboration and interaction; that they reward interdisciplinarity and support transdisciplinarity; that they are reflexive and recursive; and that they do these things at the appropriate scales and magnitudes for the issues under investigation.

5. Conclusions and recommendations

This briefing explores two questions – (a) how are transdisciplinary approaches suited to the engineering of infrastructure and cities and (b) how is the engineering of infrastructure and cities suited to transdisciplinary approaches – and finds that each has something to offer the other. The incentives are pressing, as digital technologies are already revolutionising how infrastructure and cities are designed, constructed, used and maintained. The outcomes of the study reveal clear areas for future investigation, as follows:

- disaggregating the organisational and programmatic elements for encouraging transdisciplinary research within engineering
- determining the locus of transdisciplinary values, knowledge, skills and attributes: the degree to which they must be embedded within an individual/team/organisation in order for transdisciplinary research to be successful
- developing ways to overcome perceived barriers to transdisciplinarity within engineering
- implementing the transdisciplinarity principles within UKCRIC.

UKCRIC is already making advances in each of these areas through Priming Laboratory Experiments on Infrastructure and Urban Systems (Plexus), one of its pump-priming projects, which is reflecting on its aspiration to move towards transdisciplinarity (see Leach, 2019). Beyond this, UKCRIC seeks to embed into all projects and programmes with which it is affiliated a culture of transdisciplinarity alongside delivering practical guidance and training. In order to achieve this, and if UKCRIC wishes to be seen as the national lead in transdisciplinary approaches to infrastructure and cities, then UKCRIC will need to establish and advance a programme of transdisciplinary research that includes an associated programme of education and training for all those who are drawn into the collaboratorium.

In truth, the verdict on the benefits of transdisciplinarity is still out. ‘The celebrations have begun, but the actual data on what kind of difference this makes are not in’ (Ledford, 2015: p. 311). Any assertion that transdisciplinary approaches have positive value must be underpinned by some standard of quality, but quality standards are not widely evident or agreed on – and this

may very well be holding back the uptake of transdisciplinary methods (Jahn and Keil, 2015). Nonetheless, ‘today ... we need people comfortable with collaborative work processes’, people who ‘accept the fallacy of the ‘solution’’, because ‘there are no creative solutions that don’t end up creating other problems down the line’ (Kahn and Diedrich, 2019: p. 13).

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