

# Infrastructure 4.0: Achieving Better Outcomes with Technology and Systems Thinking

WHITE PAPER

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# Contents

Preface	3
Executive summary	4
1 Recommendations	6
1.1 Creating new ecosystems	7
1.2 Creating new business models	10
1.3 Building skills and education	13
Conclusion	16
Appendix 1: Summary of recommendations	17
Appendix 2: Infrastructure 4.0 Community	18
Contributors	20
Endnotes	21

# Preface

Technology adoption is key to enhancing the delivery and performance of infrastructure systems.

The role of infrastructure in society seems straightforward. It provides basic services to our homes. It gets us to where we want to go. It provides a place for learning and healing. To many, infrastructure is a collection of separate assets that we interact with as we go about our day. But infrastructure is so much more. Infrastructure brings power and water to the places we live and takes waste away, allowing us to be healthier and more productive at home. Infrastructure provides access to economic opportunity, education and healthcare. Infrastructure can bring us closer to nature and help ensure the protection of our natural world.

Infrastructure is more than just a series of assets. It can be a service that improves our lives. It is not just one hospital building, one train line or one network of water pipes. It is a system of systems that links the built environment, the natural world and the human experience. Done right, infrastructure investment has the potential to help us build a more sustainable, equitable and prosperous world and can serve as a platform that focuses on outcomes that help the planet and its people thrive.

However, the way we currently develop infrastructure has struggled to meet these lofty aspirations. Over-budget, off-schedule and poorly performing projects inhibit infrastructure's ability to serve as an optimal platform for human and natural flourishing. One strategy to avoid these problems is to incorporate emerging technologies into the way infrastructure is developed. While other industries have wholeheartedly embraced new technologies and run headlong into the Fourth Industrial Revolution, infrastructure has struggled in comparison. Construction, a key stage of infrastructure development, is the second least digitalized sector in the economy, ahead of only agriculture.<sup>1</sup> This is not due to a shortage of innovation in the space. Indeed, a thriving world of innovators are devising solutions that can revolutionize the way we plan, design, procure, construct, operate and decommission infrastructure.

Technology has the potential to be the enabler of high-quality, outcome-focused infrastructure systems, but its adoption across project life cycles needs vast improvement. While infrastructure traditionally moves at a staid pace with projects that take years and assets that last lifetimes, this current technological revolution is outpacing previous ones at an unprecedented speed. Infrastructure is letting this wave of innovation race right by it.

This is not just a problem for those involved in developing infrastructure; it has implications for us all. Infrastructure is key to providing economic opportunity for billions and is a crucial tool for climate action. Both are looming challenges that the world needs to address now. The infrastructure development push likely to follow the abatement of the COVID-19 pandemic will shape the world for decades to come and carry ramifications for generations. It is essential to leverage technology to build a world that is better than the current one.

This is why, beginning in the late summer of 2020, the World Economic Forum Infrastructure 4.0 project community was formed to work across sectors and industries to encourage a more holistic, outcome-focused framing for infrastructure and to share the best strategies for improving the adoption of technology into infrastructure development. In a series of working meetings, project members formulated the recommendations presented in this document. These recommendations are meant to assist decision-makers in business, government, civil society and academia in working together to develop better infrastructure. As countries around the world try to understand what actions they can take to restart economies after the ravages of the COVID-19 pandemic, many are turning to infrastructure development. These recommendations, built with insights from the foremost professionals in the field, can help shape the way we build our infrastructure systems at this crucial inflection point and ensure we build a world that allows all of us to thrive.

# Executive summary

Paving the way for infrastructure systems of the future requires a dramatic shift in how infrastructure is approached today.

“ Integrating the recommendations in this paper into forthcoming policies could create generational impact on the world and be a crucial component of building back better.

The recommendations presented in this publication are intended for decision-makers in the public and private sectors as they seek to improve the adoption of emerging technologies into infrastructure development. They range from high-level strategies reflecting broad systemic commentary to tactical actions and concrete steps that can be taken by specific institutions and companies. The recommendations are categorized into three main thematic areas:

1. Creating new ecosystems
2. Creating new business models
3. Building skills and education

The recommendations were developed by gathering the insights of the Infrastructure 4.0 project community members over a series of large general workshops and smaller working group meetings focused on the three themes. The project community consists of a global group of experts and stakeholders from 17 countries spanning all regions of the world. Community members from the private sector represent multiple industries, including engineering and construction, finance, technology and real estate, and include both large industry-leading corporations and smaller disruptive start-ups. The public sector is represented by members of national and subnational governments, as well as multilateral institutions. The project community also includes several members of academia from prominent institutions. The initiative is supported by the Global Infrastructure Hub, which maintains an online case study library featuring infrastructure technology best practices to

which the Infrastructure 4.0 community members have contributed, providing real-world examples of the best strategies for integrating new technologies.

By applying Fourth Industrial Revolution framing (leveraging technology and information) to the sector and by reframing the understanding of infrastructure as a system within a system that focuses on improving outcomes for people and the planet, the high-quality infrastructure the world desperately needs can be provided. This is particularly important in the wake of the economic fallout of the COVID-19 crisis. As many governments make plans for infrastructure-development-led economic recovery, integrating these recommendations into forthcoming policies could create generational impact on the world and be a crucial component of building back better.

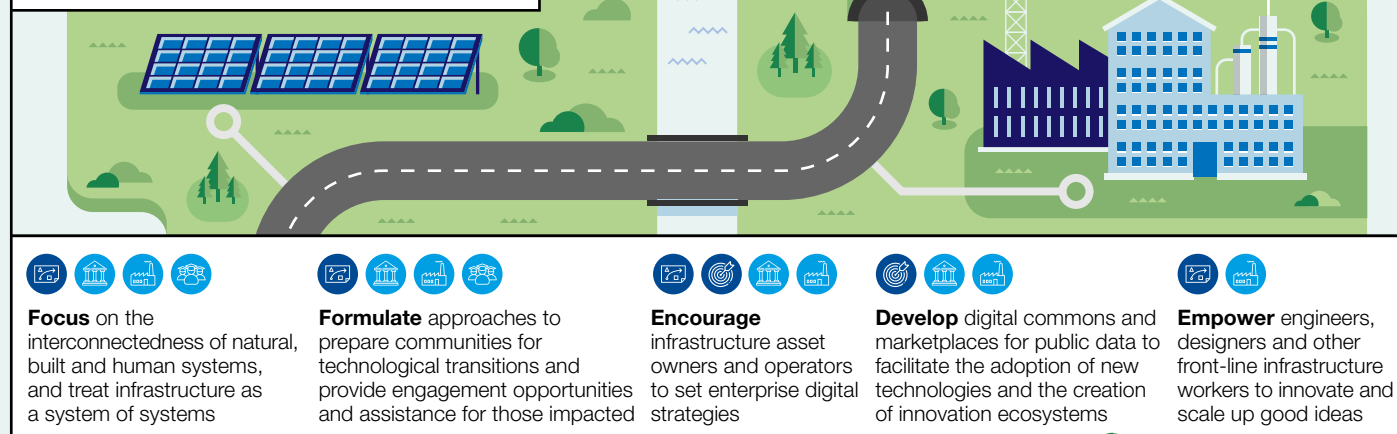
The sections of this White Paper describe the project community's 13 recommendations for enhancing the adoption of emerging technologies in infrastructure development in more detail. Each recommendation includes guidance for implementation by the pertinent stakeholder group. Where available, current examples of the recommendations in practice are provided for reference. The timing and application of the recommendations will vary depending on the specific context of each case and jurisdiction. The completion and launch of this paper mark milestones for the initial phase of the Infrastructure 4.0 project, which has defined the key challenges and identified potential solutions to accelerate technological progress in the infrastructure sector while enhancing long-term systemic thinking to produce better outcomes.

**Infrastructure 4.0:** Forward-looking infrastructure that leverages technology and information to provide high-quality environmental, economic and social outcomes, and functions as a system within broader human and natural systems.

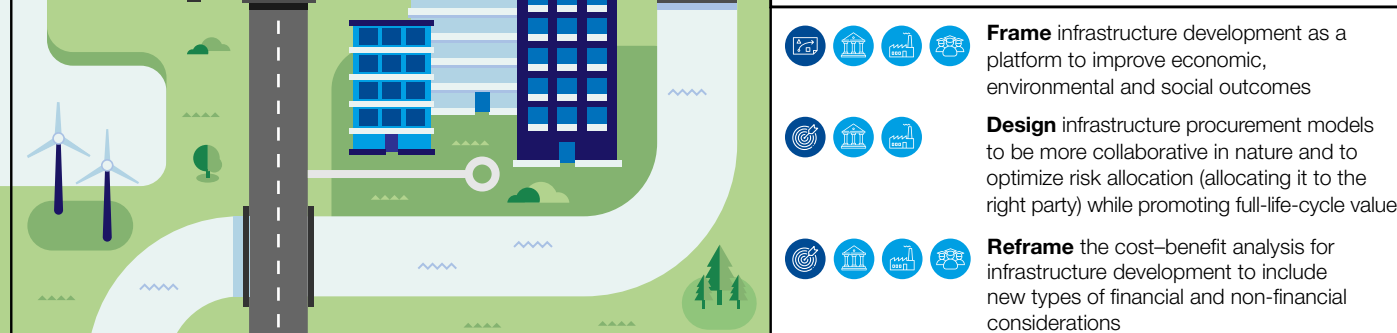
# Infrastructure 4.0: Achieving Better Outcomes with Technology and Systems Thinking

Level of implementation	Sector(s) involved	
	Strategic	Tactical
	Public sector	Private sector
	Civil society/academia	

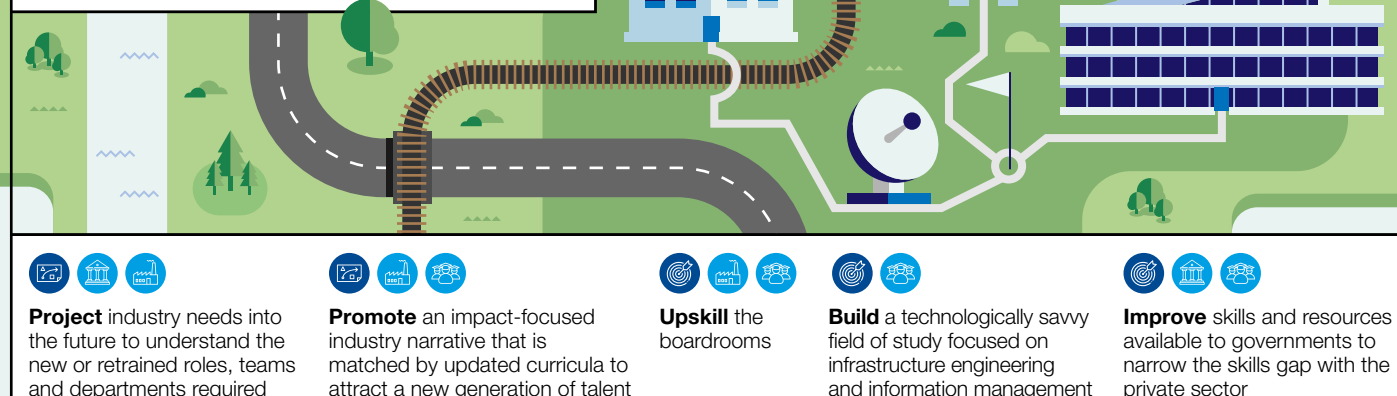
## Creating new ecosystems



## Creating new business models



## Building skills and education



Source: World Economic Forum

1

# Recommendations

Focused and collective actions by government, industry and civil society are required to drive progress and innovation in the infrastructure sector.

Over the course of three general workshops and six working group meetings, project community members explored the key barriers to greater adoption of emerging technologies and innovation across the entire infrastructure life cycle. The discussions resulted in a list of 13 recommendations that fall under three main thematic areas:

1. Creating new ecosystems
2. Creating new business models
3. Building skills and education

The first theme, **Creating new ecosystems**, is concerned with providing an enabling environment within government and private industry to foster greater collaboration and alignment. The five recommendations in this group seek to align stakeholder perspectives at a high level and encourage a systems approach by breaking traditional silos of engagement both within and between organizations.

The second theme, **Creating new business models**, aims to strengthen and align market incentives to encourage full-life-cycle decision-making, focusing on the performance outcomes of delivered infrastructure. The three recommendations in this group intend to shift the existing paradigm for decision-makers to account for externalities and non-monetary factors in business case decisions.

Finally, the third theme, **Building skills and education**, recognizes the fundamental truth that change comes from people. Lasting change in policy and practice must rely on the individuals within organizations to buy into and carry out the reforms needed to improve processes and outcomes. The five recommendations in this group seek to improve the skills and capacity of stakeholders in the present and to ensure that training and education for future generations remain flexible and relevant to a rapidly changing world.

Under each theme, current examples of the recommendations in practice are provided for reference.

FIGURE 2 Icons used with the recommendations

The recommendations presented in this paper range from high-level strategies to tactical actions and are intended for decision-makers across multiple sectors.

Each recommendation is tagged with the following icons representing its intended level of implementation and the relevant sectors involved.



Source: World Economic Forum

# 1.1 Creating new ecosystems



## 1. Focus on the interconnectedness of natural, built and human systems, and treat infrastructure as a system of systems



Our world can be understood as a series of interlocking systems. Infrastructure is but one of these systems that, when connected with many others, provides opportunities and support to help humans live, essentially transforming infrastructure into a service that connects the built environment to the human world and the natural sphere. This connection makes infrastructure critical to human success. Reframing infrastructure as one within a system of systems helps to understand how and why infrastructure projects are developed, and reorients the measure of success towards how

positive outcomes are produced. Additionally, it helps to move away from thinking about infrastructure in terms of permanent frameworks to impermanent solutions. This leads to dynamic infrastructure that better serves people, integrates natural elements, is more resilient in the face of climate change and other shocks, enables solutions to decarbonize the economy, and is more economically successful in the long term. It also helps to recognize that humans are perpetually working towards continuous improvement and that ambition will always challenge and outpace the status quo.

TABLE 1 Examples of this recommendation in practice

Name	Objective	Relevance
<b>Centre for Digital Built Britain: Flourishing Systems</b>	To advocate for a people-focused, system-based vision for infrastructure development	This paper outlines how to reframe the infrastructure development conversation around outcome-focused systems thinking. <a href="https://www.cdbb.cam.ac.uk/files/flourishing-systems_revised_200908.pdf">https://www.cdbb.cam.ac.uk/files/flourishing-systems_revised_200908.pdf</a>
<b>Our Vision for the Built Environment</b>	To provide a mission statement to unite infrastructure stakeholders around better outcomes	This paper describes a shared vision for the future: a built environment that allows people and nature to flourish together for generations. <a href="https://indd.adobe.com/view/f2092c85-cd16-4186-9035-e2a63adc2bf9">https://indd.adobe.com/view/f2092c85-cd16-4186-9035-e2a63adc2bf9</a>
<b>The Economics of Biodiversity: The Dasgupta Review</b>	To change the ways of thinking about current models of growth and development and construct a formulation of economic reasoning that always considers the biosphere, increasing prosperity and protecting the natural world	This report reinforces the importance of including consideration for nature in the way we humans build our world. <a href="https://www.gov.uk/government/publications/final-report-the-economics-of-biodiversity-the-dasgupta-review">https://www.gov.uk/government/publications/final-report-the-economics-of-biodiversity-the-dasgupta-review</a>



## 2. Formulate approaches to prepare communities for technological transitions and provide engagement opportunities and assistance for those impacted

Historically, technological transitions are hard to navigate, but doing so successfully is a crucial element of technology adoption, particularly if that technology materially changes the way people interact with their community and the built environment. Governments and businesses must ensure proper consultation with communities throughout the development process of any infrastructure system, especially if it involves using a new technology. Increasing sensitivity related to data privacy is but one example of an issue that must be addressed at a very early stage. Ensuring the user-friendliness of customer-facing aspects of infrastructure systems is another. Key to this is emphasizing the ways communities extract value from technology-enabled infrastructure. Examples include optimizing safety and stability day-to-day and during emergencies, increasing access to economic opportunity, and improving the provision of commercial, health and educational services.

These approaches require engaging with more than just the community and should include the other

stakeholders that interact with the community that would also be affected by the transition. Having government data strategies in place at the local and regional levels would be an enormous help in this regard, and they should be closely linked with national infrastructure plans. Defining clear methods and goals for why and how governments collect and use data allows governments to more clearly articulate the potential benefits of using new technologies and build trust with the communities they serve. Engaging with communities using transparent frameworks related to technology can help demonstrate that the public's concerns are understood. Clarity is also needed on the strategies for personal data as well as asset and system data.

Communities should be involved in crafting the regulations and policies that will govern the new technologies being used. Providing the opportunity to solicit input and work together across stakeholder groups builds trust, maximizing the chance of success. However, governments should be careful not to overregulate to the point of stifling innovation.

TABLE 2 Examples of this recommendation in practice

Name	Objective	Relevance
<b>Privacy Impact Assessment</b>	To help cities establish a consistent method for identifying, evaluating and addressing privacy risks	This model policy by the G20 Global Smart Cities Alliance provides a balance between the need to gather information and protect the public's privacy. <a href="https://globalsmartcitiesalliance.org/?p=839">https://globalsmartcitiesalliance.org/?p=839</a>
<b>Louisville Data Commons</b>	To store and share data generated by local communities in Louisville, Kentucky, USA	This open data website managed by a multistakeholder group of volunteers provides a real-world example of a community taking the opportunity to be involved in the stewardship of its own data, building trust with the institutions that seek to use it. <a href="https://louisvilldatacommons.org">https://louisvilldatacommons.org</a>



## 3. Encourage infrastructure asset owners and operators to set enterprise digital strategies

An enterprise digital strategy, a comprehensive business-wide plan focused on using digital technologies to achieve business goals, is an important step in ensuring technologically advanced infrastructure systems. These strategies are essential for survival in a fast-digitalizing world, and the quality of the strategy is linked to the degree

of success. However, given the importance of taking a system-wide approach, these enterprise digital strategies must also include a shared digital transformation strategy between the owner and the entire supply chain to ensure interoperability. This is crucial for creating a seamless experience on the part of customers and partners, and



improving the ability to respond to changes quickly. It is also important to note that any system-wide approach should also apply to processes between organizations to improve shared delivery. Digitally transformed organizations with digitally transformed processes lead to digitally transformed systems, which can be a powerful tool if directed towards meeting shared outcomes. Industry standards would be of great help in this regard, as they have been in other industries, such as airlines and financial services. In the end, stakeholders must define a strategy, operationalize it and use it to operate in the ecosystem.

When devising these systemic digital strategies, considering varying levels of digital maturity is key. Organizations with limited digital maturity should focus first on digitalizing large parts of the business to optimize core operations, being intentional about creating a strategy that takes them from where they are to where they want to be. Mature organizations, when devising a comprehensive digital strategy to use digital tools, should realize that they are on an ongoing journey of business improvement. All of this would then be folded into the supply-chain-wide enterprise digital strategy to ensure the coordination of efforts.



#### 4. Develop digital commons and marketplaces for public data to facilitate the adoption of new technologies and the creation of innovation ecosystems



The ability to collect, organize and use data is a key piece of the puzzle for creating a technologically advanced, flourishing infrastructure innovation ecosystem. Yet this has been a daunting task for many government entities. Local governments, in particular, have generally struggled to find effective ways to collect data in a consistent manner, and have even more trouble organizing and using the data they have to improve performance outcomes. By working to efficiently and effectively collect and manage data, governments can facilitate the creation of data commons, which can act as repositories for important infrastructure-related data and code. These repositories would be open for the use of stakeholders to improve infrastructure design.

To facilitate these data commons, governments must devise national information management frameworks. These are crucial tools for setting rules and creating a “spine” that supports entire information ecosystems. This allows would-be entrepreneurs and inventors access to the data that allows them to innovate, but also aids owners and operators who depend on a “golden thread of information” (end-to-end records and information for an asset) to properly plan, build and manage infrastructure.

It will, of course, be crucial to formulate the right regulations and policies to govern these

frameworks; this should be done in an inclusive and holistic way that involves multiple stakeholders and addresses community concerns. This should include defining standards for data collection, which not only ensures the data gathered is useful but also provides the transparency that is an important component of building trust in the system.

One important element of setting up this properly functioning data and code market is valuing digital assets the same way other assets are valued. Just like any other asset, digital assets should be judged on the cash flow they generate, which requires developing a better business case that provides a fuller range of scenarios for decision-makers.<sup>2</sup> Having an understanding of the value of digital assets improves the decision-making capability around how and when to deploy the assets, and provides greater insight on the value of new technological tools in compounding their worth. Very importantly, it also helps to establish a thriving market. However, some sort of balance is needed between the market and non-market aspects of what is shared. This requires collaborating on the rules of the market while enabling competition within it. Digital commons should catalyse a market, and the focus should be on enabling this market, not controlling it.



#### 5. Empower engineers, designers and other front-line infrastructure workers to innovate and scale up good ideas



In many industries, innovations often come into being on the front line, where problems and disconnects are most apparent to operators and end users. This is no different when it comes to infrastructure development. Allowing workers on the front line to leverage innovations can improve project performance and help attract a new generation of workers who have become

accustomed to integrating new technologies into their daily lives. It is also critical to provide pathways for employees on the front line to pass improvements and innovations across teams and upward through the levels to help increase innovations throughout organizations. A more digitalized workplace is one strategy that can help improve the ability to undertake this.

TABLE 3 | Example of this recommendation in practice

Name	Objective	Relevance
<b>MIND project (Milano Innovation District)</b>	To develop an innovation district project (an end value of about €2.5 billion) aiming to capitalize on the success of Expo 2015 and place Milan on the map of the world's gateway cities, leveraging on the local excellences in life sciences	<p>The project revitalizes the legacy project of Milan Expo 2015; it has created a digital platform which brings together an ecosystem of innovation partners (engineers, designers, investors, academics) to advise, collaborate and shape the Milano Innovation District.</p> <p>The project calls for ideas to shape the “Building of the Future concept” (currently more than 380 projects have been submitted).</p> <p><a href="https://www.mindmilano.it/en/">https://www.mindmilano.it/en/</a></p>

## 1.2 Creating new business models



### 6. Frame infrastructure development as a platform to improve economic, environmental and social outcomes



Too often, the conversation on infrastructure is myopically fixated on the specific project itself and particularly focused on the details of design and construction and the immediate need the asset is meant to serve. Instead, the conversation should be reframed, stressing not the physical infrastructure asset but how the asset serves people and nature to ensure that the built environment, natural environment and human world can work together as an optimized system of systems. Planning, designing, building and operating infrastructure should emphasize meeting economic, environmental and social outcomes. Technology is a crucial enabler of these outcomes and, if used wisely, can vastly improve them. New innovations should not be selected solely for the sake of exhibiting exciting technology in a project. Technology should be thoughtfully applied as an enabler of better results, a tool with a defined role in delivering better outcomes. Four key questions can determine whether the use of technology is value driven:

1. Can I improve the asset's current capability?
2. When I build, can I build it better with technology?

3. Can I fundamentally disrupt demand?

4. Can I use technology to disrupt the need for the asset altogether?

Stakeholders who have a hand in making major decisions about projects have an important role to play here. This includes governments and owners who define minimum specification and performance requirements, institutional investors who own concessionaires, and developers who want to push the bar higher than the minimum requirements. Given that the details of a project (e.g. what form the asset will take, what materials and methods will be used, what the asset function will be) are often left to project owners, they can take this opportunity to be explicit about capabilities and project needs as well as the outcomes it aims to produce, which can help push for more innovation. During the procurement phase, laying out preferred outcomes, rather than being highly prescriptive, can source a whole range of new ideas that inject the process with innovation. However, some elements of standardization are important to expand innovative infrastructure approaches.

TABLE 4 | Example of this recommendation in practice

Name	Objective	Relevance
<b>A Call for Infrastructure Development through Unsolicited Proposals</b>	To provide guidance on how unsolicited bids can improve infrastructure development	This paper advocates for the use of unsolicited bids. Properly structured unsolicited bid programmes from governments can encourage innovation by delineating outcome-focused criteria and providing the opportunity for non-traditional partners to submit proposals. This allows would-be innovators to present new ideas to government decision-makers.  <a href="http://www3.weforum.org/docs/WEF_UPs_Note_2020.pdf">http://www3.weforum.org/docs/WEF_UPs_Note_2020.pdf</a>



## 7. Design infrastructure procurement models to be more collaborative in nature and to optimize risk allocation (allocating it to the right party) while promoting full-life-cycle value



The procurement process for infrastructure development has often encouraged an adversarial atmosphere between partners. A lack of coordination and cooperation has been a major factor in the inefficiency of project development and the frequency of cost overruns that plague projects large and small. Outcome-focused, collaborative delivery models are emerging that are more capable of dealing with complexity and allow effective integration with existing systems. Such models leverage input from across the supplier ecosystem, bringing together engineering and technology to deliver intelligent solutions. In these models, the role of procurement is to acquire the capability to achieve the outcome rather than to secure services based on the scope of work. Additionally, risk is allocated according to each stakeholder's capability to manage and, where possible, risk is jointly owned rather than transferred down the supply chain.

While the suitability and integration of these types of models will depend on the specific context in each jurisdiction, including available sources of financing, they can be an important tool. They facilitate integration around the outcomes and align the project supply chain with these end goals. They bring parties together for a more holistic process that strikes a balance between competition and cooperation and can lead to better project outcomes all around. Aligning all parties on common outcome-based goals also makes it easier to introduce and demonstrate the value of new technologies across the entire life cycle of a project, compared to the traditional approach of evaluating proposals separately at each distinct stage of a project. However, when considering collaborative

models, it is important to note that the public-sector level of expertise and capacity are important factors. In most emerging markets, collaborative models can only realistically be implemented with the guidance of competent and experienced advisers. Capability may also be an issue even in developed markets.

For instance, in some European countries, infrastructure agencies have lost the technical expertise needed when the focus for infrastructure development has shifted from traditional contracts to integrated performance-based contracts, including public-private partnerships. This type of organizational experience is required for infrastructure agencies to effectively procure, tender and manage contracts, particularly those that are performance-based, outcome-focused and collaborative, where risks are shared and managed adaptively.<sup>3,4</sup>

Aside from the need to leverage newer models, improving communication between owners and operators is also important to keep the focus on outcomes, reducing the likelihood of costly mistakes. Additionally, more efficient dispute resolution mechanisms are helpful in reducing the amount of time and money spent on project development.

It may also help to think about which types of incentives can be introduced to improve value capture, which can push project decision-makers to procure for outcomes and promote full-life-cycle value. More innovative thinking is also needed on how infrastructure assets are combined with other value-capture models and growth platforms, a common strategy for infrastructure development in East Asia.

“ Outcome-focused, collaborative delivery models are emerging that are more capable of dealing with complexity and allow effective integration with existing systems.”



TABLE 5 Examples of this recommendation in practice

Name	Objective	Relevance
<b>Project 13</b>	To improve the way high-performing infrastructure is delivered and managed	An industry-led collaborative delivery initiative, Project 13 works with a wide group of stakeholders to improve collaborative contracting models by positioning various players around project outcomes. <a href="https://www.project13.info">https://www.project13.info</a>
<b>BEST4ROAD project</b>	To develop best-practice guidelines and tools for the efficient procurement of road maintenance; to support various national road agencies on current and future challenges	BEST4ROAD is a joint collaboration between 11 European countries to study and compare maintenance and procurement practices. The project addresses high personnel turnover by examining ways to counter knowledge loss through best practices in procurement. <a href="https://best4road.weebly.com/project.html">https://best4road.weebly.com/project.html</a>
<b>German Highway A3 project (Autobahn A3)</b>	To construct the Autobahn A3 project – the largest public-private partnership infrastructure project ever commissioned in Germany	The project is a good example of a public-private partnership between the Autobahn authority and a consortium of private companies to ensure rapid project implementation. It comprises the planning and expansion of a six-lane 76-km A3 federal motorway to be completed by the end of 2025, as well as its operation and maintenance for the next 30 years. Collaboration is enhanced by the digitalization of the entire construction cycle using 5D BIM applications to connect all stakeholders in decision-making processes. <a href="https://www.a3-nordbayern.de/projekt/projektbeschreibung">https://www.a3-nordbayern.de/projekt/projektbeschreibung</a>



## 8. Reframe the cost–benefit analysis for infrastructure development to include new types of financial and non-financial considerations



Risks for infrastructure projects have traditionally focused heavily on a fairly narrow scope of financial considerations. Attention should shift to other emerging risks, like cybersecurity and climate resilience, which should be included in an expanded definition of financial risk. This conversation should also encompass the entire life cycle of an asset to ensure that the costs, benefits, risks and mitigation are properly matched with current trends and desired outcomes. This new approach to risk should also be twinned with defining the ways emerging technologies can help mitigate these risks and provide new benefits in both financial and non-financial ways. To help ease concern over adoption, leveraging new technologies should be thought of in terms of risk

and also in terms of uncertainty. It is important to also emphasize the benefits technology creates, which will help attract attention from project developers, sponsors and financiers.

One way to understand what parameters these new cost–benefit analyses should include is to use existing global frameworks, such as the United Nations Sustainable Development Goals, as a basis. The appetite for environmental, social and governance (ESG)-related investments is increasing. The door to genuine ESG capital could open if frameworks that deal with topics like climate risk and social considerations are used to assess infrastructure projects.

TABLE 6 Example of this recommendation in practice

Name	Objective	Relevance
<b>The Business Case For Life Cycle Thinking</b>	To illustrate the important role that life-cycle thinking has played in improving the private sector's environmental credentials and commercial results	This compilation of success stories from diverse businesses exhibits life-cycle thinking and provides real-world examples of how reframing cost-benefits analyses can result in environmental and commercial success.  <a href="https://www.lifecycleinitiative.org/wp-content/uploads/2019/03/unep_nairobi_V7-LR.pdf">https://www.lifecycleinitiative.org/wp-content/uploads/2019/03/unep_nairobi_V7-LR.pdf</a>

## 1.3 Building skills and education



### 9. Project industry needs into the future to understand the new or retrained roles, teams and departments required



Before industry can fully embrace innovation on a large scale, it needs to understand how its workforce must change. As regards integrating new technologies, skills and competencies of human capital are often more important than the technology itself. What can employees do to improve a business with a given piece of technology? The first step is to apply a forward-looking lens to understand the future needs of a technologically enabled organization, often with the help of partners in academia and professional industry associations and accrediting organizations. These crucial allies can help ensure that learning occurs at all stages of a career, and that relevant accreditations and credentialing standardize employee training practices.

It is crucial to delineate the specific competencies required to leverage emerging technologies in order to build teams around them. This creates the space for companies to match their workforces with the needs of the future. However, the implementation of these steps varies in difficulty, depending on where one sits in the value chain. For example, for infrastructure operators, the incentive to retrain employees is clear with relatively distinct upfront benefits. For contractors, however, the decision to reskill workers requires rethinking the business strategy and return on investment that take longer to become clear. To assist with this, making these training and upskilling programmes work in tandem with the overall digital transformation could be helpful. It is also essential to ensure that technological on-boarding trainings are cross-disciplinary to break down silos.

TABLE 7 Example of this recommendation in practice

Name	Objective	Relevance
<b>Ove Arup Foundation–Cambridge Centre for Smart Infrastructure and Construction (TOAF-CSIC) Digital Cities for Change</b>	To create public value with responsible digitalization in the urban built environment	This programme develops a competency framework and educational outputs to enable city managers to better use built environment data and emerging technologies, informing decision-making in urban planning, management and service delivery.  <a href="https://www.smartinfrastructure.eng.cam.ac.uk/projects-and-case-studies/dc2-digital-cities-change">https://www.smartinfrastructure.eng.cam.ac.uk/projects-and-case-studies/dc2-digital-cities-change</a>



## 10. Promote an impact-focused industry narrative that is matched by updated curricula to attract a new generation of talent



In alignment with a more outcome-focused model for developing infrastructure and understanding infrastructure's place within a system of systems, companies should promote their role in helping build a better society. Infrastructure developers have a compelling story to tell. Infrastructure is key to winning the fight against climate change, setting cities and countries up for economic success, and ensuring that the built environment, society and nature are connected in an equitable and just way. There are many bottlenecks on the journey from government policy commitments to the implementation of plans that achieve tangible impacts towards Sustainable Development Goals. Engineers have a special role in closing the implementation gap and operationalizing these

goals. Companies should highlight the role they play in creating better outcomes for society and focus on infrastructure's part in addressing issues like the environment, economic inequality and social equity. It is also important to acknowledge the externalities of industry activities and ensure that transparency and accountability are practised.

Academia should work hand in hand with industry when building programmes to guide graduating students into the field. It should seek to motivate and inspire by emphasizing the broader effect of infrastructure development on the world, and work with professional bodies to ensure that curricula are nimble enough to remain relevant in an industry that fully embraces change.



## 11. Upskill the boardrooms



One of the most important steps is convincing senior management that integrating technology at all levels is imperative. This means teaching senior executives the value and importance of adopting technology across infrastructure system life cycles. In practice, this includes instilling an understanding of the importance of data maintenance and usage in management. This can involve hiring a chief data officer to unite the IT and data components of the business, lead internal digitalization efforts and coordinate enterprise digital strategies. This can also be done by diversifying corporate boards to

integrate technology-focused voices and ensure the highest levels of the organizations remain on the leading edge.

Companies should also use reverse mentoring to improve tech knowledge from the front line upward. It is often the fresh-from-university, new-to-the-job employees that have a natural handle on the latest technologies disrupting the business. Connecting them with other employees in the organization, particularly at higher levels, can help disseminate technological know-how throughout a company.



## 12. Build a technologically savvy field of study focused on infrastructure engineering and information management



Helping prepare students for a technology-forward, outcome-focused industry is crucial. This effort should include building ontologies (a set of concepts and categories that can help to understand a subject) and studying information quality management, as well as encouraging the application of systems-thinking strategies. The skills needed to manage information are the same across infrastructure sectors yet, for most organizations, information management is a missing process. Practitioners know how to use technologies, but they have little understanding of the underlying data models and protocols. There are insufficient programmes of study that incorporate the development of skills in data and information management, which would enable organizations to develop the capabilities to put required processes in place. The true "infrastructure" programmes at universities are few, and many of them are heavily focused on engineering rather than information. Holistic programmes are needed that emphasize

both the role of infrastructure in meeting outcomes as well as the planning, management and delivery aspects of infrastructure where information is the primary product.

They should include topics like ESG issues, information quality management, political and policy analysis and economics. Ideally, this would start at the bachelor's degree level, focus on technology as an enabler, and complement technical science with behavioural science. Linking ontologies, information management frameworks and the enabling effect of technologies to the wider taxonomies that are applied to policy-making, such as the policies around net-zero growth, is essential. Additionally, innovation centres that bring together academia and the private sector can help bolster this field of study. A new discipline of professionals in infrastructure information is required, integrating infrastructure and information management disciplines, and enabling the future development of infrastructure for the public good.

“ A new discipline of professionals in infrastructure information is required, integrating infrastructure and information management disciplines, and enabling the future development of infrastructure for the public good.



TABLE 8 | Example of this recommendation in practice

Name	Objective	Relevance
A Survey of Top-Level Ontologies	To assist with the creation of the UK's national digital twin by supporting a Foundational Data Model to undergird a national Information Management Framework	This survey provides an important overview of the ontologies involved in developing a national digital twin applicable to the way infrastructure technologies are thought about.  <a href="https://www.cdbb.cam.ac.uk/files/a_survey_of_top-level_ontologies_lowres.pdf">https://www.cdbb.cam.ac.uk/files/a_survey_of_top-level_ontologies_lowres.pdf</a>



**13. Improve skills and resources available to governments to narrow the skills gap with the private sector**



The private sector is at the leading edge of innovation and technological change, and there is often asymmetry between knowledge, skills and capacity in the public and private sectors. Ensuring governments have the capacity to utilize new technologies is critical to ensuring that investment in these technologies is successful. Unfortunately, governments often lack the capacity to leverage technology and to structure procurements that encourage its integration. Assistance should be provided to government agencies that need help. Multilateral development banks can play a role in bridging this public-private sector gap by providing technical and financial assistance. Planning knowledge-sharing opportunities between developed and developing countries is also a good way to build capacity. Finding ways to bring in outside experts

from other institutions within a country could help mitigate the issues of low-salaried government employees leaving for other opportunities once they have acquired new skills. With this spirit in mind, however, it is important to remember that every country is different, and homogeneous solutions must be avoided. One size does not fit all.

To drive transformation in government, a focus on organizational change is also needed, in addition to individual growth. Government officials and practitioners come and go, both as political appointees and career bureaucrats. Working towards change throughout an organization ensures long-term success in developing policy-maker experience with key technologies like building information modelling (BIM) and digital twins.



# Conclusion

As the world recovers from the pandemic, the upcoming infrastructure boom presents a window of opportunity to make critical improvements that will affect generations to come.

“ It is possible to ensure that infrastructure serves as a platform to connect the built environment, the natural world and human lives in a way that allows all three to thrive.






These recommendations can guide decision-makers through what will be a new era of global infrastructure development to ensure that the infrastructure built is technologically enabled, focused on improving outcomes for the people and the planet, and anchored within a system of systems. Given the long lifespan of typical infrastructure systems, decisions made today will chart the path for our planet and its people for generations. That is why it is so important to implement these recommendations at this critical juncture. Integrating these ideas now, at the beginning of this upcoming global infrastructure boom, increases the chances of their success and in turn the quality of the infrastructure built.

These recommendations are meant to be shared within boardrooms, government ministries, classrooms – everywhere where the future of infrastructure is debated. Existing and planned initiatives that support the implementation of these recommendations are welcome, as is continued input on the utility of the recommendations as the infrastructure technology environment evolves.

This White Paper marks a milestone for the initial phase of the Infrastructure 4.0 project, which will be followed by a call to action to translate these recommendations into impact. The Infrastructure 4.0 project community will continue to explore solutions to the issue identified and will not only work towards its own set of implementation strategies but will also work with the World Economic Forum's network to make sure these global recommendations are disseminated for practice at a local level. It will also continue to work with the Global Infrastructure Hub to highlight best-practice examples of technology adoption throughout infrastructure project life cycles. By using technology as an enabler, with a focus on improving outcomes for people and nature, it is possible to ensure that infrastructure serves as a platform to connect the built environment, the natural world and human lives in a way that allows all three to thrive.

# Appendix 1:

## Summary of recommendations

Recommendation	Level of implementation	Sector(s) involved		
	 Strategic  Tactical	 Public sector	 Private sector	 Civil society/academia
<b>Creating new ecosystems</b>				
1. Focus on the interconnectedness of natural, built and human systems, and treat infrastructure as a system of systems	Strategic	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
2. Formulate approaches to prepare communities for technological transitions and provide engagement opportunities and assistance for those impacted	Strategic	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
3. Encourage infrastructure asset owners and operators to set enterprise digital strategies	Both	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
4. Develop digital commons and marketplaces for public data to facilitate the adoption of new technologies and the creation of innovation ecosystems	Tactical	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
5. Empower engineers, designers and other front-line infrastructure workers to innovate and scale up good ideas	Strategic	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
<b>Creating new business models</b>				
6. Frame infrastructure development as a platform to improve economic, environmental and social outcomes	Strategic	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
7. Design infrastructure procurement models to be more collaborative in nature and to optimize risk allocation (allocating it to the right party) while promoting full-life-cycle value	Tactical	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
8. Reframe the cost-benefit analysis for infrastructure development to include new types of financial and non-financial considerations	Tactical	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
<b>Building skills and education</b>				
9. Project industry needs into the future to understand the new or retrained roles, teams and departments required	Strategic	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
10. Promote an impact-focused industry narrative that is matched by updated curricula to attract a new generation of talent	Strategic	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
11. Upskill the boardrooms	Tactical	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
12. Build a technologically savvy field of study focused on infrastructure engineering and information management	Tactical	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
13. Improve skills and resources available to governments to narrow the skills gap with the private sector	Tactical	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>



# Appendix 2:

## Infrastructure 4.0 Community

The World Economic Forum Infrastructure 4.0 project team thanks and acknowledges the contribution of all the Infrastructure 4.0 community members for their diligent participation, input, review and comments throughout the development of this document. The findings and recommendations in this paper are the result of their valuable insights and collaboration.

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# Endnotes

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