Response to

The Second National Infrastructure Assessment: Baseline Report

Consultation

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February 2022

Introduction

The Second National Infrastructure Assessment: Baseline Report represents a significant achievement and the opportunity to provide additional evidence to support the next steps on the route to the Second Assessment is warmly welcomed.

This document responds to questions 1, 2, 3, 6 & 7 posed in The Second National Infrastructure Assessment: Baseline Report. It has been prepared by Dr Maria Pregnolato and Dr Neil Carhart and represents our views and expertise with the acknowledgement that many others within the Faculty of Engineering and beyond at the University of Bristol can offer significant additional insights to the questions not addressed here in detail.

The first selection below offers a summary of the themes of this response with the detailed responses covered over the subsequent pages. The responses have been kept deliberately brief with further information and data highlighted in relevant references. The responses are largely concerned with the scope and strategy of the Assessment. We would be happy to address any further questions or points of clarity and would be delighted to offer our future support to the Commission in the preparation of the Second Assessment.

Summary of Response

We strongly endorse the NIC's underpinning principle of taking a whole system approach but highlight that capacity to do this is also a fundamental challenge for the wider infrastructure industry. Therefore, regarding Question 1, the nine challenges would benefit from a complementary explicit focus on the importance of interdependency (between the challenges themselves and elements of the infrastructure system-of-systems) and the need for inclusive cross sector collaboration. Furthermore, health impacts, particularly those associated with major new infrastructure projects could be given greater prominence under the climate and environment theme. Funding policy (Question 2) could be amended to ensure it better facilitates the collaboration and joined-up thinking capacity required.

The Design Principles (Question 3) are of great value and would be complemented by additional case studies, stories of success and practical examples for those who perhaps do not see themselves as operating in a design-orientated way.

Addressing Question 6, digitalization and related technologies can help with the maintenance and management of infrastructure, for example with the optimization of actions during the life cycle of a structure. Work on the Clifton Suspension Bridge provides an example of some novel applications to legacy infrastructure assets. Living laboratories (such as the European project SERA or the Clifton Suspension Bridge in Bristol) are also advocated by the South West Infrastructure Partnership (SWIP) to accelerate transitions to net zero, enable rapid experimentation, prototyping and assessment of innovations at scale in the real world.

Finally, barriers for the uptake of Digital Twins in the Civil engineering sector are discussed (Question 7), including technological maturity, availability of skills and understanding of use cases and potential value. Consultation in Bristol on Digital Futures identified general challenges in the transition to a more digital future including the consideration of currently underrepresented communities in the planning of the built environment.

Response to Specific Questions

Question 1: Do the nine challenges identified by the Commission cover the most pressing issues that economic infrastructure will face over the next 30 years? If not, what other challenges should the Commission consider?

While we agree that addressing the nine challenges identified by the Commission will be critical, we would like to use this opportunity to also emphasis and endorse the particular importance and challenges associated with one of the Principles which underpin the Assessment: "**taking a whole system approach, understanding and studying interdependencies and feedbacks**". Reaching net-zero, levelling up and achieving climate resilience cannot be achieved in isolation from one another. Many of the challenges in delivering these outcomes arise because they must be delivered simultaneously. Balancing the demands each present is critical, but often underappreciated. Actions to address urban mobility can impact surface water management in positive and negative ways; transitioning to a circular economy can influence heat and energy efficiency.

The role interdependencies play in the resilience, fragility, efficiency, efficacy and sustainability of the infrastructure system-of-systems in terms of cascading or other emergent effects is widely acknowledged. It aligns with previous NIC studies[1] and cuts across all nine challenges. Successfully addressing these challenges and enabling infrastructure to facilitate the satisfaction of society's needs over the next 30 years cannot be achieved by addressing these challenges in isolation from one another. The previous National Infrastructure Assessment highlighted the impacts that a fragmented approach can have and this key consideration should be taken forward to emphasize the complexity and interconnectedness of the nine challenges themselves as well as the infrastructure system-of-systems and the wider environments of society, politics and governance within which they sit.

It is therefore right that this whole system approach is central to the Commission and the undertaking of the Second Assessment, but achieving this approach across the wider infrastructure community is also both necessary and a challenge in its own right. The National Infrastructure Commission is well placed to foster this cross sector inclusive collaboration. The themes may therefore benefit from an acknowledgement of the importance **of interdependency and inclusive collaboration** whenever they are presented.

Tools associated with a 'systems approach', as indicated in the NIC Design Principles, and advocated by the Institution of Civil Engineers (ICE)[2,3] and others, provide a potential solution to the challenges of interdependency. Assessing progress in adopting initiatives like the ICE's 'Systems Approaches to Infrastructure Delivery', their extension through the whole lifecycle of infrastructure systems and the

[1] National Infrastructure Commission (2020) Anticipate, React, Recover – Resilient infrastructure systems [online] Available at: https://nic.org.uk/app/uploads/Anticipate-React-Recover-28-May-2020.pdf]

[2] Institution of Civil Engineers (2020) A Systems Approach to Infrastructure Delivery [online] Available at: https://www.ice.org.uk/getattachment/knowledge-and-resources/briefing-sheet/a-systems-approach-to-infrastructure-delivery/ICE_Systems_Report_final.pdf.aspx]

[3] Institution of Civil Engineers (2021) Engineering rebellion – A study into the future of civil engineering [online] Available at: https://www.ice.org.uk/ICEDevelopmentWebPortal/media/Documents/News/ICE_Engineering_Rebellion_Report.pdf]

industry's abilities to utilize these methods could be within scope of the Second National Infrastructure Assessment.

The South West Infrastructure Partnership (SWIP) consulted with over 500 infrastructure stakeholders across the south west region to develop a route map to net zero. This consultation also advocated for a joined-up systems view. The consultation underlines how urban and interurban transport cannot be considered in isolation from decarbonization of the energy system, new digital technologies, climate change and flood management[4]. The route map has three key pillars: Carbon Literacy, a Net Zero Systems Mindset & Leadership, and Collaboration. While these relate directly to challenges 2, 3 and 5, the transferable aspects of knowledge, leadership and collaboration are applicable to all nine.

In addition to this explicit focus on interdependency and a systems approach, we would also like to endorse the importance of health as mentioned in relation to 'climate resilience and the environment; and 'levelling up'. Again, there is the potential for improving the consideration of **health impacts and health inequalities** associated with major new economic projects to also become a cross-cutting challenge that could be emphasized alongside the existing nine.

Transdisciplinary collaboration and meaningful (as per the NIC Design Principles), equitable co-design with all stakeholders and at all stages of built environment decision making are also a key feature of the Tackling the Root Causes Upstream of Unhealthy Urban Development project (TRUUD)[5]. Funded by the UK Prevention Research Partnership, this £6m project is looking upstream at the complex system of urban development decision making to reduce health inequalities and non-communicable diseases. It has a particular focus on major new infrastructure and transport projects. This focus cuts across challenges of urban mobility, multimodal interurban transport and digital technologies as well the prevention and adaptation to climate change. This project also advocates a systems approach to try and address these complex interconnected systems and issues[6].

Question 2: What changes to funding policy help address the Commission's nine challenges and what evidence is there to support this? Your response can cover any number of the Commission's challenges.

Following on from our response to Question 1, as with the structure and operation of the industry, funding policy can be siloed around sectors or specific challenges. We suggest there is a potential need to complement this with initiatives that purposefully support inclusive collaboration across sectors and stakeholders and which help them in taking a holistic and joined up approach to addressing the interactions between all nine challenges.

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[4] https://southwestinfrastructurepartnership.co.uk/wp-content/uploads/2020/07/SWIP-Workshop-Report-FINAL.pdf
[5] https://truud.ac.uk/
[6] https://truud.ac.uk/systems-approach/

Question 3: How can better design, in line with the design principles for national infrastructure, help solve any of the Commission's nine challenges for the next Assessment and what evidence is there to support this? Your response can cover any number of the Commission's challenges.

The principles are clear, concise and have the potential to deliver significant value in the addressing the nine challenge areas and beyond. However, the **translation of principles such as these in practice is often challenging**, particularly for those who may not see their activities through an explicitly design-orientated lens. For example, 'value' is broad and will be interpreted differently by different stakeholders. **Case studies, stories of success, and experimental application to test the principles** in challenging scenarios would provide tangible examples, add value and help in their broader application and development. Test applications may also present opportunities for collaboration.

Case studies related to the ICE's Systems Approaches to Infrastructure Delivery, as mentioned above provide practical examples where application of a systems approach have supported greater appreciation for the wider context and the delivery of improved value. An approach to Strategic Performance Indicators for measuring and improving, with an emphasis on first understanding the purpose of infrastructure in producing valued societal outcomes and benefits through complex interactions across the infrastructure system-of-systems was developed[7] and applied[8] through a collaboration between the International Centre for Infrastructure Futures, the iBUILD research consortium and Infrastructure UK. This focus on outcomes is particularly important when considering new technologies or modal shifts.

Earlier work by the International Centre for Infrastructure Futures developed a framework for identifying and managing the outcome-orientated value that emerges from infrastructure interdependencies[9]. This consists of three elements which align with some of the design principles: (i) problem structuring, (ii) measurement and appraisal, and (iii) creating stakeholder understanding. These are operationalized through tools which facilitate several sub-activities including exploring the system boundary, establishing and framing the core development needs, identifying additional socio-economic and environmental needs, establishing measurement criteria and identifying collaboration mechanisms. Elements were applied to High Speed 2[10] and the Lower Thames Crossing[11].

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[7] Dolan et al (2016) A conceptual approach to strategic performance indicators, Infrastructure Asset Management, 3(4) p132-142 [Online] Available at: https://www.icevirtuallibrary.com/doi/full/10.1680/jinam.16.00015

[8] Carhart et al (2016) Applying a new concept for strategic performance indicators, Infrastructure Asset Management, 3(4) p143-153 [Online] https://www.icevirtuallibrary.com/doi/full/10.1680/jinam.16.00016

[9] https://discovery.ucl.ac.uk/id/eprint/1455020/4/ICIF_Interdependency_Framework_Report_Oct_2014.pdf

[10] https://discovery.ucl.ac.uk/id/eprint/1455383/2/ICIF_HS2_Interdependencies_Case_Study_Oct_2014.pdf

[11] https://discovery.ucl.ac.uk/id/eprint/1455371/3/ICIF_Lower_Thames_Crossing_Case_Study_Oct_2014.pdf

Challenge 1: The digital transformation of infrastructure – the Commission will consider how the digital transformation of infrastructure could deliver higher quality, lower cost, infrastructure services.

Question 6: In which of the Commission's sectors (outside of digital) can digital services and technologies enabled by fixed and wireless communications networks deliver the biggest benefits and what how much would this cost?

Digitalization and related technologies can help with **the maintenance and management of infrastructure**, for example with the optimization of actions during the life cycle of a structure (Structural Health Monitoring, SHM). Sensors allow for modelling structural and functional deterioration using observations and algorithms. SHM can reduce up to 90% the expected total costs and risk of a system, although it depends on a series of factors[12]: (i) technological system (equipment, connection); (ii) considered infrastructure system and context; (iii) the scope behind the SHM. SHM can be also connected with early-warning systems, e.g., for failure prevention.

In Bristol, a rapid deployment of a SHM system for short-term monitoring was deployed for the Clifton Suspension Bridge[13;14]). The system integrated wireless SHM and open-source data management systems to gather valuable information about the loading while the bridge was in use. The deployed system was an example of how SHM can be used to inform structural response models, as well as studies for traffic engineering purposes. The use of open-source software was critical to the successful deployment.

Work led by the University of Bristol in collaboration with others across Europe as part of the Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe (SERA) project looked at architectures and uses cases for smart city technologies employed in the context of urban living laboratories[15]. These **living laboratories**, also advocated by the South West Infrastructure Partnership to accelerate transitions to net zero, enable rapid experimentation, prototyping and assessment of innovations at scale in the real world. This also aligns with UKCRIC's City Observatory Research platfOrm for iNnovation and Analytics (CORONA) based in Newcastle, Bristol and Sheffield[16]. The Bristol Observatory in particular is gathering data and evidence relating to integrated monitoring to inform outcomes-focused infrastructure decision making.

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[12] Sousa et al. (2019). Quantifying the value of Structural Health Monitoring for Decision support. COST Action TU 1402 https://bit.ly/3ABFFYB
[13] Gunner et al. (2017). Rapid deployment of a WSN on the Clifton Suspension Bridge, UK. In: Proceedings of the Institution of Civil Engineers-Smart Infrastructure and Construction, 170(3): 59-71.
[14] Pregnolato et al. (2022). Towards Civil Engineering 4.0: concept, method and application of Digital Twins for existing infrastructure. Automation in Construction. In review
[15] Taylor et al; (2020) D7.3 Assessment of the potential for city laboratory based multi-hazard research and a long term development route map [online] available at: http://static.seismo.ethz.ch/SERA/JRA/SERA_D27.3_Assessment_of_the_potential_for_city-laboratory.pdf]
[16] https://urbanobservatory.ac.uk/corona

Question 7: What barriers exist that are preventing the widescale adoption and application of these new digital services and technologies to deliver better infrastructure services? And how might they be addressed? Your response can cover any number of the Commission's sectors outside digital (energy, water, flood resilience, waste, transport).

Our response here focuses on the barriers for the uptake of Digital Twins (DTs) in the Civil engineering sector[14], where the actual application is still largely at the prototype stage. Civil Engineering remains significantly behind other industries in the development and application of DTs. In the built environment, DT application is just beginning to take off, since "fully-realised examples are rare, even at the level of individual assets"[19] and "their form and formats are yet to be fully developed"[17]. DTs are seen as something very complex and difficult to achieve[17], whose "processes are uncertain and in their relative infancy"[18]. Current literature lacks practical insights into the "real-virtual-link" paradigm, e.g., how enquiry into the real structure should be performed, how the virtual structure should be designed, and the link implemented.

Despite the clear potential of DTs, multiple barriers prevent their wide application. Firstly, there is a lack of tangible understanding of the potential benefits, and the value of a DT (e.g., business models) is yet to be defined. Secondly, DTs require a high level of expertise, interoperability of models and multiple stakeholders. A further challenge is the computing demand due to data collection, digitisation representation and real-time synchronisation, alongside the high dependence on IoT. Finally, data collection relates to issues of accuracy and storage, privacy and security, IP protection and data exchange[19;20]. Overall, it is difficult to develop a business case that justifies the investment (and the complexity), and the DT revolution seems to need a social and cultural change of the workflow[20].

The limited demonstration of DT's value starts from a gap in the practice centred on the low level of development[20]. Also, DTs in the built environment are underrepresented, and detailed studies are recommended to align sector competency to technical and managerial aspects while exploring the relationship among DTs, outcomes and principles[19]. Further advances in modelling and simulation are needed to establish DTs in AEC practice.

Consultation in Bristol on Digital Futures (funded by the Centre for Digital built Britain) identified more general challenges and barriers in the transition to a more digital future together with actions to support the transition. The first of these aspects relevant to the question relates to establishing principles for the adoption of digital technologies to avoid potential adversarial consequences before their rollout. This issue was seen as particularly relevant in relation to the use of Artificial Intelligence. Improving citizen engagement was also a key recommendation. Barriers preventing citizen engagement should be identified and removed. Mechanisms to provide voices to those from underrepresented communities should be explored. Ways to demonstrate the value of citizen engagement must be found. The consultation suggested that this engagement must start with understanding the concerns of communities at the margins and developing experimental projects to prioritise areas of work. Knowledge and skills were also seen as a core challenge. Themes from this are being studied through the Bristol Digital Futures Institute[21].

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[17] Evans et al. (2020). Digital twins for the built environment. The IET (Institution of Engineering and Technology): London.

[18] Daskalova, M. (2018). The 'digital twin' – a bridge between the physical and the digital world [online]. Available at: https://cobuilder.com/en/the-digital-twin-a-bridge-between-the-physical-and-the-digital-world/ (accessed on 09.06.2020).

[19] Lamb, K. (2019). Principle-Based Digital Twins: A Scoping Review. [online]. Available at https://www.cdbb.cam.ac.uk/files/scopingreview_dec20.pdf (accessed on 5/5/2020)

[20] Arup (2019). Digital Twin - Towards a Meaningful Framework [online]. Available at: https://www.arup.com/-/media/arup/files/publications/d/digital-twin-report.pdf (accessed 1/06/2020)

[21] https://www.bristol.ac.uk/bristol-digital-futures-institute/