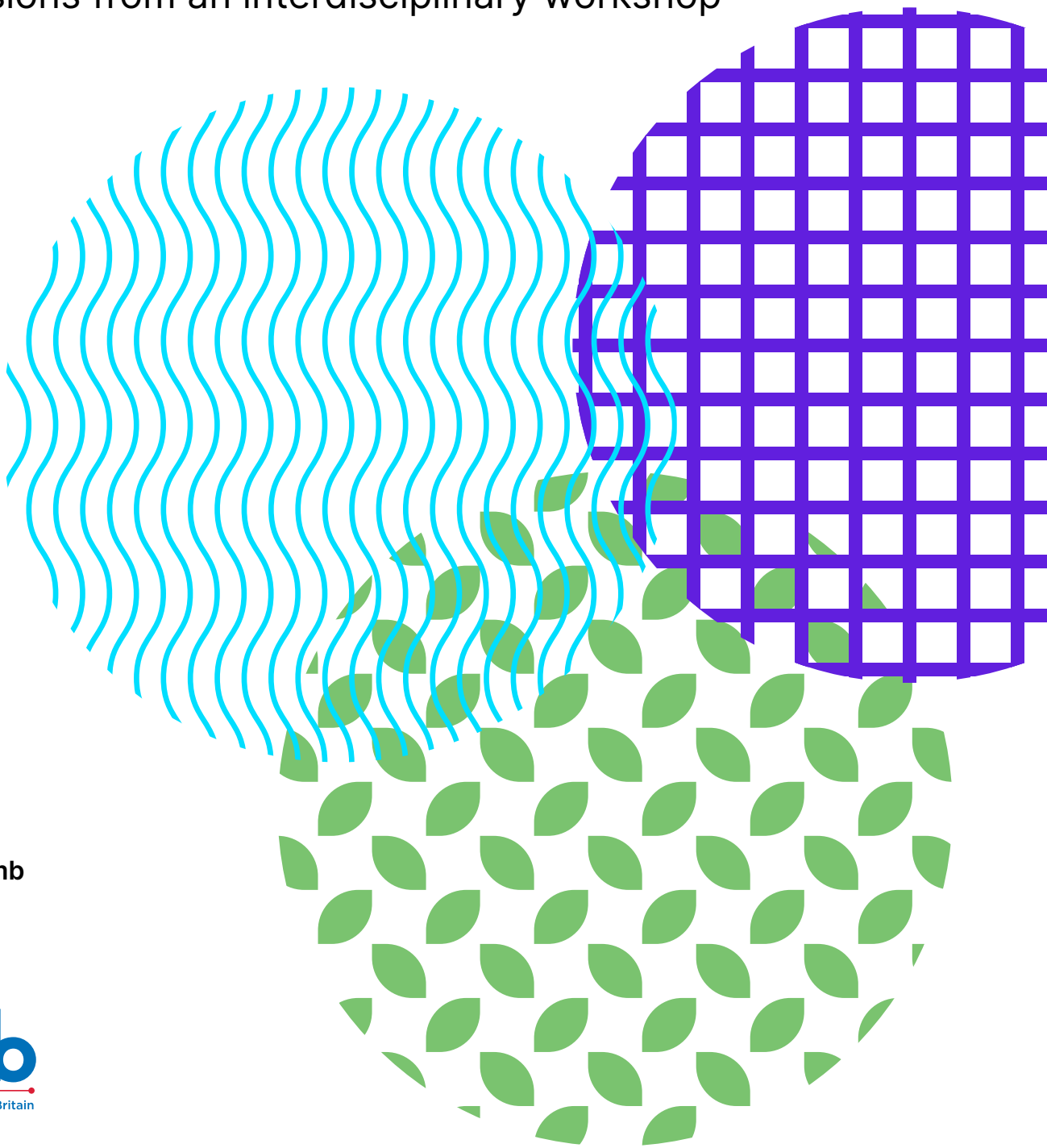
NATIONAL DIGITAL TWIN PROGRAMME

Modelling across the built and natural environment interface:

Conclusions from an interdisciplinary workshop



Kirsten Lamb

June 2021

cdbb
Centre for Digital Built Britain

Contents

Summary

The built environment both impacts and relies on the natural environment in complex ways. **Understanding this relationship better can lead us to make better decisions about how we manage both systems in balance with one another.** Both systems must continue to provide services and opportunities for people and nature to flourish for generations to come, and integrated digital modelling has a huge role to play in the ability to make that happen.

The workshop discussed in this report brought 12 experts from the built and natural environment modelling communities together virtually to discuss what opportunities could arise from better integration of digital models across this sectoral divide. Centred around the National Digital Twin programme (NDTp) on the built environment side and the Landscape Decisions programme on the natural environment side, the participants came together with mutual respect and curiosity about what could be learned from colleagues in other disciplines.

The consensus was that sharing models across interdisciplinary silos provides a valuable opportunity to address some of the world's most pressing problems and priorities. To enable this, the workshop concluded that the UK's research, industry and policy bodies must focus on the following priorities, simultaneously and systematically:

Make interconnected models accessible to stakeholders to drive better decisions, by making built and natural environment models visible early in the decision process

Bring communities together around a shared vision in order to frame better questions, as the basis for model integration

Develop a common approach / platform to enable better data and model sharing across disciplines, joined by shared architectures, and common standards for security and quality

Establish and share best practice at all scales, to support better local, regional and national decision-making.

This report argues that these would be key priorities for an interdisciplinary programme on model-based decision-making. If achieved, these priorities would lead to a better understanding of the complex trade-offs, risks and opportunities to manage the built and natural environment in ways that are better for people and nature long-term. Whether the intended outcomes are the enhancement of a local area of natural beauty, better respiratory health rates nationally, or the achievement of the global Sustainable Development Goals (SDGs), **model and data integration used thoughtfully and intentionally has the potential to help us achieve them**. Climate change is an urgent threat, but model integration represents a valuable opportunity.

We already have many of the tools we need to integrate models. However, there is a need to change the culture and processes around these tools so that decision-makers have the right information at the right time to identify critical trade-offs and opportunities. **Investment, processes, and cultures need to come together to ensure that we use these tools better.** The NDT and Landscape Decisions programmes are key stakeholders in this work which was enabled by the Construction Innovation Hub.

Key Terms

Built environment

A complex system of buildings, infrastructure, services and spaces, the purpose of which is to support to wellbeing of people and communities. It sits within the wider context of the natural environment, drawing resources and services from it and having various impacts on it.

Natural environment

A complex system of climate, geology, ecosystems and other processes, which arise organically, but is in part managed by humans to provide services and resources to society. It touches every part of the built environment, and is impacted by it.

Modelling

Using digital data - historical, real-time or projected - models can be used to answer questions about the current or future state of an object, system or process.

- **Predictive modelling** - Aids in decision-making by presenting the likely future state of an object, system or process with a focus on forecasting.
- **Exploratory modelling** - Aids in decision making by presenting possible scenarios with a focus on exploring uncertainties and seeking better questions.
- **Connected models** - Joining models of different objects, systems or processes together can provide new insights to decision-makers. For example, connecting predictive flooding models with models of transportation networks can help identify vulnerabilities in the system, and guide interventions that mean that emergency services are able to reach those impacted by natural disasters.

Digital twin

A model of a physical object, system or process that allows for analysis, insights and interventions into the performance of its physical twin in a reciprocal relationship. A National Digital Twin (NDT) would be a collection of connected models operating at the national level. Where digital technology has a reciprocal interaction with the physical world, this is also known as a **cyber-physical system**.

1.0 Why integrate natural and built environment models?

Digital models of the **built environment** are used to monitor the condition of assets – buildings, bridges, energy grids, buried pipes, etc. – and predict their performance in the future. This helps decision makers know when to repair, replace or modify them to improve their longevity or the services they provide. In the **natural environmen**t, ecosystems and processes are also monitored, enabling decision makers to understand how to minimise risk and maximise benefit from areas of land.

While there are a few instances where these two modelling disciplines are connected – for example, the Environment Agency using catchment models to predict flood damage to low-lying cities, or engineers using river flow models to predict scouring on bridge supports – the disciplines have remained largely separate when it comes to making important decisions. These silos are mirrored by funding bodies for academic research, the government departments that set policy priorities, and even the way we talk about built and natural environments as separate systems.

However, almost nowhere in the UK is nature untouched by human intervention or impact. Built infrastructure both relies on nature for resources and has a range of impacts on it. The built and natural environments of the UK are complex, interdependent systems that cannot continue to be considered separately if we are to face the climate and nature emergencies. Nor can they be considered separately from systems like logistics, manufacturing, and food and agriculture.

The big picture

The built environment relies heavily on nature – for materials, air, water, food, recreation – and in turn has a tremendous impact on it – including filling the atmosphere with carbon dioxide faster than it can be absorbed by existing plant matter and soils. From tree cover, to hydrology, to greenhouse gas emissions, to animal behaviour, our built systems are changing the planet more rapidly than nature can adapt. If we fail to bring the built and natural environment into better alignment, undoing some of the damage humans have caused during the Anthropocene Era, we will not be able to leave a liveable world to future generations.[1]

There are many ways we could accomplish this, but understanding which interventions are most effective, and which benefit society at the same time, is a difficult job. This is why integrated digital modelling is so important.

The insights and recommendations in this report were developed over the course of two workshop sessions held in January 2021. To see how these conclusions were reached, please read the background material for this report, available on request.

2.0 Better decisions through modelling systems-of-system

'Involving policy-decision-makers in the design of the integrated model [will] ensure it is relevant to their decision-making context and will be used.'

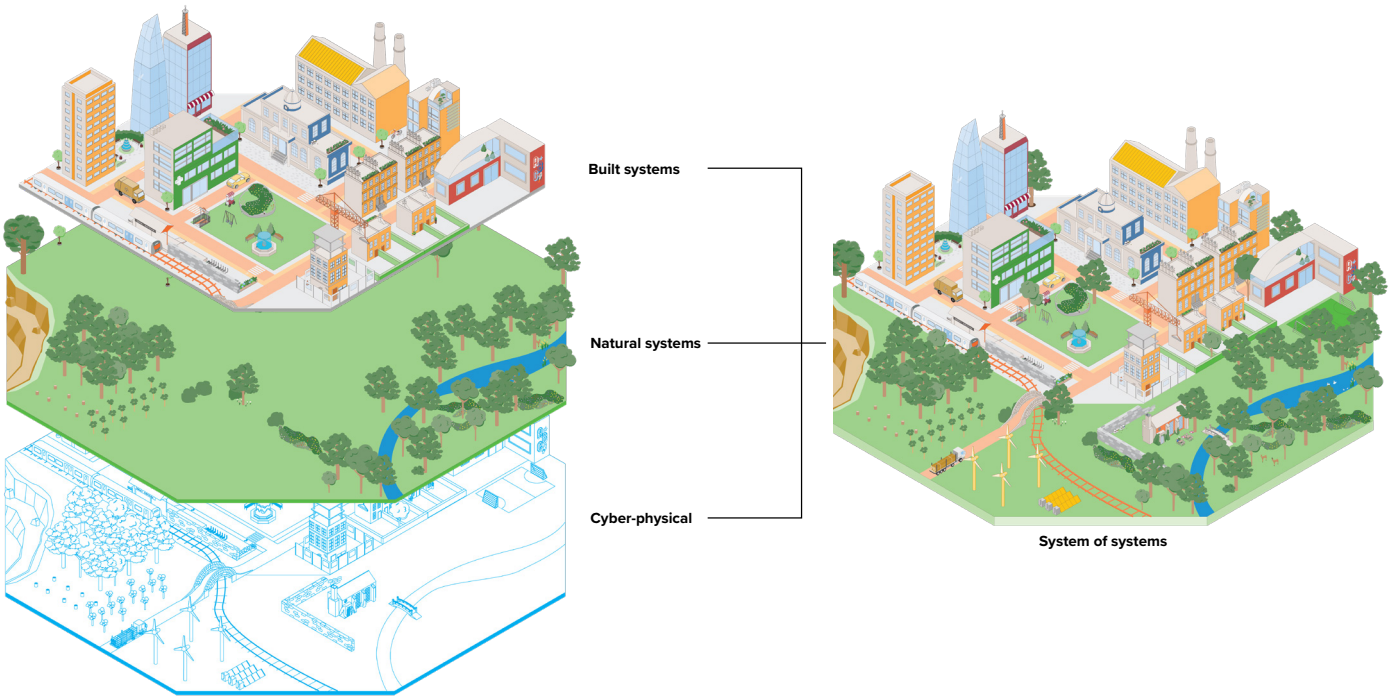
Workshop participant

Complex decisions require tools that can navigate complexity. For decades, computers have been helping to model scenarios and phenomena. Historically, these models have been limited to isolated, discrete contexts. Now, our improved computing capabilities have enabled us to join data and models together to create bigger and more accurate pictures of complex systems, interactions, and processes. This opens opportunities for new insights into our most thorny problems, and integrated pathways to meet multiple goals (e.g. Net Zero carbon emissions and biodiversity) at the same time, getting more environmental and social benefit from smaller, better-targeted investments.

2.1 Built and natural environment as complex, interconnected systems

To address the climate and nature crises, we cannot continue to think about the built and natural environment as independent from one another. The materials that buildings and infrastructure are made from; the energy transformed into heat, light and propulsion; the food we consume; the clean air and water we need all come from nature. What we build also changes the way soil and water behave; our energy consumption puts greenhouse gases into the atmosphere; forests and fens are cleared to make way for our farms and cities; animals change their behaviour in response to the presence of houses and roads.

Adding to the complexity of these intertwined systems is the internal complexity of both individually[2]. The built environment contains layers of interdependent infrastructure systems, **cyber-physical systems**, culturally significant spaces and buildings, the many services it provides, and the people who depend on them. The natural environment contains a complex web of interdependent processes, ecosystems, hydrological and climatological systems. Most importantly, changes to any of these systems have impacts that ripple out far wider, damaging the delicate web that sustains life on this planet. There are complex, reciprocal relationships between the built and natural environment that means it is impossible to make responsible decisions about one without understanding the other.



The built environment sits within and relies upon the natural environment. Cyber-physical systems, like digital twins, can model across both, giving us a better understanding of how they interact, and how the decisions we make in one will impact the other. Combined, these form a complex, interconnected system-of-systems.
Image source: 'Our Vision for a digital built Britain', 2021

2.2 Exploratory modelling for decision support

Decision-makers are faced with the difficult task of planning and taking actions without fully understanding the impact they will have. **Predictive modelling** shows a likely future state, seeking relative certainty to allow forecasting, and can therefore help determine, for example, when a component might need servicing, or what would happen to traffic at a junction if one lane of traffic was closed. In complex systems with many potential permutations, however, this type of modelling struggles to provide accurate forecasting. The likelihood of accurately predicting the future becomes much lower the more complex the system.

Therefore, **exploratory modelling** could help decision makers to explore and understand a range of possible outcomes[3], and plan around different scenarios to arrive at a decision based around flexibility and resilience in the face of uncertain futures[4]. By reframing the questions, better options may become visible. A truly joined-up approach for planning sustainable land use and urban development would look at how complex systems interact, the trade-offs made between them, and the impacts on the desired outcomes at all scales.

2.3 Environment-led design

In the current planning system, the workshop participants noted, environmental impact is often considered only after a decision has been made about what to build, and a design is being drawn up. The needs of nature and local communities, therefore, come up as roadblocks that designers must find a way around. What if instead nature and people were at the centre of the design criteria from the start? What if we made decisions based on what would lead to better outcomes for them?

One of the key concepts that emerged from the workshop was termed '**environment-led design**'. This is an approach to planning of both built and natural environment interventions that uses models and makes insights visible earlier in the decision process, providing a range of options. A planner may be faced with a challenge such as reducing congestion, providing affordable housing, or preventing flooding. Environment-led design would use data, models and input from a range of stakeholders to provide them with a wider menu of possible options; communicate the trade-offs between these options; present the whole-life value of assets and resources, not just financially but socially, culturally and environmentally; and align with local, national and global priorities. All of this would be visible to planners before any decisions are made about what and how – or whether – to build.

Workshop attendees asserted the importance of **involving policy decision makers** in the design of integrated modelling to ensure it is relevant to their decision-making context and will be used. They also pointed to the importance of wider participatory processes with community stakeholders and environmental experts. In environment-led design, local communities would understand the uncertainty of the models used and the need to align local projects with national

environmental strategies. They would have meaningful input into the decision and design, and they would have transparent access to understand the beneficial outcomes of any trade-offs they have made.

This proposal, which bears much in common with a change to Strategic Environmental Assessment (SEA) put forward by the UN Environment Programme[5], marks a substantial change from business as usual. Therefore, we need changes in the culture, processes and tools of landscape and urban decision-making. The workshop participants provided many ideas about how this could happen over the short term and long term.

Finding the best option

Sometimes the best intervention to achieve our desired outcomes is to build, but sometimes there is another solution. If our decision processes drive us toward new construction as the best, or only, option, we may not actually get the results we want. Various studies have shown that adding new lanes and new roads to relieve congestion, for example, often drives demand up and congestion increases as a result.

With the materials and energy required to build and demolish, often re-using what we have in creative ways is the greenest solution to providing housing or meeting changing use needs[6]. Nature-based solutions such as habitat restoration can help with flooding[7], biodiversity, air quality and various other problems we face. Where new assets are required, there may be ways of mitigating the impact, capturing carbon, and providing opportunities for nature to flourish.

The challenge is to understand the impact of different interventions so that the right decision can be made in each unique case, considering how they will contribute to the flourishing of people and nature. Taking environmental modelling and local needs as core to the decision process is key to arriving at better interventions, and targeting the allocation of scarce resources.

3.0 Stronger communities, better insights

'Before you integrate the data, you need to integrate the people.'

Workshop participant

Modellers and decision makers often point to the ability of models to provide insights. For the purposes of the workshop, the facilitators talked about this as 'better questions' that integrated built and natural environment models could help to answer. Questions that are already being asked of integrated models include:

- How much damage would a 100 year flood cause to this city centre?
- Can renewable energy meet projected future demand in the UK?

Rather than predicting a definite future state, however, the workshop was interested in how exploratory modelling could help decision makers come up with a range of possibilities, scenarios, and options for interventions. For example:

- How do green bridges over motorways benefit local species and ecosystems?
- How should the UK manage land use to produce a strong domestic timber supply and protect tomorrow's ancient woodlands if cross-laminated timer becomes a key building material in new builds to enable carbon capture?
- 'Will the housing crisis be solved by boosting housing supply with the government['s] new dwelling target through the planning system? What will the environmental cost of this achievement be?'[8]

The workshop participants agreed that exploring potential 'better questions' would be an important next step, involving a bigger, more diverse cohort of modellers, decision makers, and stakeholders. To enable this discussion, there would need to be better visibility of the models available, the relevant strategic priorities, the key stakeholders, and the gaps in the decision process where integrated models could be used.

Participants also pointed to the need for better visibility and coordination across sectoral gaps and governing bodies on environmental and social goals. They went on to discuss how to bring interdisciplinary communities together around these questions and a shared vision of better outcomes.

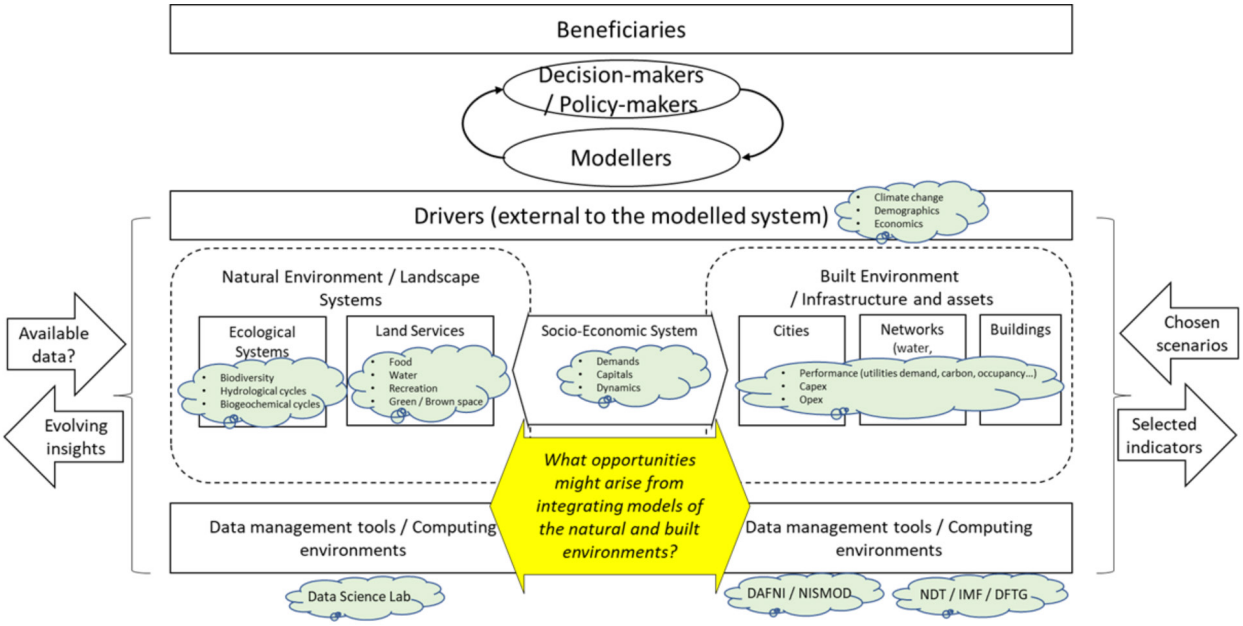


Figure 1: This simplified map of decision-making in the built and natural environment silos was presented to workshop participants, shown here with annotations from topics discussed during the workshop.

3.1 Bring interdisciplinary communities together

This workshop brought together people with different skills and areas of expertise. Despite differences in vocabulary, outlook and expertise, there were striking similarities between the visions, blockers and enablers shared by these practitioners from different disciplines. As illustrated by these participants, people coming together from different disciplines with respect and a common purpose have enormous and transformative potential.

Therefore, bringing together interdisciplinary communities is a fundamental first step in model integration. Some of this work may be done through formal interdisciplinary research or industry initiatives, where differences in methodology, language and data are addressed methodically. Section 4.1 discusses the idea of a shared platform for practitioners and model developers that provides better visibility of the models that already exist, and would provide space for shared glossaries and other reference tools.

Surrounding that platform would be a community of people who would benefit from sharing ideas, experiences, and expertise with others outside of their usual silos. This requires a different set of skills from disciplinary expertise[9], including building trusted relationships, sharing and resharing the right data, and developing shared goals. The workshop participants demonstrated that there are worthwhile conversations to be had informally to better understand the expertise and world views held by others and to begin developing trust.

3.2 Start with an aligned vision of better outcomes

Collaboration requires people to navigate different language, priorities, cultures, standards and assumptions about the world. Building trust and respect around a common vision is vital to ensuring that these challenges are opportunities to learn and not barriers to progress. This common vision can centre around the outcomes we want and need to see for people and nature at all scales.

At the global level, the desired outcomes are articulated in the Sustainable Development Goals (SDGs). National policies and strategies further refine the timelines and mechanisms for pursuing better outcomes. Local and organisational priorities will differ depending on the context, but if they are aligned with the outcome-based strategies at larger scales, then individual interventions and decisions become the vehicle for wider strategies. This means that good decisions made at the level of local planning or individual organisations drive the achievement of the national priorities and SDGs[10].

There is valuable work to be done to recognise where the opportunities for integrated modelling are in the planning process. One participant suggested gathering intelligence from recent government reviews such as Project Speed, New Construction Playbook and the National Infrastructure Planning Reform, and exploring where on the infrastructure life cycle data and models are needed. This type of review is important for making the business case for investment in digital technology and for understanding how far we are from our shared vision.

3.3 Frame compelling questions as the basis for model integration

There was agreement among the participants that collecting data and connecting models simply because we can is the wrong approach. Instead, model integration should be based on specific questions that need to be answered to achieve better outcomes. **Starting from clear, yet flexible, questions was voted as the most important short-term priority for driving model integration.**

The participants did not delve into what these questions might be and noted that framing these questions is a key area of short-term work that needs to be done. This should be a collaborative process between modellers, decision makers and wider communities of stakeholders. To achieve this, one participant suggested the following process:

1. Brainstorm specific cross built-natural environment stakeholder needs
2. Source long-term funding
3. Raise awareness of benefits of transdisciplinary learning to gain buy-in from stakeholders across domains
4. Showcase examples where a decision maker was brought into a modelling team early on.

Others framed this process as being driven by problems rather than questions. Integrated models could be used to solve problems at local, regional or national scales – for example traffic congestion, air quality or community wellbeing – in cross-sectoral, environmentally-led ways. In addition, this process could be used to look at multiple pressures acting on cities and communities ‘downstream’ of planned interventions, be they land use change or construction projects.

Assessing the value of model integration should come from the end users: decision-makers at all levels, and communities who are impacted by their decisions. The point of making this process participatory is to use stakeholder input to understand what the problems are from different perspectives before deciding on a solution, then get feedback as to whether the problem was solved and whether new problems were created. This is the participatory element of environment-led design, discussed in Section 2.3, and can happen iteratively across the many overlapping lifecycles of the built environment.

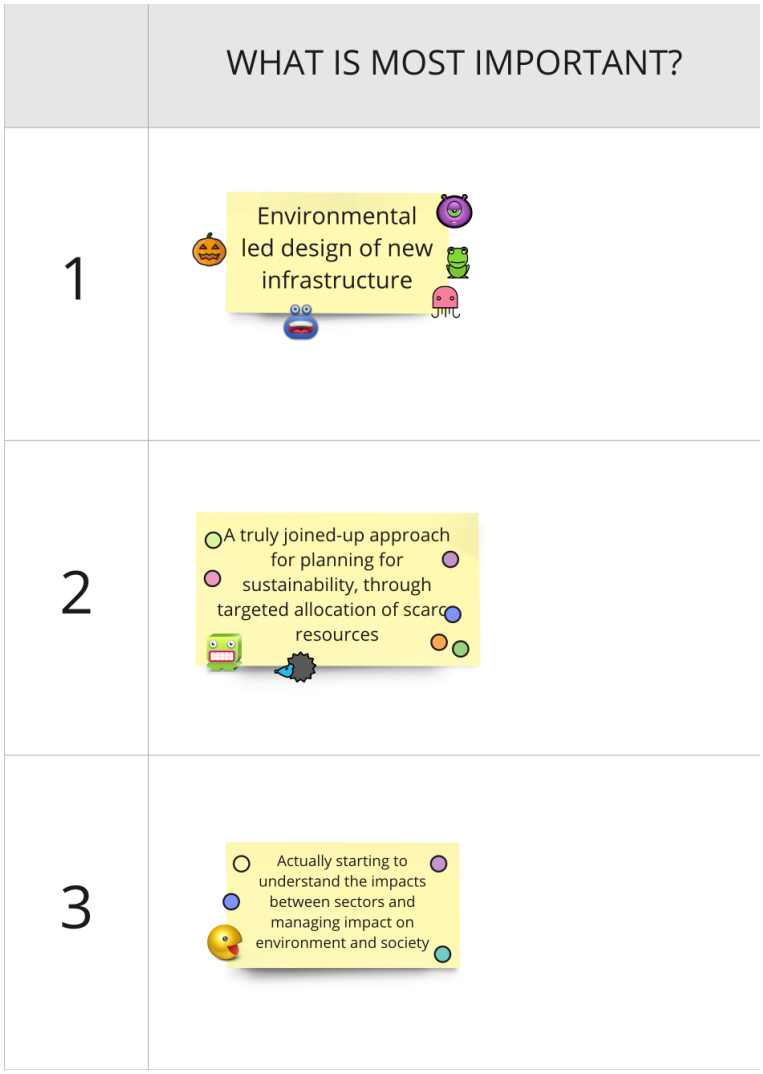


Figure 2: A screen grab from the first workshop, showing early thinking on the top priorities that model integration would enable. The stickers represent votes by participants.

4.0 Better data

'Articulate what it takes for organisations to originate, manage and share high data quality.'

Workshop participant

To balance the needs of society and the limits of nature in developing the built environment, decision-makers need a better understanding of how the components of a system-of-systems interact. This requires better management of, and access to, high quality data. As the fuel for integrated models that help us untangle the complexity and understand causal relationships, interoperable data represents an enormous opportunity to reach environmental goals[11] while ensuring human flourishing[12].

4.1 Develop a platform for data and model sharing

Participants agreed that, **collaboration platforms and integrated tools are the third most urgent short-term priority**, as well as a long-term enabler of model integration and asking better questions. It was described as, 'A platform for making better planning decisions by systematically evaluating the environmental and social costs and impacts of planning decisions'.

This platform should help assess potential interventions using standardised impact metrics and factors such as the agricultural and natural land resources lost, soil sealed under the urbanised land, urban heat island effects and climate change, biodiversity loss, urban sprawl and resulting commute times, health consequences, reduction in wellbeing, and so on. It should also be able to operate across various scales and resolutions, from the high frequency of a mechanical lift motor to slow seismological shifts.

Participants noted that a shared platform and shared tools would ensure that data collection can be coordinated, and that models and approaches proposed by experts are commented on and tested by practitioners. It could be based on a review of and cooperation with existing similar data sharing platforms – for example OpenStreetMap, GitHub, and the European Environment Agency – as well as existing resources used by researchers. While existing tools may not be fit for purpose, each of them will have faced similar problems, such as how to develop shared conduct and practices, and how to provide context and space for discussion around the data and models being shared.

Sector-specific work has already been done on big data platforms in the built environment sector. Initiatives like the Data & Analytics Facility for National Infrastructure (DAFNI) or DataLabs[13], a configurable coupling framework within a virtual lab environment, may be a useful basis for further development. However, both tools are predominantly by and for an academic audience rather than decision-makers, so work is needed on interfaces and interpretation that make

models useable by non-experts. Existing big data platforms like these may not be appropriate for the use cases discussed in this workshop, but learning from them is a good way to avoid duplicating effort.

One participant pointed out that a platform alone is not enough to prompt better questions, pointing to the need for behaviour and culture change in planning as an important companion to platforms, as discussed in Section 4.3. Others pointed to the fundamental need to get the basics of collaboration right and not offloading this effort to a tool. Developing a shared platform for such an important purpose cannot be all about the technology; it must centre on the communities that the platform brings together, and the communities who are impacted by the decisions it helps inform.

Finally, a platform for model sharing and collaboration should not be inward-facing only. It is important for non-technical people to be able to engage with and understand what the tool can deliver, including policy makers and the public. Several times the idea came up that better communication is needed between different communities of experts and by expert communities to decision makers and end-users. If it is well designed, a platform could enable this kind of transparency and make the case for further model integration and environment-led decision-making.

4.2 Develop common standards

Better decisions are based on better models, which require better data. This includes good quality, security-mindedness and an information architecture that supports data from different disciplines being used together – known as interoperability.

The data standards agenda has long been a driver in the built environment and business information world, and has fed directly into the work of the NDTp on data architectures discussed below. Developing good data standards is a long-term project and, according to one participant, will probably never be finished. The slow pace of standards development has led to problems, however, as potential benefits from sharing data across silos have been missed. Therefore, there was general agreement that moving toward open standards was an important enabler long-term, and one participant pointed to standards developed in the USA as an example of what the UK should move toward.

Data Quality

Data quality was mentioned by several participants as the key enabler to model integration, and the lack of a widespread culture and standards for data quality was seen as a barrier. ‘Quality’ does not refer only to sound metadata or architecture, but also to relevant, contextualised data and models that carry with them information about their uncertainty and limitations. This will help those who wish to reuse a model understand what types of questions it can – and cannot – help answer.

One participant noted how important it is to articulate, alongside standards, what kinds of processes, tools and frameworks it takes for organisations to originate, manage and share high quality data. Others agreed, noting that this is a matter of culture change, as discussed in Section 4.3.

Data quality can become a highly technical issue and is written about extensively elsewhere. Since the workshop did not dwell on it, neither will this report, beyond noting it as a vital enabler of better decision-making.

Security

Secure, ethical and resilient architectures for integration were listed among the technical considerations. If a platform is developed, it needs to be designed and managed with security-mindedness from the start. The intersections between the built and natural environment are some of our most delicate and vulnerable national assets, such as our energy and water infrastructures. While enormous benefits could come from making some data and models available to colleagues in other disciplines, these must not expose infrastructure, nature or communities to harm. There are, therefore, both physical security and deep ethical issues wrapped up in open data and model integration[14] alongside considerations of data ownership and competitive advantage.

Security across the built and natural environment interface

Digital security is an essential consideration in the digitalisation of assets for reasons that were made obvious in February of 2021, when a hacker operating remotely managed to raise sodium hydroxide levels in the water supply of Oldsmar, Florida to dangerous levels. The cyberattack was detected by the plant's automated safety systems and stopped, but it raised public awareness of how vulnerable digitally operated built assets can make the communities that rely on them for services.

In the natural environment, greater implementation of sensors and Internet of Things may help solve wildlife and ecocide crimes, but may also lead to similar vulnerabilities. For example, if contentious species are released into the wild equipped with sensors, they could be easier for poachers or protesters to locate and harm.

In addition to a clear purpose, the integration of data and models across the built and natural environment interface should have security-mindedness embedded at all levels, based on an understanding of the potential benefits and risks to these delicately interwoven systems of collecting and sharing data.

Architecture

Participants agreed that robust information architectures, including metadata and ontologies, need to be developed and standardised to enable cross-sectoral integration of models.

There is a great deal of technical work ongoing in this area in the built environment sectors. Through broad consultation with industry experts, the NDTp is working on an Information Management Framework (IMF), the architecture underpinning a National Digital Twin. This will be comprised of:

- A Foundation Data Model and Reference Data Library, the standardised language to enable data sharing within and between sectors
- An Integration Architecture, providing 'the transport mechanisms, together with authorisation and security protocols, to ensure that information can be accessed seamlessly, but only by those authorised to do so.'[15]

This work is based in the Gemini Principles[16], which acknowledges that when it comes to data, the art of the possible and measurable is not always the right thing to do. The architecture and standards around digital modelling need to be based on a clear purpose – better outcomes for people and nature – as well as open, interoperable data where appropriate for the security and ethical contexts. Similar principles were discussed in the workshop, demonstrating the need for technical standards and architectures to be supported by frameworks and cultures for creating, managing and using data and models responsibly. The ability to work across different scales and resolutions, and apply data to different purposes ethically and securely were discussed as essential digital skills for model integration.

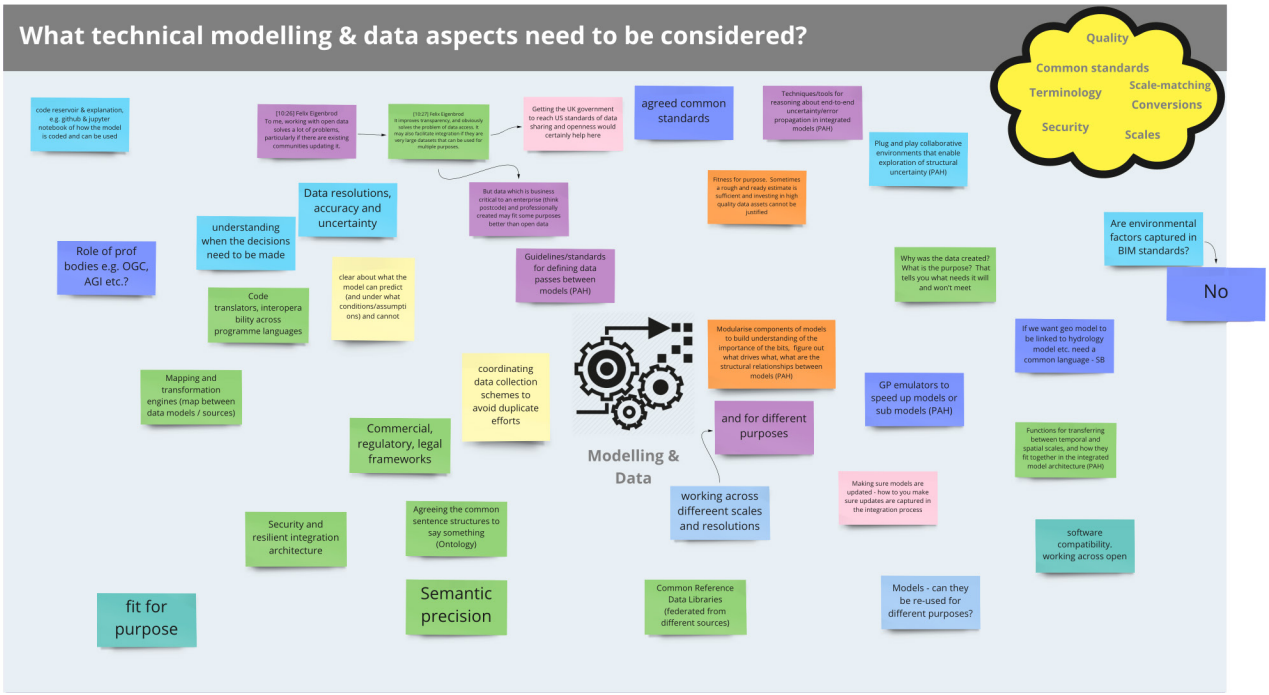


Figure 3: During the workshop, participants noted down these long-term technical priorities for data and modelling. Despite recieving fewer votes, participants agreed these underpinned the capability to make better decisions using integrated models.

4.3 Develop a cross-disciplinary culture of data sharing, data quality and collaboration

Platforms and standards are useful to enforce the creation of quality, interoperable data, but if this is not coupled with a change in culture, it will be reduced to a box-ticking exercise. Therefore, a culture of sharing quality data with interdisciplinary collaborators is also vital to integration.

Shared model outputs should be comparable and falsifiable, for example by encouraging model creators to describe the uncertainty of key model variables and model assumptions alongside their models. They should be subject to cross-validation and competition to encourage quality and ensure that we use the models and datasets that are best fit for the purpose. One participant suggested that competition itself could foster better data quality. This participant pointed out that a culture of sharing assumptions underlying models, and clarifying their limitations is very important to trusting models for integration.

Cultural change around collaboration more generally is also important, with participants agreeing that breaking down siloes and benefitting from knowledge sharing will stop them from reinventing the wheel. Reduplication of effort was seen as wasteful and frustrating, and was often caused by a siloed way of working. This cultural change can be driven by strong leadership and champions in the sectors, and by sharing examples of good practice from real projects.

This change cannot simply come from below. Funding and governance should support it. One participant noted that, '[interdisciplinary model sharing] has been going on for a long time, so governance [is] needed to create momentum toward standard practice and communities of work'. Others agreed that buy-in from key stakeholders – through long-term funding, policies, licensing, and cross-functional collaboration across decision-making bodies – are important enablers of model integration. However, there is a need to identify who the appropriate governance bodies are to bring a cross-disciplinary collaborative modelling community together, and some noted the political sensitivities of identifying who that would be.

These decision-makers, in turn, need to understand when the important decisions need to be made during interventions. Having oversight across complex systems, they may also be able to coordinate data collection schemes to avoid the duplication of efforts. The change in culture should happen at all levels, from the data gatherers and model creators to the decision-makers and research funders.

5.0 Share good practice

'Share learning, collaborate better, stop reinventing the wheel. Get the basics right of collaboration.'

Workshop participant

Participants agreed that demonstrators, case studies and examples would be crucial to realise the benefits of interdisciplinary model integration for people and nature. **Awareness-raising using champions and business cases, was rated the second highest priority for bringing about model integration in the short term**, as well as an ongoing priority for long-term success.

They recommended identifying and funding projects in which stakeholders are brought in from the beginning and in which modelling is used early on to identify options, trade-offs, and impacts. Projects at any scale are relevant and will provide valuable lessons in their differences and connections, but a few participants recommended starting with a focus on the local scale. Publicising where previous projects have succeeded – and failed – will progress work at a greater rate, as will recruiting champions from these projects to share their experiences with other organisations, planners, and policymakers.

Champions could communicate the good practice case studies in the context of the wider vision and compelling questions framed at the beginning of the projects. This will ensure that investors, decision-makers and the general public understand why and how digital modelling have been used, what was decided and the level of uncertainty about the outcomes.

COP26 was highlighted as an opportunity to showcase good work in this area, in the context of long-term development pathways to net zero, including nature-based solutions. Demonstrators more generally were seen as crucial in articulating the case that data integration across sectors is on the critical path for Net Zero, pointing to the recurring refrain that effective communication to stakeholders in industry, government and the public is of paramount importance. As one participant said, 'Don't underestimate the budget and resources required for engagement'.

An early piece in an interdisciplinary programme would likely be a literature review highlighting existing demonstrators and case studies of integrated modelling used in decision-making, participatory planning and environment-led design. The shared platform discussed in Section 4.1, and the community around it, would be an ideal place to publicise this good practice among practitioners, as would forums such as the Digital Twin Hub.

Good practice worldwide

The UN Environment Programme[17] has already published numerous examples of good practice in infrastructure that has been designed in alignment with the SDGs. Some of these have been explicitly enabled by digital technology in ways similar to those discussed in this workshop.

For example, Malawi's Growth and Development Strategy has recently prompted an overhaul of existing infrastructure procurement leading to greater transparency. Their Information Platform for Public Infrastructure is a public portal for publishing data on key milestones of infrastructure projects. This is just one of many channels for disseminating information to the public and increasing accountability for built environment projects, including virtual events and radio broadcasts.

6.0 Other insights

Over the two half-days of the workshop, the 12 experts brought up a wide range of ideas that did not get picked up as key priorities. This section highlights some of these insights.

First, the issue of **ownership and oversight of data governance** came up. As models of assets and processes are integrated across organisational and political boundaries, who owns the data and insights? Who is responsible for ensuring data quality, security, and access? Who is liable? The answers to these questions need to be agreed at multiple levels of decision-making and across multiple organisations and stakeholders.

Second, participants recognised the need to acknowledge and accommodate diverse perspectives when interpreting the model outputs. Data is not objective, vulnerable people or ecosystems may be left out of decision processes, and insights may be open to interpretation. Decision-makers cannot rely solely on models to make better decisions, but should consult with **vulnerable or under-represented stakeholders**, to understand the many lenses through which a single problem can be viewed.

Many of the decisions that impact the lifetime environmental footprint of a built asset happen early in the design stage. However, that should not be the sole focus of modelling. One participant noted that, 'Monitoring of environmental performance after a scheme is built is poorly done due to the lack of data'. There are opportunities to spot inefficiencies and make better interventions over the whole life of assets. Digital twins could monitor existing assets during their operational lives against the environmental promises made at the planning stage and optimise them as more data becomes available. This is an opportunity to **ensure that the whole lifecycle of the built environment is managed in balance with nature**, and in alignment with national and global priorities. The participant who brought up this point noted that built environment digital twin work in operations does not touch on environmental impact in a meaningful way yet, and that a state-of-the-art review is required.

Integrated modelling is a tool, not a cure-all. At the same time as illustrating the art of the possible, integrated models come with compounded complexities. There are limitations to what can be modelled and much of what matters most cannot be measured. Decision-makers, modellers, researchers and practitioners from all sectors need to understand these limitations and uncertainties inherent in models. Model integration needs to be accompanied by processes for bringing in meaningful stakeholder feedback, qualitative insights, and a **deeper understanding of what is at risk when making decisions**. Digital models can help us map complexity, but we are the ones who need to decide which road to take.

Both disciplines involved in this workshop have a great deal to learn from one another. Some participants from the natural environment modelling sector mentioned that the work on interoperability and standardisation in their discipline is not as advanced as in built environment modelling and connected digital twins. However, they have integrated more with socio-economic modelling, an area that could have profound benefits in planning, designing and operating the built environment. **Collaboration between these two sectors could therefore accelerate progress in these areas**. The barriers that both sectors share add further weight to voices already calling for better communication, culture change, and ethics- and purpose-driven model integration.

Conclusion

We urgently need to change the way we develop the built environment to work within the limits of the natural environment, and to understand the impact of land use decisions on communities. In short, we need to take a systems-based approach to manage our built and natural systems.

The opportunity that integrated modelling creates is enormous: to better understand and develop the built and natural environments together in ways that support the wellbeing of people and the planet for the long-term. Shared, curated, right-time information could enable decision-makers to better manage the trade-offs, identify the risks and impacts of decisions, and create beneficial outcomes. However, creating the systems, processes and frameworks to enable this would involve the retooling and reconfiguration of existing practices and disciplinary silos, requiring time, attention and cooperation that could be managed through a dedicated programme.

According to the experts who attended the workshop, the UK's research, industry and policy bodies must focus on the following priorities for integrating models of the built and natural environment are:

- Make interconnected models accessible to stakeholders to drive better decisions, by making built and natural environment models visible early in the decision process
- Bring communities together around a shared vision in order to frame better questions, as the basis for model integration
- Develop a common approach / platform to enable better data and model sharing across disciplines, joined by shared architectures, and common standards for security and quality
- Establish and share best practice at all scales, to support better local, regional and national decision-making.

These priorities are interdependent. They address cultural as well as technical barriers to model integration faced by both disciplines. However, the need is urgent, and by coming together now these disciplines may be able to combine their skills to accelerate the development of better decision processes and tools, leading to better outcomes for people and the planet.

There is a tremendous opportunity to bring together the existing programmes to explore the opportunities raised in this initial workshop, working toward a set of compelling questions and small-scale case studies that inform how the Information Management Framework – and other frameworks and standards – develop.

More importantly, a joined-up programme should provide a supportive environment for cross-disciplinary exploration based on trust, respect and a common purpose. Through expert workshops, peer networks and publicising of good practice, a central programme focused on integrating built and natural environment modelling would accelerate the development of tools and processes that use these models to make better decisions for the future of the UK. The National Digital Twin and Landscape Decisions programmes are two key stakeholders in this process, and future collaboration between them could be mutually beneficial.

Call to Action

The siloed approach to making decisions about how we use and develop land and the built environment has driven us to the brink of environmental disaster.

There is tremendous value in working together to solve the big problems we face.

Collectively, the built and natural environment sectors, academics and government need to make decisions that support human flourishing, while operating within the safe limits of what our planet can provide.

Bringing together digital modelling from built and natural environment disciplines would help provide new insights to decision makers by providing a better understanding of the dependencies, causalities and trade-offs of different interventions on these complex, interdependent systems.

An interdisciplinary programme that seeks to address this opportunity should focus on uniting the stakeholders, creating a platform for sharing data and models, and developing the data architectures to enable the sharing of quality data and case studies.

References

1 Dasgupta, P. (2021) The Economics of Biodiversity: The Dasgupta Review. HM Treasury. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/962785/The_Economics_of_Biodiversity_The_Dasgupta_Review_Full_Report.pdf

2 Whyte, J. et al. (2020) 'A research agenda on systems approaches to infrastructure', *Civil Engineering and Environmental Systems*, 37(4), pp. 214-233. Available at: 10.1080/10286608.2020.1827396

3 Bankes, S. (1993) 'Exploratory modeling for policy analysis', *Operations Research*, 41(3), pp.435-499. Available at: http://pubsonline.informs.org/doi/abs/10.1287/opre.41.3.435

4 Gurdur Broo, D., et al. (2020) *Four Futures, One Choice - Options for the Digital Built Britain of 2040*. Cambridge: Centre for Digital Built Britain. Available at: https://doi.org/10.17863/CAM.59803

5 UN Environment Programme (2021a) International good practice principles for sustainable infrastructure: integrated, systems-level approaches for policymakers. United Nations. Available at: https://www.unep.org/resources/publication/international-good-practice-principles-sustainable-infrastructure

6 Adam, R. (2019) 'The greenest building is the one that already exists', *Architects Journal* [Online]. Available at: https://www-architectsjournal-co-uk.ezp.lib.cam.ac.uk/news/opinion/the-greenest-building-is-the-one-that-already-exists

7 Hartmann, T., Slavíková, L. and McCarthy, S. (2019) 'Nature-Based Solutions in Flood Risk Management'. In Hartmann, T., Slavíková, L. and McCarthy, S., eds.) *Nature-Based Flood Risk Management on Private Land: Disciplinary Perspectives on a Multidisciplinary Challenge*. Springer International Publishing.

8 Quote from a workshop participant.

9 Plummer D, et al. (2021) Skills and Competency Framework - Supporting the development and adoption of the Information Management Framework (IMF) and the National Digital Twin. Centre for Digital Built Britain and National Digital Twin programme. Available at: doi.org/10.17863/CAM.52659

10 'Our Vision for a digital built Britain' (2020) Centre for Digital Built Britain. Available at: https://indd.adobe.com/view/f2092c85-cd16-4186-9035-e2a63adc2bf9

11 Figueres, C. and Rivett-Carnac, T. (2020) *The Future We Choose: The Stubborn Optimist's Guide to the Climate Crisis*. Bonnier Zaffre Ltd.

12 Centre for Smart Infrastructure and Construction and Centre for Digital Built Britain (2020) *Flourishing systems: re-envisioning infrastructure as a platform for human flourishing*. Available at: https://www.cdbb.cam.ac.uk/news/flourishing-systems

13 Holloway, M. et al. (2020) 'Tackling the challenges of 21st Century Open Science and beyond: a Data Science Lab approach', *Patterns*, 1, pp. 100-103. Available at: https://doi.org/10.1016/j.patter.2020.100103

14 Centre for Digital Built Britain (2018) 'Security-mindedness for smart infrastructure: challenges and opportunities', CDBB Blog. Available at: https://www.cdbb.cam.ac.uk/news/2018Nov1Security

15 National Digital Twin programme (2020) *The approach to develop the Foundation Data Model for the Information Management Framework*. Centre for Digital Built Britain. Available at: https://www.cdbb.cam.ac.uk/files/250221_the_choice_of_start_point_for_the_foundation_data_model_for_the_information_management_framework_1.pdf

16 Bolton, A. et al. (2018) The Gemini Principles: guiding values for the national digital twin and information management framework. Centre for Digital Built Britain and Digital Framework Task Group. Available at: https://doi.org/10.17863/CAM.32260

17 United Nations Environment Programme (2021b). Integrated Approaches in Action: A Companion to the International Good Practice Principles for Sustainable Infrastructure. Nairobi: United Nations. https://www.unep.org/resources/publication/integrated-approaches-action-companion-international-good-practice-principles

The author gratefully acknowledges the support of the UKRI funded Landscape Decisions programme. Thanks also to the workshop participants, facilitators and experts consulted by the author.

Join the conversation on the Digital Twin Hub.

An extensive appendix, covering a brief literature review and the design and details of the workshops, is available upon request. Please contact enquiries@cdbb.cam.ac.uk for access.

The National Digital Twin programme is funded by the University of Cambridge and the Department for Business, Energy and Industrial Strategy via Innovate UK, part of UK Research and Innovation.

This research was enabled by the Construction Innovation Hub (the Hub). The Hub is funded by UK Research and Innovation through the Industrial Strategy Challenge Fund.