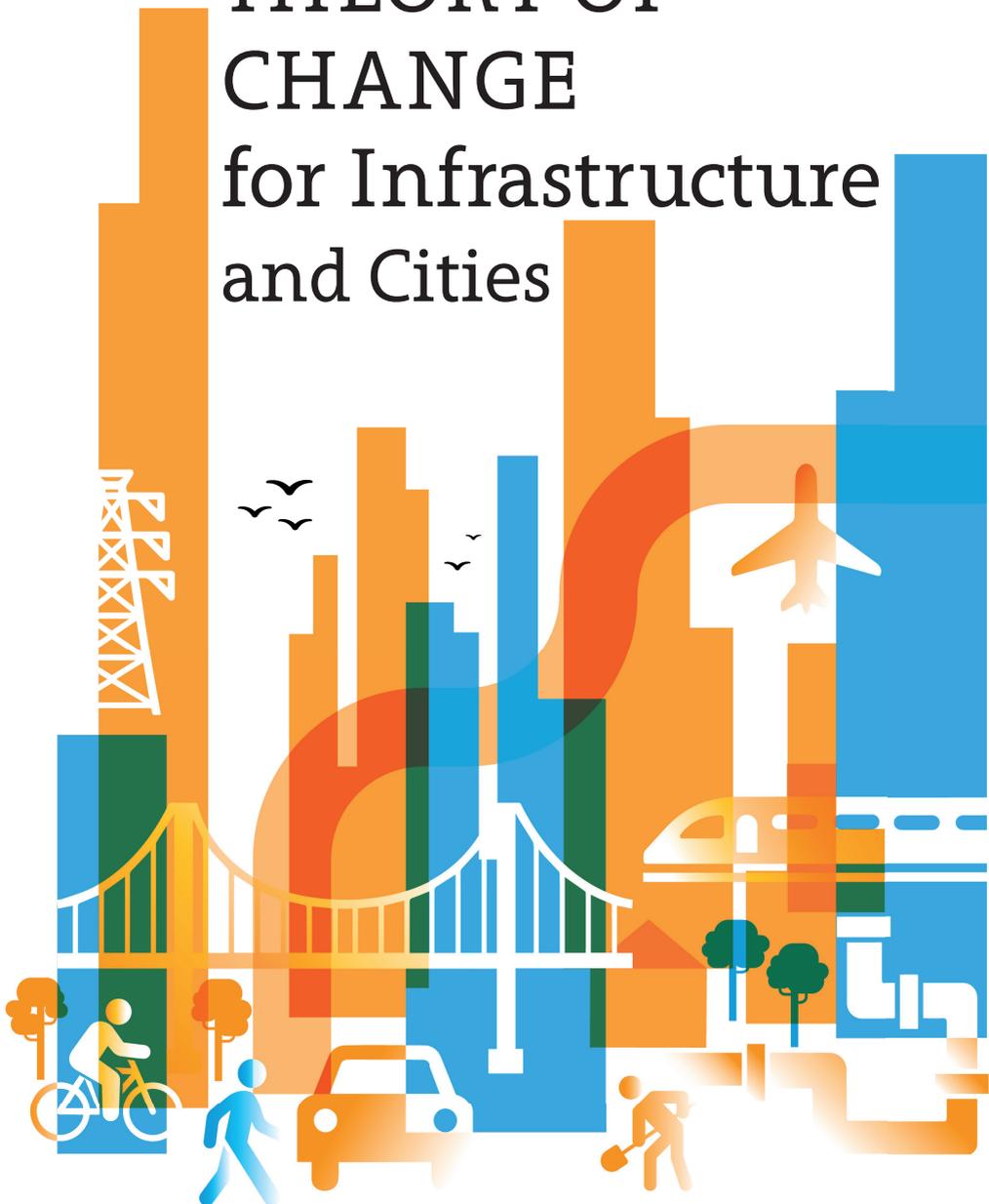# The Little Book of THEORY OF CHANGE for Infrastructure and Cities

Chris Rogers, Lewis Makana, Joanne Leach and the UKCRIC Community

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Acknowledgements

Contents

What this Little Book Tells You

This Little Book arises from the UK Collaboratorium for Research on Infrastructure and Cities (UKCRIC[1]), whose vision is to connect policy and practice with internationally leading, systems-based transdisciplinary research for the transformation of infrastructure and urban systems to enable safe, resilient and sustainable living, and to generate wellbeing and prosperity for all. This Little Book explores how such transformative changes can come about. More importantly, it is about how change isn't just something to be hoped for, it is something that can be planned. This book explores the following ideas:

- How to ensure that everyone has a voice in shaping the infrastructure and urban systems that support them, including the public who are paying for them.
- How to ensure that the problems with these systems are fully and accurately diagnosed.
- How to ensure that the alternative solutions recognise the unique features of the places in which they operate and are synergistic with them.
- How to ensure that these solutions would yield their greatest potential value, socially and environmentally as well as economically.
- How to ensure that these solutions would function well if they were implemented today.
- How to ensure that the designs are resilient – they would continue to function well, and deliver outcomes that meet the collective aspirations of all, in the far future.
- How to ensure that the risk of unintended consequences is minimised.
- How to ensure that the governance regimes provide an enabler of, rather than a barrier to, a more sustainable, resilient and liveable future.

This Little Book offers a general guide to how to identify and plan for the short-, medium-, and long-term positive consequences of making changes to our infrastructure and urban environments.

1. Introduction

Infrastructure and cities are crucial components in creating a more sustainable and liveable world. Despite their role in supporting civilised life, we have allowed them to age and deteriorate, making them less effective. At the same time, they are under pressure from our increased and changing demands, and they are required to deliver their services in a fast-changing world (it's rare a week goes by without some major story). Thinking about places and the way they operate as a 'system-of-systems' helps us understand that a change made to one part of the system will have consequences in other parts. Infrastructure and city systems involve people and this makes them infinitely complex: people are not robots, we behave in different ways and our actions can't be easily predetermined. To add to this, infrastructure and cities serve the entire country, demanding a certain degree of internal consistency, but they must also be synergistic with global systems in this joined-up world we now inhabit. What we do in the UK has an impact beyond our borders. It is these combined impacts that are the focus of this Little Book.

Treating change as a system intervention introduces the need to 'think systemically' and work seamlessly across disciplinary, sectoral and government silos – multidisciplinary teams of people collaborating on interdisciplinary problems using transdisciplinary working practices. These principles underpin the work of UKCRIC, which seeks to improve the support our systems provide for people while moving our places and what we do to a more sustainable, resilient and liveable state. These system changes, which can refer to the creation of or change to an artefact (such as installing smart electricity meters), an operational system (such as the entire UK energy transmission system), a policy (such as the energy 'feed in tariff') or a practice (such as everyone turning down the central heating), usually take the form of a project (a discrete activity) or a programme (several activities combined). The term 'intervention' is used herein to cover both.
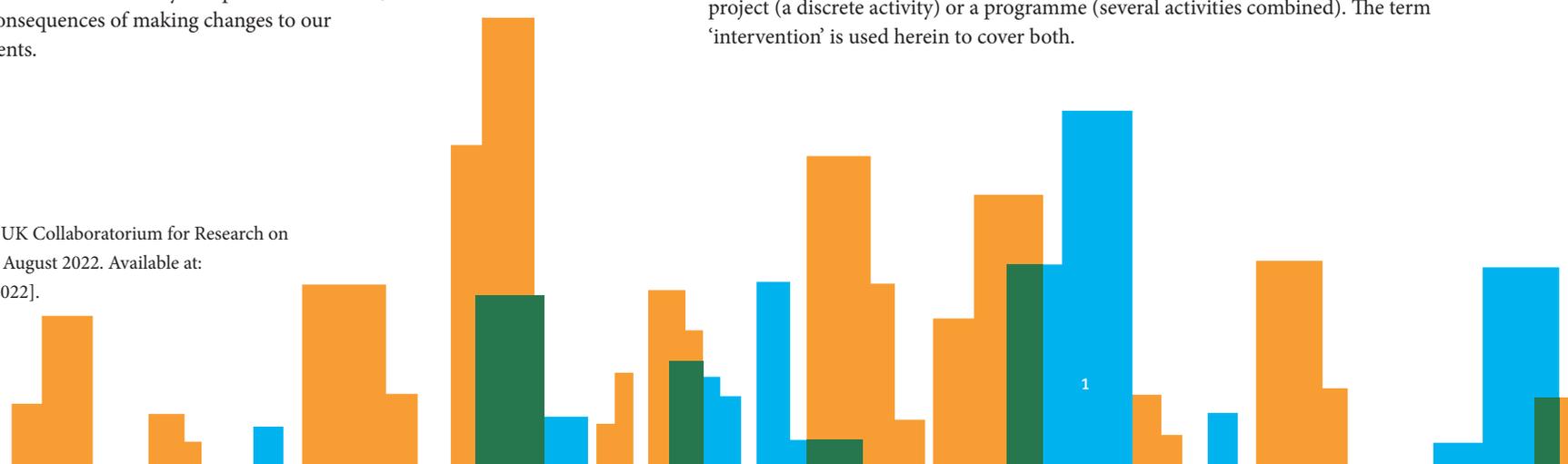
2. Responding to a Changing World

Change is concerning, disconcerting, unsettling, and uncertain. Change is also exciting and has connotations of novelty, vitality, and improvement. The inverse of change has different connotations: stability, conservatism, certainty, and, for some, stagnation.

Change is, however, essential if we are to make progress as progress is founded upon new knowledge and understanding – and understanding progressively matures because change is always happening and we are continually reacting to it. Change and progress are interdependent, and this is because the way the world works, and how we react to it, is context dependent.

If the context remains constant – unchanging – then incremental change to take advantage of new knowledge and understanding is all that is needed (unless there is evidence that harm will result, such as social injustice, inequity, or damage to the planet). This isn't true for the context in which our infrastructure and urban systems operate. That context is changing rapidly and, in some cases, dramatically, and in many different ways. Therefore, we must:

- Reverse the harm we are doing to the planet. Moving to net zero to slow global warming is one imperative, but we must go far beyond this narrowly-targeted goal.
- Provide for a growing and increasingly urbanised population with ever-rising expectations of standards and service (supply of housing for all is one core demand; access to electricity, clean water and sanitation is a need in some countries).

- Allow for demographic changes (towards younger and older populations).
- Address a seriously ageing and deteriorating existing built environment that we cannot afford to replace.
- Do all this while acknowledging a pervasive financial austerity that has manifestly deepened as a result of the Covid-19 pandemic.
- Provide resilience in the face of a changing climate that is manifesting in weather events of rapidly increasing severity.

Added to these contextual changes is technological change, much of which can, and must, be harnessed for the good of people, the nation and the planet. However, technology alone cannot deal with the challenges we face.

The case for change – in fact multiple synergistic changes that combine to address all of the above challenges – is compelling: we cannot go on as we are and hope that things will turn out alright. It is not a question of *if* there should be change, but *what types of change we should make*.

3. Thinking Systemically about Infrastructure and Cities

It is easier to select a gift for a close friend than for a stranger because we know what our friend values. We know this because of our close association with them over time and we would give our gift confidently expecting it to be well received. But, imagine we haven't spoken to our friend for a very long time. We would be less confident in selecting a gift and we'd be wise to check with them before spending our hard-earned money.

In a similar way, for our infrastructure and urban systems to deliver services valued by society, either the same deep understanding of society's needs and aspirations (now and in the future) must already exist, or it must be re-established.

A single change to an infrastructure or in a city – the creation of a new artefact, the maintenance or upgrading of an existing artefact, the development of a new operational protocol, or suchlike – is typically complicated. If making the change is approached solely from a technical perspective then, no matter how complicated the change to be made is, there is usually a most appropriate way to achieve technical efficiency and effectiveness.

However, if the system boundaries are cast wider – beyond a focus on the technical – to include the awareness, knowledge, attitudes and behaviours of the people who will use the services or take advantage of the artefacts, then making the change moves from being complicated to being complex. Complex challenges include some degree of uncertainty and are responsive to how the change is happening. This might be thought of as 'advancing while learning and learning while advancing' and it requires infrastructure and urban professionals to be on their toes – alert and responsive.

Geotechnical engineers and engineering geologists are familiar with such an approach to their work, since they have to engineer with and within a natural, infinitely variable material: the ground. They must interrogate the ground as best they can, with a range of both simple and sophisticated techniques that, at best, can only provide an indication of the ground's nature and properties. They therefore adopt what is termed the 'observational approach' to engineering, which, at heart, means acting, observing and responding with changes in design and construction techniques.

However, the problems associated with the provision of infrastructure and urban systems cut across many disciplines and sectors and require a new way of working: transdisciplinary working. This is difficult because it requires all those involved to have an adequate appreciation of all of the other disciplines and sectors – and this takes time, effort and trust.

Moreover, translating this practice to the creation, maintenance, upgrading and operating of infrastructure and cities means that we must take the opportunity to learn from every change that is made. Every piece of infrastructure and every town or city should be treated as a 'learning observatory' in its own right, from which we collectively learn and respond as we advance.

This leads to one final imperative: the need to think systemically. When making a change to a piece of infrastructure or in a city, it is inevitable that the system of interest will influence and will be influenced by many other systems and that these systems will be interdependent to some degree (think about the creation of nuclear energy, which requires much water for cooling; and, the creation of drinkable water, which requires energy to clean the water). It is the sum of all the consequences to these systems that, collectively, determines the value gained or lost through making an intervention. The design of the intervention will determine the nature and magnitude of the value gained and lost (i.e., the outcomes), and this in turn forms the evidence base on which to decide whether or not it is worth implementing the intervention.

4. Theories of Change

A theory of change is a methodology that identifies outcomes that are needed and wanted, and works out what must happen in order for the outcomes to be delivered. It uses critical and systemic thinking to inform the design, implementation and evaluation of an initiative that, itself, supports the management of this change over time in a particular context.

INITIAL COLLABORATIVE RESEARCH ACTIVITIES *Phase 1*	EXPECTED OUTCOMES	COLLABORATIVE RESEARCH TO INFLUENCE ACTIVITIES *Phase 2*	SHORT-TERM OUTCOMES	REPLICATION AND AMPLIFICATION *Phase 3*	MEDIUM TO LONG-TERM OUTCOMES	IMPACT DELIVERED
SPHERE OF CONTROL			SPHERE OF DIRECT INFLUENCE	SPHERE OF INDIRECT INFLUENCE		SPHERE OF INTEREST
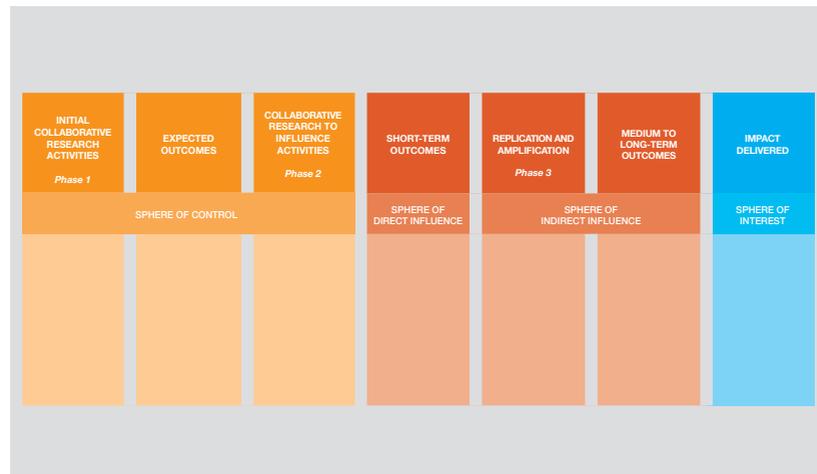
Figure 1. A typical framework for a Theory of Change

Theories of change, which often look like Figure 1, are increasingly used for infrastructure and urban systems projects and programmes. They are used by government departments, funding bodies, international non-governmental organisations, development agencies, and research programmes to deal with the increasing complexity of delivering multi-dimensional outcomes and de-risking investments.

A wide ranging review of the literature[2] found that there is no single definition of what a theory of change is and no set methodology for implementing it. Given the many definitions and approaches that exist, people use the term flexibly in line with their needs. A broad definition defines a theory of change as simply "The description of a sequence of events that is expected to lead to a particular desired outcome"[3]. You will find a fuller definition, and the one that underpins this Little Book, in the Appendix.

Theory of change draws strongly from the well-established area of evaluation that is embedded in programme theories. Some view it as a way to map the logical sequence of a system intervention (or project) from inputs to outcomes. Others see it as a catalyst for a deeper reflective process amongst colleagues and stakeholders, reflecting on philosophies of change, worldviews and values that make clearer the underlying assumptions people hold of how and why change could happen as an outcome of an intervention. The greatest benefits are likely to occur when both these approaches are combined.

Regardless of how it is perceived, there is consensus on the core essentials of a theory of change:

- The **context** for the intervention, including all economic, social, environmental and political considerations, must be completely understood. This includes the current problem the intervention is seeking to influence (the 'baseline performance'), its interdependencies with other systems, and all actors capable of influencing the intended change.
- The **long-term change** (the 'outcomes') that the intervention seeks to enable and who the ultimate beneficiaries are.
- The **sequence and process of change** needed to bring about the intended long-term outcomes.
- **Assumptions** of how this change takes place within the context.
- **A narrative and visual summary** that captures the outcomes from implementing the theory of change.

[2] Funnell SC & Rogers PJ (2011). *Purposeful Program Theory: Effective use of Theories of Change and Logic Models* (Vol. 31). John Wiley & Sons.

[3] Davis R (2012). *Criteria for Assessing the Evaluability of a Theory of Change*. [Online]. Rick on the Road. Last Updated: 01 June 2012. Available at: www.mandenews.blogspot.co.uk/2012/04/criteria-for-assessing-evaluablityof.html [Accessed 13 July 2022].

Theories of change should not be prescribed, but rather they should be kept flexible, adaptable, responsive, and nimble, which might better be described as *theory of change thinking* – both a process and a product of change.

A review of current practice[4] indicates that theories of change are most effective when integrated into existing processes to foster critical thinking and reflective practice throughout the implementation of change. If funding agencies are keen to embrace the benefits that a theory of change offers, they should be prepared to relinquish the imposition of constraints as conditions of funding – these lead to prescriptive practices that turn an opportunity for ingenious thinking into a compliance exercise, hence restricting the potential value of the outcomes.

A core tenet of theory of change thinking is to make assumptions explicit. Assumptions echo deeply-held values and viewpoints, inform our choices, and influence the design and implementation of projects. Making all assumptions (even the obvious ones) explicit exposes their influence which, in turn, enables that influence to be augmented or diminished as needed. By promoting critical reflection, theories of change encourage innovation and adaptation in response to the various contextual changes that could influence the outcomes and thus the effectiveness of interventions. A focus on the ultimate outcomes enables users to look past short-term technocratic or political responses and to draw on peer-reviewed evidence, tested in robustly-constructed future scenarios, to reveal appropriate courses of action.

There is a powerful circularity in revisiting the problem, the context, the solution, and the outcomes. This circularity ensures that the outcomes do not become compromised by originally unforeseen factors.

However, theories of change rely upon a willingness to be open-minded, trusting and engaged: with other stakeholders (via transdisciplinary working), with the complex and changing context (system interdependencies and thinking systemically), and with the intervention (at all points from design and implementation to operation). This requires time, intellectual effort and dedication, and a willingness to embrace flexibility.

For some professions, this goes against the practices embedded in their education and training. Engineers, for example, are often taught to define the problem and design an optimised solution under all anticipated performance conditions. For a narrowly-framed problem (a component in an engine, say) this is generally appropriate. For complex infrastructure and urban systems, it is not. Different design options have different sets of consequences that depend on many factors, including the behaviours of the users. This introduces uncertainties into the decisions that need to be made, something we will return to as part of UKCRIC's Theory of Change.

Adjusting the design, construction or mode of operation (so called operational protocols) in response to how an intervention is performing is often neither easy nor financially possible. Adjustment introduces a dynamic component and business models[5] must adapt so that intended outcomes can still be delivered.

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4 Pawson R (2013). The science of evaluation: A Realist Manifesto. Sage Publications Ltd. ISBN: 9781446252437.

5 Business models are traditionally interpreted as a company's core profit-making plan; in this Little Book we interpret the term more broadly as a balance between all of the positive consequences of an intervention balanced against all of its negative consequences (including cost).

5. UKCRIC's Approach to System Interventions

Because of the enormous capital and operational costs involved with infrastructure and cities – the materials and resources consumed (and wasted), the potential for environmental and social harm – we cannot afford to continue doing what we have been doing. We must change the way that we create and operate the life support mechanisms for civilised life.

UKCRIC has a mission to underpin the renewal, sustainment and improvement of infrastructure and cities. It was formed because of the evident struggle of those who commission, design, construct, operate and govern infrastructure and urban systems to think and act in a joined-up way (in part because current approaches do not enable it). In short, UKCRIC seeks to address the adverse consequences that arise from siloed thinking and working.

UKCRIC is a distributed set of facilities, capabilities and staff, hosted by 15 of the UK's leading research-intensive universities, who are eager to transform the way they conduct research in this domain – from competition to collaboration. The Collaboratorium was funded by a £138m capital grant from the UK Government, a sum matched by its partner institutions, to create a suite of complementary, world-class laboratories, urban observatories, and an advanced modelling and simulation facility. UKCRIC has a shared understanding of how to design, test, monitor and adapt newly-created or refurbished existing infrastructure systems, and engineer them to be synergistic with the urban systems with which they are interdependent.

UKCRIC targets two primary outcomes:

- For everything that is done to deliver a far more extensive range of benefits than has traditionally been achieved.
- To de-risk investment decision-making by articulating all the likely consequences of an intervention.

Working in this domain is inherently complex and requires those contributing to an intervention to think systemically, and to continually learn, iterate and refine their practices, recognising that what it does will both influence and be influenced by a very wide range of systems and stakeholders. The challenge is to harmonise these systems and stakeholders by joining up their thinking and practices across sectoral, practitioner, governance and academic disciplinary silos. UKCRIC aims to do this by weaving pioneering research and development into routine practice using a range of methods.

UKCRIC's approach recognises that the foundation for all decision-making, whether to choose 'business as usual' or transformative advances in creating, operating, refining and repurposing infrastructure and urban systems, demands a comprehensive and rigorous evidence base. The creation of this evidence base must emerge from theories and practices (tried and tested experimentally and numerically) founded on a deep and pervasive understanding of how infrastructure and urban systems work to deliver effective and efficient outcomes. This is where UKCRIC's facilities come into play.

UKCRIC's systemic approach recognises that any design process involves repeated iteration and that any intervention in infrastructure and urban systems is inherently complex – uncertainties arise from several sources, but particularly how people, the users of the systems, react to the changes. UKCRIC therefore advocates the use of a logical sequence of methodologies embracing multiple feedback loops. This approach to dealing with complexity and uncertainties reinforces the earlier argument that every intervention should be designed to be 'an observatory' in its own right – an approach that embraces rather than fears uncertainty. This implies the need for an unprecedented degree of agility, trust and buy-in from all those involved, and new forms of contract and governance, to provide support and confidence to decision-makers. Empowered by this thinking, the challenges of changing our infrastructures and cities for the better can be confidently addressed.

6. The Three Theory of Change Spheres – Control, Influence and Interest

The three-spheres concept, which derives from a method based on outcome mapping[6], describes the change pathways of a theory of change, from conception and design through monitoring, evaluation and learning, to outcome delivery. The three spheres model illustrated in Figure 2 enables:

- Accurate design of the projected outcomes ('level-headed objectives and expectations').
- A comprehensible depiction of the influence of activities on the outcomes.
- The obligations required to realise the intended outcomes.
- A clearly-articulated time horizon.
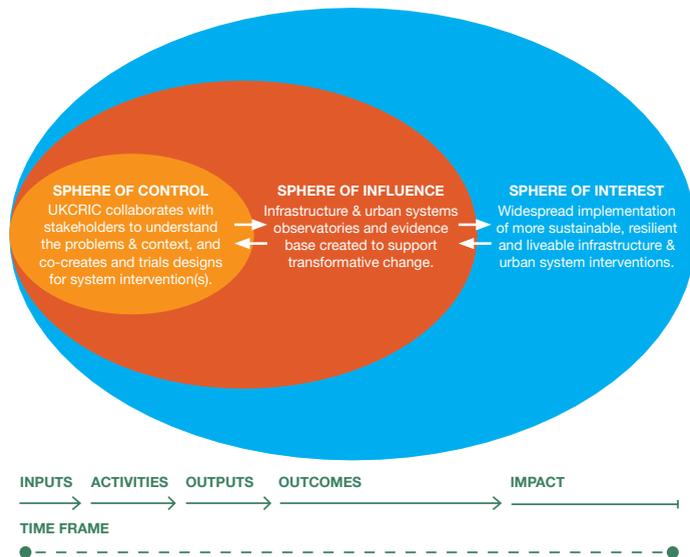
Figure 2. The three-sphere model of the change process

[6] Earl S, Carden F & Smutylo T (2001). *Outcome Mapping: Building Learning and Reflection into Development Programs*. IDRC, Ottawa, ON, CA.

This framework reflects the consistent narrative thread running through UKCRIC members' research over the past 20 years. Each sphere in Figure 2 (and described below) includes processes that are prompted by changes in other spheres, replicating UKCRIC's requirement for iteration and circularity of thinking embedded in its systemic thinking.

- Sphere of Control – represents all a project or programme can control and is completely responsible for: the inputs, activities and outputs of those activities, including the quality of the work and interactions with stakeholders.
- Sphere of Influence – denotes the outcomes from a project's or programme's activities that have culminated in trialling design options for the intervention(s). The sphere of influence is outside the control of the project or programme (i.e., one cannot control the actions of others), yet influence can be brought to bear on the decisions and behaviours of others due to the rigour of this foundational work, the collaborative approach that has embraced all relevant stakeholders, and the comprehensive and transparent reporting of the trialling of the interventions. Direct influence concerns the short-term translation of outputs to outcomes since they are exactly tied to a project's or programme's activities. Indirect influence is about reactions to those short-term outcomes and involves responses to and iteration with decision-makers when making the case for change, shaping the business models and governance regimes, and 'socialising' the thinking with the wider communities of interest who are influenced by the interventions. As will be shown later, the UKCRIC approach is to involve stakeholders throughout the change process, and to be comprehensive and transparent in describing all of the likely consequences arising from the interventions. It is the fear of unintended consequences, hence risk to the decision-maker, that often compromises such a change process.
- Sphere of Interest – represents lasting structural change, changes in the nature and operation of systems supporting individuals and society, hence changes in the lives of people and the settings in which they exist.

The three-spheres model naturally maps to the three-layered outcome framework of the logic model – outputs, leading to outcomes and hence impact – yet it avoids any sense of linearity as it takes into account the feedback loops that inevitably occur in real world projects and programmes.

7. UKCRIC's Theory of Change

UKCRIC's Theory of Change has emerged from more than 20 years' research on different aspects of the introduction of collaborative working and thinking systemically to the challenges faced by infrastructure and urban systems. The methods developed for general application when focussing on different technical challenges have been combined into the framework shown in Figure 3.
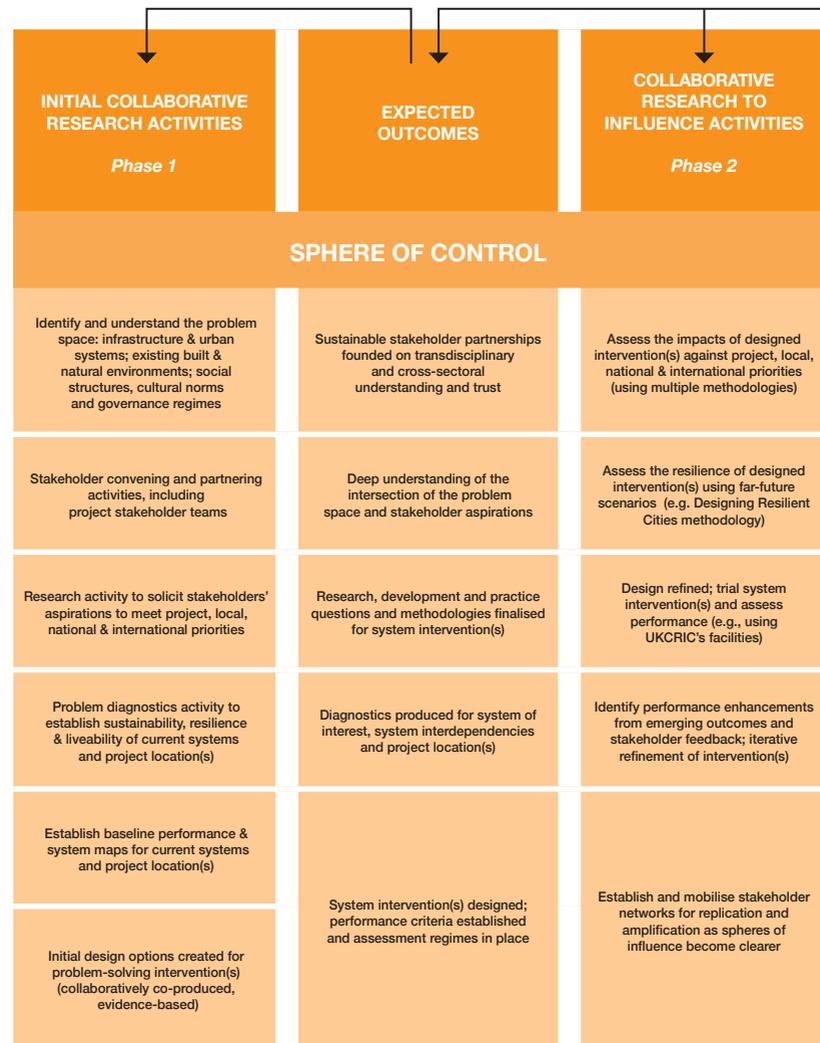
While many, perhaps naturally, have involved the authors and colleagues at the University of Birmingham collaborating with researchers at UKCRIC's partner institutions and elsewhere, the thinking of the whole UKCRIC community has helped progressively to shape and test the framework. The framework is underpinned by causal logic and conveys the cause-and-effect relationships reflected in iterations between interventions and outcomes according to the three spheres model. The core aspects of the approaches in each sphere are detailed in the remainder of this Little Book.

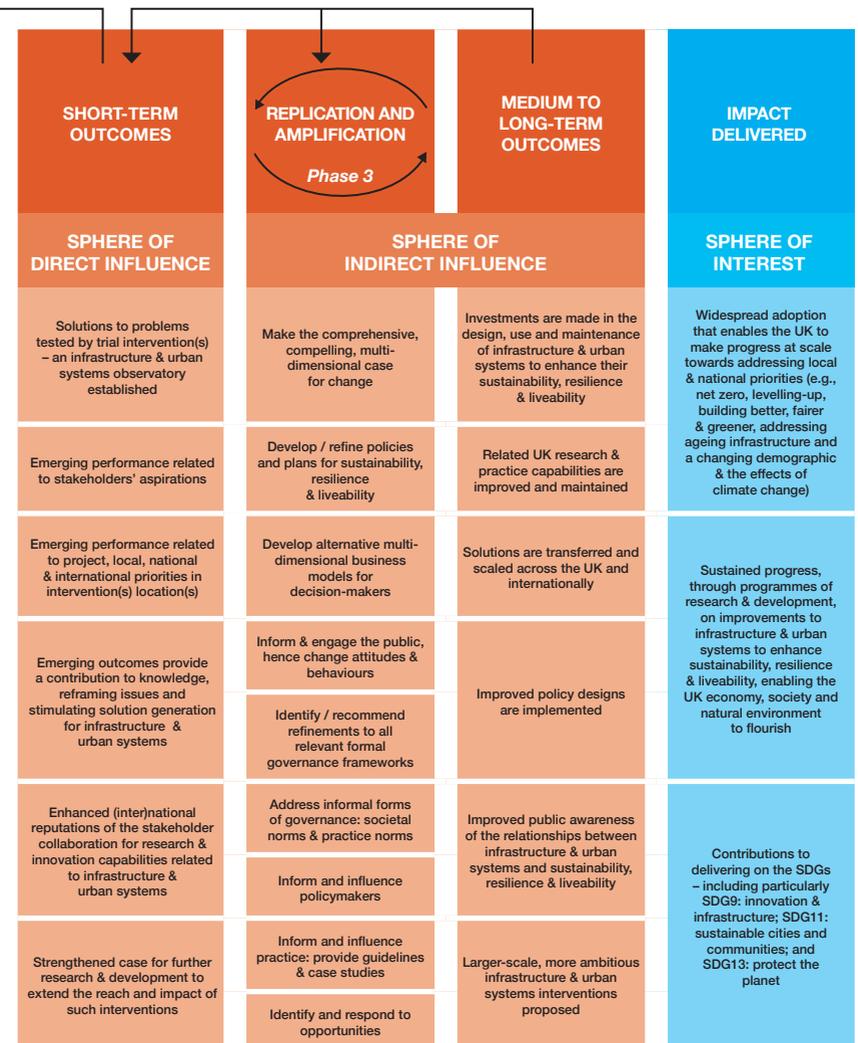| INITIAL COLLABORATIVE RESEARCH ACTIVITIES *Phase 1*	EXPECTED OUTCOMES	COLLABORATIVE RESEARCH TO INFLUENCE ACTIVITIES *Phase 2*
SPHERE OF CONTROL		
Identify and understand the problem space: infrastructure & urban systems; existing built & natural environments; social structures, cultural norms and governance regimes	Sustainable stakeholder partnerships founded on transdisciplinary and cross-sectoral understanding and trust	Assess the impacts of designed intervention(s) against project, local, national & international priorities (using multiple methodologies)
Stakeholder convening and partnering activities, including project stakeholder teams	Deep understanding of the intersection of the problem space and stakeholder aspirations	Assess the resilience of designed intervention(s) using far-future scenarios (e.g. Designing Resilient Cities methodology)
Research activity to solicit stakeholders' aspirations to meet project, local, national & international priorities	Research, development and practice questions and methodologies finalised for system intervention(s)	Design refined; trial system intervention(s) and assess performance (e.g., using UKCRIC's facilities)
Problem diagnostics activity to establish sustainability, resilience & liveability of current systems and project location(s)	Diagnostics produced for system of interest, system interdependencies and project location(s)	Identify performance enhancements from emerging outcomes and stakeholder feedback; iterative refinement of intervention(s)
Establish baseline performance & system maps for current systems and project location(s)	System intervention(s) designed; performance criteria established and assessment regimes in place	Establish and mobilise stakeholder networks for replication and amplification as spheres of influence become clearer
Initial design options created for problem-solving intervention(s) (collaboratively co-produced, evidence-based)		

SHORT-TERM OUTCOMES	REPLICATION AND AMPLIFICATION *Phase 3*	MEDIUM TO LONG-TERM OUTCOMES	IMPACT DELIVERED
SPHERE OF DIRECT INFLUENCE	**SPHERE OF INDIRECT INFLUENCE**		**SPHERE OF INTEREST**
Solutions to problems tested by trial intervention(s) – an infrastructure & urban systems observatory established	Make the comprehensive, compelling, multi-dimensional case for change	Investments are made in the design, use and maintenance of infrastructure & urban systems to enhance their sustainability, resilience & liveability	Widespread adoption that enables the UK to make progress at scale towards addressing local & national priorities (e.g., net zero, levelling-up, building better, fairer & greener, addressing ageing infrastructure and a changing demographic & the effects of climate change)
Emerging performance related to stakeholders' aspirations	Develop / refine policies and plans for sustainability, resilience & liveability	Related UK research & practice capabilities are improved and maintained	
Emerging performance related to project, local, national & international priorities in intervention(s) location(s)	Develop alternative multi-dimensional business models for decision-makers	Solutions are transferred and scaled across the UK and internationally	Sustained progress, through programmes of research & development, on improvements to infrastructure & urban systems to enhance sustainability, resilience & liveability, enabling the UK economy, society and natural environment to flourish
Emerging outcomes provide a contribution to knowledge, reframing issues and stimulating solution generation for infrastructure & urban systems	Inform & engage the public, hence change attitudes & behaviours	Improved policy designs are implemented	
	Identify / recommend refinements to all relevant formal governance frameworks		
Enhanced (inter)national reputations of the stakeholder collaboration for research & innovation capabilities related to infrastructure & urban systems	Address informal forms of governance: societal norms & practice norms	Improved public awareness of the relationships between infrastructure & urban systems and sustainability, resilience & liveability	Contributions to delivering on the SDGs – including particularly SDG9: innovation & infrastructure; SDG11: sustainable cities and communities; and SDG13: protect the planet
	Inform and influence policymakers		
Strengthened case for further research & development to extend the reach and impact of such interventions	Inform and influence practice: provide guidelines & case studies	Larger-scale, more ambitious infrastructure & urban systems interventions proposed	
	Identify and respond to opportunities		

Figure 3. UKCRIC's Theory of Change

7.1.1 Conversations and Cooperation Towards an Aspirational Future

It is widely appreciated that the starting point for any intervention in infrastructure and urban systems is to understand the collective aspirations of all involved in relation to the context that the intervention seeks to change. In the language of urban design professionals, this would be termed the 'design brief' to which all should work. There are several strands of activity that need to be integrated – and harmonised – when creating this design brief.

Firstly, the designer must acknowledge that, no matter the nature of the intervention, it happens in a geopolitical environment where considerations of national and international importance should influence what is done. These are best considered as guiding principles, and they include sustainability, resilience and liveability[7].

The definitions of the guiding principles, and the design brief as a whole, need to be comprehensive, clear and couched in accessible language. Some argue for 'smart' as an independent guiding principle. There are many interpretations of 'smartness' – including technologically-enabled, real-time data feeds to inform actions – yet the most helpful interpretation is perhaps 'smart' is only 'truly smart' if it delivers more sustainable, resilient and liveable outcomes[8]. Smart initiatives should therefore feature as a contribution to the design options for the intervention, where relevant, but should not be separated from the process. Although counterintuitive, 'dumb' solutions to problems (eschewing technology) might be more appropriate.

In the world of 2022, 'top down' priorities include the 17 UN Sustainable Development Goals[9], with their 169 targets and 232 indicators. These are widely accepted, timeless in nature and routinely used to assess policies, practices and research[10]. National priorities, while usually laudable in their intentions, are more ephemeral in terms of their detail. In the UK, they include the move to Net Zero, Levelling-Up, Building Back Better, Fairer, Safer, Stronger and Greener, and so on.

[7] Rogers, CDF (2018). Engineering Future Liveable, Resilient, Sustainable Cities using Foresight. *Proceedings of the Institution of Civil Engineers – Civil Engineering*, **171**(6), 3-9.

[8] Cavada M, Hunt DVL & Rogers CDF (2017). *The Little Book of Smart Cities*. ImaginationLancaster, Lancaster University, UK. ISBN: 978-0-70442-949-9.

These priorities, along with regional and local government priorities, should accompany the guiding principles by being reflected in the design brief as top-down considerations. The priorities are often embedded in regional or city visions, and these too should be taken into account.

Equally relevant are the bottom-up aspirations from the public. These can be more difficult to unearth and may require some form of consultation process. While much has been written about methods for participatory visioning, planning and design, and any one could beneficially be used, a particularly effective approach adopted by UKCRIC is the Aspirational Futures methodology[11].

This brings together representatives from all of the relevant stakeholders to articulate their aspirations for the places in question, consider and discuss them, and develop a co-created, synthesised set of target outcomes. When combined with 'top-down' needs and aspirations, this process can yield an unusually broad project brief. UKCRIC's approach goes beyond setting the design brief by recognising the need for all relevant stakeholders to be involved throughout the process – from identifying societal needs and problem diagnoses through to implementation of solutions – working in a manner that extends beyond disciplinary, practice and governance boundaries. UKCRIC has been researching how all involved in these ongoing conversations can move towards transdisciplinary working[12] to create holistic, integrated and successful outcomes.

7.1.2 Context is Everything – A Multidimensional Platform for Considered Change

Alongside stakeholder participation, a deep understanding is needed of the context in which the intervention is to bring beneficial change – the place (its history, geography and culture), the systems that currently support it (and how well they

[9] UN (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development*. [Online]. United Nations. Published: UN, New York, USA. Available at: www.sdgs.un.org/2030agenda [Accessed 10 June 2022].

[10] Guenat S, Purnell P, Davies ZG, Nawrath M, Stringer LC, Babu GR, ... & Dallimer M (2022). Meeting sustainable development goals via robotics and autonomous systems. *Nature Communications*, **13**(1), 1-10.

[11] Rogers CDF & Hunt DVL (2019). Realising Visions for Future Cities: An Aspirational Futures Methodology. *Proceedings of the Institution of Civil Engineers – Urban Design and Planning*, **172**(4), 125-140.

[12] Leach JM & Rogers CDF (2020). Briefing: Embedding Transdisciplinarity in Engineering Approaches to Infrastructure and Cities. *Proceedings of the Institution of Civil Engineers – Smart Infrastructure and Construction*, **173**(2), 19-23.

are performing) and the economic, social, environmental and political structures under which it is operating. The stakeholders collectively will know this, but this information must be collated, made uniformly available and communicated transparently since it forms an essential part of the evidence base to inform decision-making.

It also provides the foundation for defining current problems and, using predictive tools and models[13], for understanding how these problems will manifest if nothing is done to address them – the baseline 'business-as-usual' scenario.

Once again, many methods are available from the engineering and, particularly, social science domains for identifying and characterising the problems that could be addressed by improvements to infrastructure and urban systems. A tool developed by the UKCRIC community[14] uses a rigorous, explorative mixed-methods approach for identifying all critical challenges and, crucially, how they are interdependent.

While the outline of the approach shown in Figure 4 is straightforward, problems and solutions are complex and the network maps, in particular, will reflect this complexity[15]; the challenge maps and narratives provide more accessible interpretations.

This reflects the systems-of-systems perspective[16] that underpins all of UKCRIC's activities, and one that logically demands an understanding of the interdependencies between the system of interest (the system associated with the intervention) and all other infrastructure and urban systems. System mapping (Figure 5) enables this by identifying the systems that influence, or are influenced by, the system of interest, and by interrogation the nature and strength of the influence, the stakeholders involved and the likely consequences of the intervention in the system of interest.

Figure 4. Diagnosing urban problems and identifying interconnections

The final consideration before focussing on solutions is the consideration of the performance of the places themselves alongside the infrastructure and urban systems that support them. This is difficult because there are so many factors that affect this performance (performance parameters) and all need to be considered and assessed.

A method developed under the UKCRIC umbrella has identified 345 such performance parameters[17], although only a subset of these are likely to be significant for any intervention. This assessment derived from research where the focus was on the wellbeing of people and the planet – the essential considerations for how effectively infrastructure and urban systems support civilised life.

While these systems exist in the physical world, they can beneficially be modelled in the virtual world using 'digital twins' to understand system interdependencies and propose beneficial change[18]. Whatever approach is taken to characterise the context and establish the baseline performance of the place and how it operates, it is ultimately a judgement based on sustainability, resilience, and liveability.

[13] Hall JW (2019). UK Reveals New Platform for Infrastructure Data Analysis and Simulation Modelling. *Proceedings of the Institution of Civil Engineers – Civil Engineering*, **172**(3), 102.[14] Leach JM, Mulhall RA, Rogers CDF & Bryson JR (2019). Reading Cities: Developing an Urban Diagnostics Approach for Identifying Integrated Urban Problems with Application to the City of Birmingham, UK. *Cities*, **86**, 136-144.

[14] Leach JM, Mulhall RA, Rogers CDF & Bryson JR (2019). Reading Cities: Developing an Urban Diagnostics Approach for Identifying Integrated Urban Problems with Application to the City of Birmingham, UK. *Cities*, **86**, 136-144.

[15] Figure 3 in Leach, Mulhall, Rogers & Bryson (2019) showing a network map of Birmingham's city-service challenges.

[16] Hall JW, Tran M, Hickford AJ & Nicholls RJ (Eds.) (2016). The Future of National Infrastructure: *A System-of-Systems Approach*. Cambridge University Press. ISBN: 9781107066021.
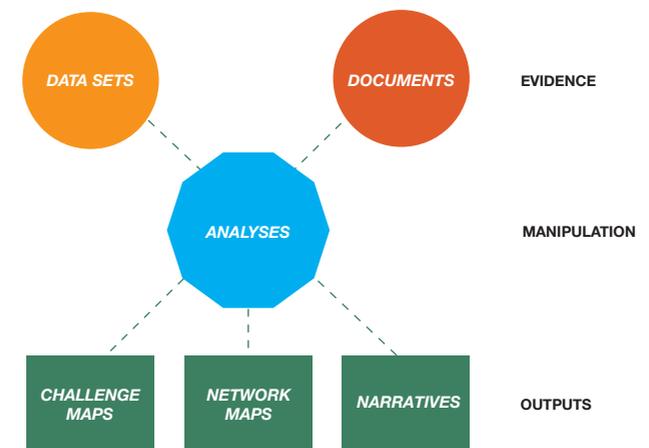
[17] Leach JM, Rogers CDF, Ortegon-Sanchez A & Tyler N (2020). The Liveable Cities Method: Establishing the Case for Transformative Change for a UK Metro. *Proceedings of the Institution of Civil Engineers – Engineering Sustainability*, **173**(1), 8-19.

[18] Schooling J, Enzer M & Broo DG (2021). Flourishing Systems: Re-envisioning Infrastructure as a Platform for Human Flourishing. *Proceedings of the Institution of Civil Engineers – Smart Infrastructure and Construction*, **173**(1), 166-174.
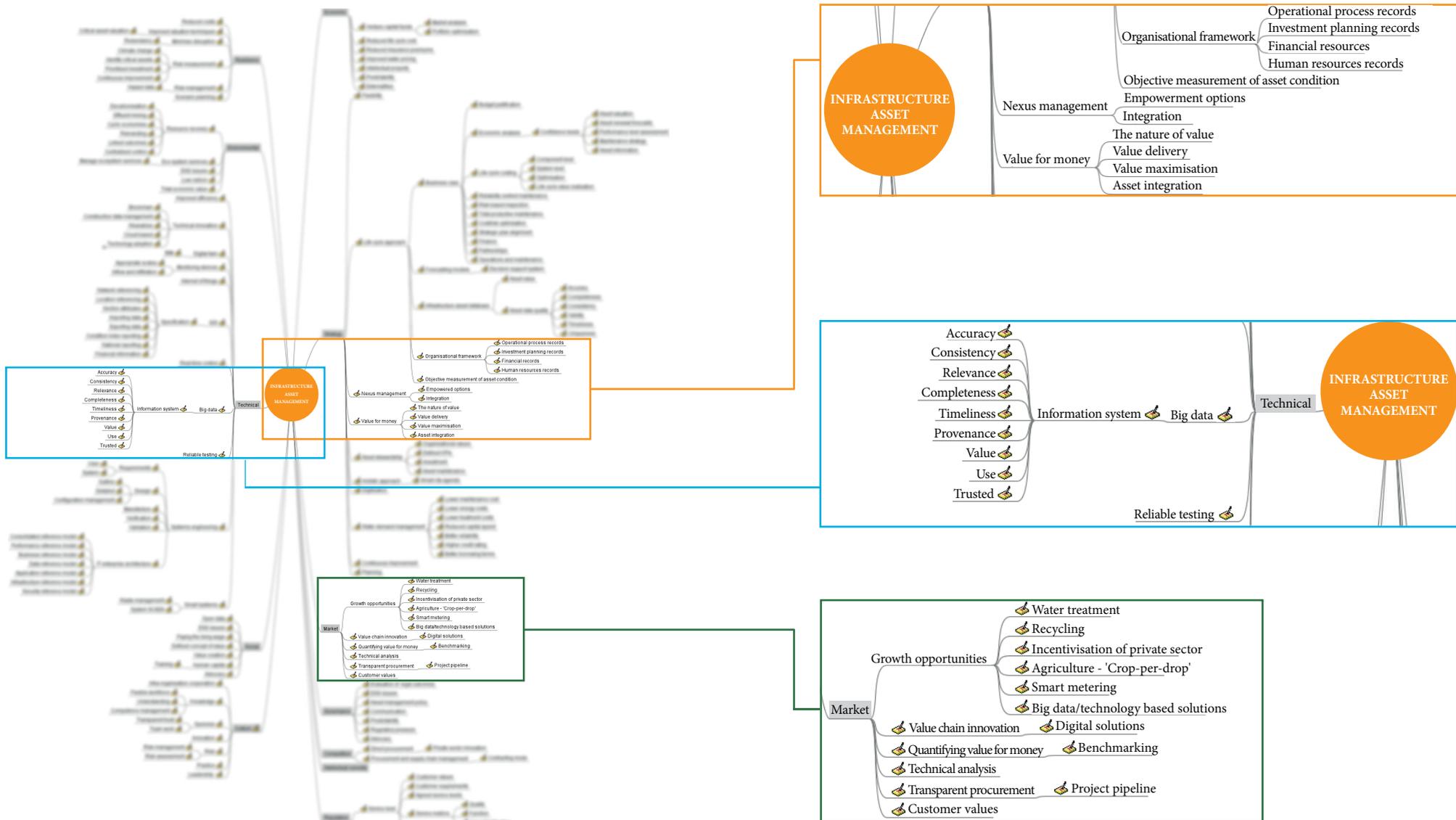
INFRASTRUCTURE ASSET MANAGEMENT

Organisational framework
- Operational process records
- Investment planning records
- Financial resources
- Human resources records

Nexus management
- Objective measurement of asset condition
- Empowerment options
- Integration

Value for money
- The nature of value
- Value delivery
- Value maximisation
- Asset integration

INFRASTRUCTURE ASSET MANAGEMENT

Technical — Big data — Information system
- Accuracy
- Consistency
- Relevance
- Completeness
- Timeliness
- Provenance
- Value
- Use
- Trusted

Reliable testing

Market
- Growth opportunities
  - Water treatment
  - Recycling
  - Incentivisation of private sector
  - Agriculture - 'Crop-per-drop'
  - Smart metering
  - Big data/technology based solutions
- Value chain innovation
  - Digital solutions
- Quantifying value for money
  - Benchmarking
- Technical analysis
- Transparent procurement
  - Project pipeline
- Customer values

Figure 5. Example system map identifying the value generating opportunities for Infrastructure Asset Management in the water industry by showing the interdependencies with other infrastructure and urban systems

7.1.3 Design Options – The Appliance of Ingenuity

All of the above activity – creating the design brief, understanding the context, diagnosing the problems, identifying the system interdependencies and establishing the baseline performance – provides the foundation for the creation of engineering solutions: the application of ingenuity (the root of the word 'engineering') to create design options for interventions. Just as there is typically no single problem, but several that combine to form the challenge, so there will be no single solution. Each of the design options will involve different actions and will yield different outcomes – it is for the decision-makers to choose between them. Design of such interventions will be accompanied by myriad uncertainties and will be based on assumptions (of system performance, user responses and user behaviours, for example). The purpose of the prior work described above is, as far as possible, to reduce or remove the uncertainties (understanding the context, problem diagnosis, system mapping) and pave the way for users to welcome the changes and act accordingly (co-creation of the design brief). However, the process should not be considered linear and sequential, but circular and iterative, and involve stakeholders in shaping and refining the design.

The design process requires urban professionals to draw on their education, training and experience in their core discipline when contributing to a multidisciplinary team that covers all essential disciplines. However, to be truly effective urban professionals should become sufficiently aware of the other disciplines so that they are confident to challenge thinking beyond their disciplinary boundaries and, in so doing, create new ways of doing things – that is, engage in *transdisciplinary* working. Designs carried out in this way will, inevitably, throw up searching questions of the diagnosis or the evidence base, and suggest refinements to the design brief – iterative working between the 'problem space' and the 'solution space' enriches the design process and improves the outcomes that it can achieve. It also serves to make clearer all of the likely consequences of implementing the intervention: negative unintended consequences are major causes of time and cost overruns on infrastructure and cities projects.

One of the critically important ways in which uncertainty can be removed from the design process is by trialling the designs. This is precisely the reason for creating UKCRIC's suite of infrastructure laboratories and urban observatories to physically test designs, and modelling and simulation facilities that can virtually test the designs (e.g., via digital twins). The scientific and business cases for conducting such trials when investing so much money on our infrastructure and urban systems is

incontrovertible (which is indeed why UKCRIC's facilities were funded). The crucial point here is that it is an investment, and not simply a cost. In any other sphere of operation, the investment in a large capital outlay to create something would be preceded by a significant investment in research and development (a modest percentage, perhaps 3-5% of the initial capital outlay) to ensure that the capital outlay would yield desired outcomes (a return on investment if it were a business proposition, for example). This is something that has traditionally not happened with major infrastructure and cities projects and programmes, with all-to-often serious consequences in time and cost overruns.

7.1.4 Fit for the Future – Ingenious Iteration

Infrastructure and urban system interventions often have to operate for decades or longer, making it is necessary to account for potential future changes. Design options may be straightforward to assess for their efficacy if implemented today, but assessing their future efficacy is far more uncertain.

This has traditionally been done by creating models and using them to generate predictions of future performance by adjusting the input parameters, such as growth in the number of users, changes in demography and climate, and so on[19]. Such models have become ever more sophisticated and now comprise 'digital twins' that replicate the physical situation in the virtual world[20]. This means that the interactions between physical systems that form our system-of-systems has a parallel in a digital system-of-systems, and this can be used to explore future changes[21].

Both sustainability and resilience are future-looking concepts, yet it is resilience – the ability of an intervention to function and continue to deliver its benefits in the face of change – that is of most concern to designers and commissioners of interventions alike.

[19] Hall JW, Thacker S, Ives MC, Cao Y, Chaudry M, Blainey SP & Oughton EJ (2016). Strategic Analysis of the Future of National Infrastructure. *Proceedings of the Institution of Civil Engineers – Civil Engineering*, **170**(1), 39-47.

[20] Centre for Digital Built Britain (2021). Digital Twin Toolkit: *Developing the Business Case for your Digital Twin*. [Online]. Digital Twin Hub at the University of Cambridge. Last Updated: March 15, 2021. Available at: www.digitaltwinhub. co.uk/files/file/62-digital-twin-toolkit/ [Accessed 13 July 2022].

[21] Centre for Digital Built Britain (2021). *Gemini Papers: How to Enable an Ecosystem of Connected Digital Twins*. [Online]. Digital Twin Hub at the University of Cambridge. Available at: www.cdbb.cam.ac.uk/files/gemini_how.pdf [Accessed 13 July 2022].

Much attention has been paid to this aspect of infrastructure design and authoritative guidance is available[22]. The approaches taken in practice, not unreasonably, concern anticipated changes in a world that looks and operates in a similar manner as today.

However it is necessary also to consider the implications if the world operates very differently and free from the constraints of current practices and governance regimes, and for this it is necessary to work with scenarios. Many organisations use scenarios to consider alternative futures influenced in different ways by the dominant effects of different drivers. While all scenario analyses have value because they prompt the user to think 'what if?', like modelling they are based on assumptions. If these assumptions prove to be wrong then the outcomes of the scenario analysis will be inaccurate. This has led some commentators to dismiss scenario analysis: "it is all very well to dream up scenarios, but what if they are wrong?" The same criticism can be levelled at modelling, of course.

To avoid this pitfall, it is recommended that extreme-yet-plausible scenarios are used to test the design of system interventions. This is the basis of the Designing Resilient Cities methodology[23], which has characterised four future worlds in different directions of travel from today:

• Market Forces – competitive, open markets drive development, materialism and individualism spread as core human values and social and environmental concerns are overlooked unless they get in the way of the markets.
• Fortress World – an authoritarian elite living in interconnected, protected enclaves control access to resources, while an impoverished majority are disenfranchised.
• Policy Reform – strong government policies support social and environmental practices and control people's choices and actions.
• New Sustainability Paradigm – a pervasive ethos of 'one planet living' leads to more sustainable living and working practices.

[22] National Infrastructure Commission (2020). *Anticipate React Recover: Resilient Infrastructure Systems*. [Online]. National Infrastructure Commission UK. Last Updated: May 2020. Available at: https://nic.org.uk/app/uploads/Anticipate-React-Recover-28-May-2020.pdf [Accessed 13 July 2022].
[23] Lombardi DR, Leach JM, Rogers CDF *et al.* (2012). *Designing Resilient Cities: A Guide the Good Practice*. IHS BRE Press, Bracknell, UK. 164pp. ISBN 978-1-84806-253-5.

These represent the core four of the six scenarios developed by the Global Scenario Group[24], and are founded on a long history of 'futures research'. They are effective testbeds because they free users to 'parachute in' to these worlds, explore how the interventions either work or are prevented from working, and enable designers to rethink their interventions based upon the results.

This method shows why interventions might be vulnerable if the way the world operates changes drastically and enables them to be adjusted to reduce or remove such vulnerabilities[25]. As with all of the methods described herein, this aids the decision-maker (or investor) by helping to de-risk decisions and investments by avoiding unexpected consequences. If, following the futures analysis, it is evident that an intervention is highly sensitive to changes in the future, then a decision to continue can still be made; it is simply a more informed decision.

[24] Raskin PD (2005). Global Scenarios: Background Review for the Millennium Ecosystem Assessment. *Ecosystems*, **8**(2), 133-142.
[25] Rogers CDF, Lombardi DR, Leach JM & Cooper RFD (2012). The Urban Futures Methodology Applied to Urban Regeneration. *Proceedings of the Institution of Civil Engineers – Engineering Sustainability*, **165**(1), 5-20.

The short-term outcomes of the above activities include major advances in understanding and knowledge of the system of interest and its relationship with both the places of interest and the way that the world works in these places. Equally importantly, it will have brought together stakeholders to create a community of interest. These outcomes alone are of profound value in ensuring that what happens to this particular system of interest in the future will be directed by unprecedented information in a comprehensive evidence base and a joined-up approach.

In other domains, this might lead to a handbook or manual that would inform users how best to use whatever it is that has been created. Such a handbook for an infrastructure and urban systems intervention might be provided by a Building Information Model (BIM), in which the infrastructure or system would be described (in terms of words, images, drawings, calculations, system models, digital twins and so on), design options for change described, and the outcomes of their assessment under both today's conditions and possible far futures reported. The potential for BIM goes far beyond the notion of a description of the system and the way it operates: it should contain the thought processes and governance regimes associated with the system's conception, design, operation and future possible developments. This would allow a stakeholder in the future to understand how it became the thing that it is, and inform future refinements free from uncertainties about its history.

More generally, these activities will have advanced the knowledge base on the domains covered by the system and provide a detailed case study of how similar systems could be designed or refurbished to deliver better outcomes. In addition, publication of the processes and the outcomes will reflect well on the stakeholders who have been involved: enhancing reputations and brand value as appropriate. In guiding actions in other, similar or parallel, systems, the activities will serve to improve urban professional practices and lead to enhanced value generation, thereby delivering benefits to the economy and society, and attracting further investment in such interventions.

[26] Cavada M, Bouch C, Rogers CDF, Grace M & Robertson A (2021). A Soft Systems Methodology for Business Creation: The Lost World at Tyseley, Birmingham. *Urban Planning*, **6**(1), 32-48.

[27] Construction Innovation Hub (2020). *The Value Toolkit*. [Online]. Designing Buildings: The Construction Wiki. Last Updated: 16 July 2020. Available at: www.designingbuildings.co.uk/wiki/The_Value_Toolkit [Accessed 13 July 2022].

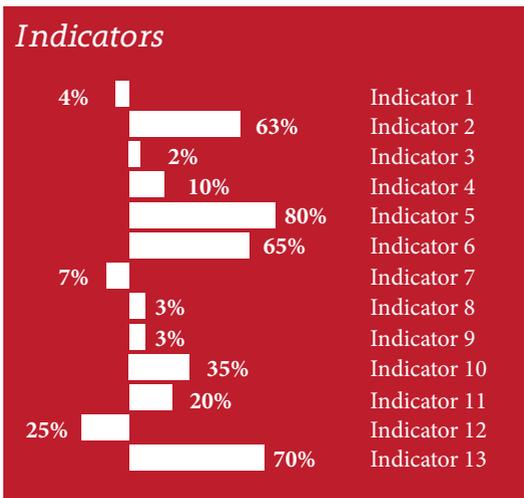### 7.3.1 Cases for Change – Considering (All) the Consequences

Having done all of this foundational work, UKCRIC's point of difference hereafter is its approach to formulating alternative business models, or value frameworks, in which the positive outcomes of design options are weighed against the negative outcomes[26]. The diagnostics analyses and system mapping will have identified the interdependencies with other infrastructure and urban systems that make up the system-of-systems operating in the place in question. What we now need to do is to establish the benefits, or not (disbenefits, if you wish), of implementing each of the design options – is it worth it? 'Worth', of course, depends upon the perspective of the person judging it, and it is therefore necessary to present the information in a manner that is accessible to any judge.

Drawing on the collective skills, knowledge and experience of the collaborative stakeholder group, armed with the network and challenge maps (and associated narrative) from the diagnostics analysis and system maps, combined perhaps with the findings from one or more of the many 'toolkits' created to identify the value realised by the intervention (e.g., the Value Toolkit[27], a 'capitals approach'[28], the City Analysis Methodology created by the authors[29], or other means of covering the full range of economic, social, environmental and cultural dimensions of impact) we come to a judgement on the likely value to be gained, or lost, to all of the impacted stakeholders and infrastructure and urban systems affected as a result of the sum of the impacts.

The key point here is to be comprehensive in identifying value outcomes, for which it is important to consider all of the possible impacts of the intervention. The City Analysis Methodology wheel shown in Figure 6 helps with this, for example, by considering goals, actions and indicators (or performance parameters) in support of societal and planetary wellbeing. While many of the indicators will not be relevant to the intervention (the indicator will remain unaffected, and hence value will be neither gained or lost), the mere fact of considering the indicator will have helped in the consideration of the value proposition of the intervention.

[28] Capitals Coalition (2020). *The Capitals Approach*. [Online]. Capitals Coalition. Last Updated: 14 January 2021. Available at: www.capitalscoalition.org/capitals-approach/ [Accessed 13 July 2022].

[29] Leach JM (2020). *Measuring City Performance and Diagnosing City Challenges: A Decision-Making Framework for Policymaking and Urban Design*. PhD Thesis, University of Birmingham, Birmingham, UK.

Lenses

Goals

Actions

Indicators

4%	Indicator 1
63%	Indicator 2
2%	Indicator 3
10%	Indicator 4
80%	Indicator 5
65%	Indicator 6
7%	Indicator 7
3%	Indicator 8
3%	Indicator 9
35%	Indicator 10
20%	Indicator 11
25%	Indicator 12
70%	Indicator 13

Figure 6. The City Analysis Methodology, which has 345 performance parameters (indicators)

Lenses:

- Environment
- Society
- Governance
- Economy and Finance

Goals (amalgamated):

- Ensure resource security and efficiency
- Enhance biodiversity, ecosystem services, and community and individual wellbeing
- Ensure equity, economic vitality, and appropriate governance and policies
- Maximise sustainable financial investment

Actions (amalgamation of selected actions)

- Minimise materials, food and water use and waste
- Ensure an enabling physical, social and economic environment to maximise individual capabilities in the context of carbon reduction and resource security
- Uncouple economic vitality from the CO_2 emissions associated with economic growth
- Uncouple governance structures and timescales from political cycles

Indicators (amalgamation of selected indicators)

- Energy saving attributes of households
- Population satisfaction with the quality of their city / neighbourhood / accommodation
- Access to and quality of parks and waterways
- Flows of energy, water, food, materials and people
- Appetite for and awareness of sustainable energy, water, food and materials
- Air quality and CO_2 emissions
- Population life satisfaction and standard of living
- Social cohesion
- Quality of education services
- Local authority spend on research, development and innovation

A simple example would be a road-widening project: the travelling public could benefit; those living on the road could be adversely affected by increased traffic; emissions due to local traffic delays might be reduced; traffic might be generated, increasing regional emission levels; there is a cost to the public, who are paying for it from their taxes; journey modes (cycling, walking, bus and train travel) might alter; local businesses might be boosted; not-so-local businesses might find trade reduces; travellers might shift their allegiance to this place (for the arts, central shopping, leisure facilities) as it is now more accessible; and so on.

Viewing an intervention in this way enables iteration of the designs to enhance the positive and reduce or remove the negative impacts[30]. For the road-widening project, measures could be implemented to limit the mobility modal shift to the car (separate, more pleasant walking and cycling routes; bus priority features to differentially benefit bus travel times; etc.). Some of these allied changes might be obvious and included as a matter of course, whereas some might not yet have reached the consciousness of the designer and be overlooked. By considering all likely (and perhaps all possible) consequences, then unforeseen consequences are unlikely to emerge and the decision to invest will be far less (politically, financially) risky. Likewise, accounting for all possible sources of value will make the 'value propositions' better. There will still be different sets of values and consequences associated with different design options, but each will be as comprehensive and transparent as possible.

For a theory of change, which, no matter what detailed approach is taken, is universally acknowledged to be outcomes-focussed, an analysis of all of the potential or likely outcomes fits perfectly with its core philosophy. Crucially, transparent and thorough analyses, design options and business models enable a comprehensive, transparent, compelling and defensible case for change to be formulated. Providing a multi-dimensional and robust evidence base for decision-makers is a primary goal of this work – multi-dimensional because the questions and criticisms will emerge from any of the stakeholder viewpoints, and robust so that the evidence cannot be gainsaid. It is the case for change that must be accepted by those responsible for the decisions on what is right for society, the economy and the environment, and hence those responsible for decisions on investment.

7.3.2 Good Governance – Another Case of 'Top Down' Meets 'Bottom Up'

However, even if there is an overwhelmingly compelling case for change, this is not enough to ensure that change will happen or will happen effectively. All of the forms of governance (both formal and informal) must be in alignment if the business models are to deliver their desired outcomes completely and effectively. Crucially, both these dimensions of governance must be identified once the design brief has been established since the 'governance landscape' influences the ability of an intervention to achieve the intended outcomes. It follows that the general governance landscape must be understood as part of the context when devising design options in the Sphere of Control, but detailed analysis of all relevant aspects of governance is needed once the alternative business models are under construction to support, where necessary, recommendations for changes to the governance regime (the action for which lies beyond the projects' or programme's control, and exists in the Sphere of Indirect Influence).

The formal mechanisms of governance include legislation, taxation and incentives, regulations, and codes and standards, and represent a 'top down' control on what can happen – the 'levers of government'. These mechanisms of governance will have been introduced for specific reasons to protect society, the environment or perhaps the economy; this means they will have been formulated and progressively refined to deal with 'issues of the day' and they might not be well-framed to deal with novel 'issues of the future'. In relation to the proposed system intervention, they must be identified and analysed to understand whether they would enable, or provide a barrier to, the intervention delivering its intended outcomes. If they provide a barrier, the analysis must extend to how they should change to help deliver the intended outcomes.

Likewise the informal forms of governance – individual and societal attitudes and behaviours, social norms that often govern end user compliance, and practice norms that frequently defer to sticking with the existing ways of doing things – need to be identified and nudged to avoid hindering intended outcomes. Once again, it is the involvement of all stakeholders, including representatives of the user community and practitioners, in setting the design brief and co-creating and testing the designs that provides confidence that the informal forms of governance will not be a barrier to delivery of the intended outcomes.

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[30] Rogers CDF (2018). Engineering Future Liveable, Resilient, Sustainable Cities using Foresight. *Proceedings of the Institution of Civil Engineers – Civil Engineering*, **171**(6), 3-9.

7.3.3 Policy, Practice and People – Preaching to Those You Want to Convert

Having reached the point of identifying the full suite of potential value outcomes and incorporating them in alternative business models so that decision-makers are able to judge which is best, the full detail of the process needs to be communicated in a manner that can be appreciated by the audience. Alongside the detail of the intervention must be included the case for change, the outcomes and what else might need to change (such as the governance regime).

In a nutshell, the information to be communicated consists of what is being proposed, why it is a good thing, and what the consequences will be of doing it (including what will change as a result of it being done). The evidence base and analyses must be sufficiently comprehensive and rigorous so that questions starting "what if … ?" can be answered authoritatively. The audience will, of course, dictate the nature of the communication.

Policymakers (usually politicians) and investors will judge the value generated in different ways, and yet all should appreciate the full range of:

- Direct economic value (typically the first consideration)
- Indirect economic value (which is often hidden, but which these methods will 'unearth')
- Social and cultural value (for politicians, the effect on people who vote them in; for investors, the end-users of the infrastructure or urban system service purchased in some way)
- Environmental value (for which they, and we, all have a responsibility to protect and enhance)
- Political value (since it will enhance the 'brand value' of the policymaker or investor)

By revealing all of the likely consequences of making a decision in favour of the intervention, the decision is de-risked as much as possible, while by offering as broad a set of valuable outcomes the decision is encouraged – these are the two primary goals of the UKCRIC suite of methodologies underpinning its theory of change.

Those in practice, such as urban professionals (engineers, architects, planners and so on), will need the information to be presented in a different, and in some ways more detailed, manner. Details of the design brief, the nature and performance of the existing context (including existing infrastructure and urban systems) and the results of the trials of the intervention, for example, will be important if the intervention is to be scaled up or transferred to different contexts. Building Information Models have been advocated as a platform for this information, backed up by peer-reviewed publications and authoritative reports. Alignment with the formal forms of governance will also be important. Case studies are a particularly powerful mechanism of providing confidence to practitioners, but only if they include this detailed information.

Informing and engaging the public – the end users of the infrastructure and urban system services – requires a different approach still, starting with the use of accessible (though not superficial) language. Informing involves raising awareness and presenting the information in such a way that the receiver of the information becomes knowledgeable on the nature of the context, the intervention and its outcomes. Engaging involves a degree of transformation of the receiver of the information, by changing attitudes and ultimately behaviours because of the strength of the evidence. While again the involvement of end-users throughout the process should help, for those not involved the spectrum of awareness-knowledge-attitude-behaviour[31] must be borne in mind in devising any form of dissemination.

While written documents of different sorts are likely to prove most effective for policymakers (white papers, for example), investors and those in practice, all backed up by peer-reviewed papers and reports, a variety of media might be used to inform and engage the general public.

The UK, and indeed all countries with well-established and highly-developed infrastructure and urban systems, faces many challenges in changing (developing, refurbishing, upgrading and augmenting) its existing built fabric and operational systems so that what we have available to us is sustainable, resilient and liveable – in other words, fit for the future. This has to be done in the context of limited budgets and pressing social and environmental imperatives, meaning that all investments must be as effective as possible in delivering valuable outcomes across all three pillars of sustainability: economy, society and environment. The economic gains to be generated by efficiently created and operated infrastructure and urban systems are well established and understood and need no advocacy; it is the other two pillars that require deeper consideration.

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[31] Topal HF, Hunt DVL & Rogers CDF (2021). Exploring Urban Sustainability Understanding and Behaviour: A Systematic Review Towards a Conceptual Framework. *Sustainability*, **13**(3), 1139.

The inherent tensions of climate change – minimising our adverse effects on the atmosphere to minimise future climate change, and building in resilience to our systems so that we can accommodate the changes in climate that we will face in the future – are frequently headline news. This imperative is written into law and espoused by almost all in authority, and therefore will feature in the design brief for infrastructure and urban systems interventions. However there are very many other ways in which we need to live 'within our planetary boundaries' (e.g., pollution, waste, resource scarcity and security, protecting biodiversity), and these also must feature in the design brief and intended outcomes of this theory of change.

Likewise, social justice should lie at the heart of the provision and improvement of infrastructure and urban systems, which should be responsive to the needs and wants of the people they serve. These are, again, reflected in the priorities of local and national governments. Although they are likely to persist in some form no matter the political priorities of those governing, perhaps a better touchstone for the inclusion of social dimensions to the design brief would be the 17 UN Sustainable Development Goals[32].

Treating this very broad set of aspirational, or desired, outcomes – and in some cases absolute imperatives – as the reasoning behind making changes to our infrastructure and urban systems, then making sure that any one change delivers as much value as possible across all of these elements of the design brief should be the goal of all urban professionals. This Little Book sets out a means of achieving this movement towards a better future.

[32] UN (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development*. [Online]. United Nations. Published: UN, New York, USA. Available at: www.sdgs.un.org/2030agenda [Accessed 10 June 2022].

8. Conclusion

This Little Book starts from the premise that change is happening all around us, some of it has profound consequences, and that infrastructure and urban systems must respond by changing too. Also, we must make this responsive change with limited resources so it must be economically efficient and, far from damaging the natural environment and society (as our current systems often do), we must do it in a way that enables both to flourish. Finally, we argue that we have one opportunity to get this right – we cannot afford (in any sense) to fail to deliver the best overall outcomes. Since we are focussing on outcomes, a theory of change is an appropriate vehicle to enable us to deliver them.

Several researchers and academic institutions have been working collaboratively, and across academic disciplines, over the past 20 years or so to create methods that support effective change, and many of them are now core members of UKCRIC, which is picking up the challenge of creating greatest value from our infrastructure and urban systems interventions and de-risking the investments needed to make them a reality. The theory of change presented herein embraces these methodologies.

This Little Book is written for a wide audience and it, like the theory of change it describes, aims to satisfy the needs and wants all of the potential audiences who should have an interest in making change happen in the systems that support civilised life efficiently and effectively. We have tried to construct a narrative in accessible language and have made references to more detailed sources of information for those who want or need it.

Importantly, this Little Book does not attempt to provide solutions – it is for those trained in the design, operation and governance of infrastructure and urban systems to bring their skills and knowledge to bear on the creation of solutions. Nor does it tell decision-makers what decisions to make – it is likewise their responsibility. What it does do is seek to enable better problem diagnosis, better solution formation, better cases for change founded on better and broader value propositions, and de-risked decision-making by removing many of the uncertainties that currently accompany decisions in this domain.

The methods are constantly maturing as they are applied to new challenges and people introduce their own ideas and experiences – perhaps these should be captured as scribbled margin notes so that this Little Book becomes a working document for those joining the struggle to move us all towards a more sustainable, resilient and liveable future.

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Appendix – A Definition of Theory of Change

There are many different definitions of the term 'theory of change'. Although academics might argue about the robustness of entries in popular information sources, for the purposes of this Little Book the definition in Wikipedia will suffice[33]:

- Theory of Change (ToC) is a methodology for planning, participation, adaptive management, and evaluation that is used in companies, philanthropy, not-for-profit, international development, research, and government sectors to promote social change. Theory of Change defines long-term goals and then maps backward to identify necessary preconditions[34].
- Theory of Change explains the process of change by outlining causal linkages in an initiative, i.e., its shorter-term, intermediate, and longer-term outcomes. The identified changes are mapped – as the "outcomes pathway" – showing each outcome in logical relationship to all the others, as well as chronological flow and feedback loops. The links between outcomes are explained by "rationales" or statements of why one outcome is thought to be a prerequisite for another[35].

The innovation of Theory of Change lies (1) in making the distinction between desired and actual outcomes and (2) in requiring stakeholders to model their desired outcomes before they decide on forms of intervention to achieve those outcomes.

Theory of Change can begin at any stage of an initiative, depending on the intended use. A Theory of Change developed at the outset is best at informing the planning of an initiative. Having worked out a change model, practitioners can make more informed decisions about strategy and tactics. As monitoring and evaluation data become available, stakeholders can periodically refine the Theory of Change as the evidence indicates. A Theory of Change can be developed retrospectively by reading program documents, talking to stakeholders, and analysing data. This is often done during evaluations reflecting what has worked or not in order to understand the past and plan for the future.

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