Digital Twins and the Systems Perspective

A buildingSMART Digital Twins Working Group Paper

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Introduction

We live in a volatile and challenging world greatly impacted by social, economic and political factors that show no sign of abating. Our existence is intricately woven into a complex web of systems governing healthcare provision, energy distribution, education, transportation, currency flow, water purification, communication and much more. In many ways, these systems are the pinnacle of human achievement and they underpin everything that sustains societies. But not all is well with our systems.

While these systems have long fulfilled their intended purposes, the landscape is becoming increasingly complex, particularly as we accelerate the 'twin transition' [1]. The organisations and institutions that manage our systems are struggling to cope with the growing complexity in between the silos that they have traditionally operated within.

While the socio-economic challenges are growing and becoming more complex, this is counter-balanced by a growing set of opportunities, mainly in the field of data, standards and technologies like AI, digital twins, quantum and robotics. Growing computational capability is giving rise to cyber-physical systems, that is, systems that integrate data and digital technologies with physical assets and processes to help make insightful decisions and perform advanced tasks to achieve desired outcomes. Cyber-physical systems include smart grids, industrial system controls, avionics, and construction robotics to name a few. This relationship between physical and digital worlds is also at the heart of the topic of digital twins [2].

Given the connections, there is a clear opportunity to align different sectors like transportation, energy, healthcare, legal services, and others for a more data-driven future. The built environment has an essential role to play in this future because it is effectively the host of society's most important systems. And given its clear transition from file-based to data-based exchanges, there is a huge opportunity to consider a larger and more connected future – also described as "connected wholes rather than separate parts" [3].

However, with well-documented productivity and performance challenges facing the built environment, coupled with an urgent need to tackle climate change, resilience and decarbonization, a change in mindset is needed. That is, a shift to think of the built environment in terms of systems and to see how this can deliver better environmental, social and economic outcomes.

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The Purpose of the Digital Twins Working Group

The Digital Twins Working Group (DTWG) is advocating a new way of thinking – to raise awareness of the concept of the built environment as a "system of systems" towards an ecosystem and, in conjunction, to accelerate the adoption of open standards so that the foundation of our work can be open, collaborative and guided by the right principles. In order to make this transition, we require standards and alignment to make it a success.

Following on from the 2020 paper by the DTWG, titled "An ecosystem of digital twins", the group broadened its vision in 2023 by incorporating the Three Horizons Framework to guide the transition towards a synergistic ecosystem of digital twins, a pivotal discussion at the buildingSMART International Rome Summit. Subsequently, at the buildingSMART International Lillestrom Summit in September 2023, the group enriched this framework with the Seven Perspectives. Each successive paper has built on the previous work and, together with this paper, they provide an increasingly coherent conceptual framework for understanding the big picture of the built environment.

This paper aims to add a Systems Perspective to the framework. In Part 1, we delve into the socio-economic transformations that have taken place. Part 2 is dedicated to highlighting significant advancements in technology and data. Moving forward, in Part 3, we expand the perspectives model to include the systems perspective, before the Conclusion.

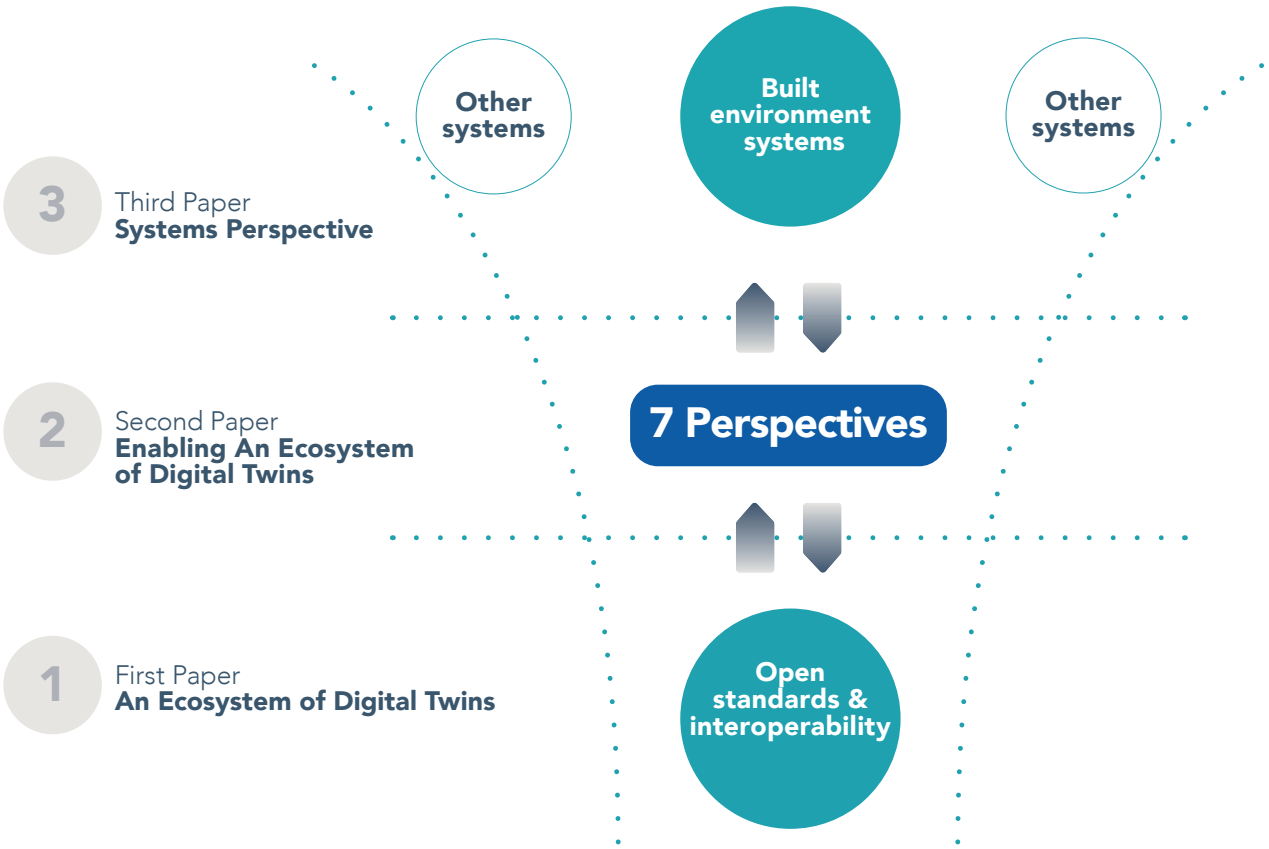

Image: The approach from the Digital Twins Working Group

Part 1:
A Challenging Outlook for the Built Environment

Socio-economic developments have a major influence on the requirements of our built environment systems. For example, the demographic shift towards ageing populations puts obvious direct pressure on healthcare and residential facilities. More broadly, a shift towards prioritizing the improvement of health outcomes of citizens would also include improving air quality, providing healthy transport options and reducing heat stress in urban areas. Consequently, health and wellbeing are not just the remit of healthcare systems, rather the wider built environment has a key role to play as well.

In this example, the challenge of improving health is the focus, but the same is true for using our built systems to improve other outcomes for people and nature. Understanding these challenges through a systems perspective highlights the importance of understanding and continuously enhancing our interconnected systems to meet the evolving needs of our populations effectively [4].

Adaptations of systems are required to deal with the challenging outlook, but in many cases, these interventions can sometimes have little effect, or even be detrimental [5]. Therefore, it is essential that we do the right projects, as well as doing the projects right. It also means that we need to look even beyond to make sure that the resulting built systems deliver on their promise. Every system has challenges once in operation, but we tend to ignore their value once they are built. For example, what is the value of existing building stock and how can it be adapted into housing systems to support an ageing population better? Or how do we better manage existing assets to improve health outcomes? Or how do we decarbonize existing transport infrastructure? And how do we adapt our existing infrastructures to new forms of transportation like electric and, in the near future self-driving vehicles in an environmentally friendly way? These questions also drive us to consider how the silos of our current organisational, and institutional incentive structures sometimes hinder us.

Climate change and the need to address decarbonization and resilience are top of the agenda for the built environment. The well-documented net zero approach is gaining traction for good reason: construction and buildings in operation are one of the most significant contributors of CO2 emissions. To create a low-carbon future, we must rethink sustainability throughout the asset lifecycle, starting with 'use' and supporting it with a data-driven approach. With the advent of AI, there is a growing body of research to suggest this could positively impact how we deal with growing complexities [6].

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As a society, we must focus on transforming our infrastructure, reducing energy consumption, and embracing renewable resources. This involves a holistic approach that encompasses the design and construction of new buildings and infrastructure and the retrofitting and optimization of existing structures. We can create a more resilient and environmentally friendly built environment by integrating sustainable practices into urban planning, transportation, and waste management.

At the sector level, labour shortages persist; unfortunately, the situation does not appear to improve. This challenge extends beyond mere numerical deficits; in our increasingly digitized and interconnected world, there is immense pressure to reskill the existing workforce. Meanwhile, productivity within the sector has lagged behind other industries and, in some regions, has even declined. As the demand for construction and reconstruction continues to surge, the strain on available capabilities and capacities becomes ever more pronounced.

In addition to labour shortages, the construction industry grapples with well-documented material scarcity, a challenge that reverberates across policies advocating for circularity. These discussions often centre around the strategic autonomy of regions. As we pivot toward a circular economy, the repercussions will be felt deeply within existing value chains—particularly those tied to materials like steel and concrete. New materials are composed of a diverse range of resources, whose properties and origins must be considered for sustainability during the design process. The ongoing management of the assets used is an important aspect in this context. The critical question emerges: How can we develop solutions that facilitate a circular economy model? With a systems thinking lens, circularity is not just about reducing construction waste or increasing recycling rates, rather it is about maximising the value in use of our built assets and systems.

The final angle to consider centres around the pivotal role of technology in addressing industry-related challenges. While technology holds immense potential—as we'll delve into in Part 2—we currently grapple with a relatively low level of technology adoption within our sector. Our digital mindset remains underdeveloped, and our training and experience predominantly align with a project-based approach, rather than one that is system-wide. Additionally, the value chain remains highly fragmented so data and digital integration continues to be a huge challenge.

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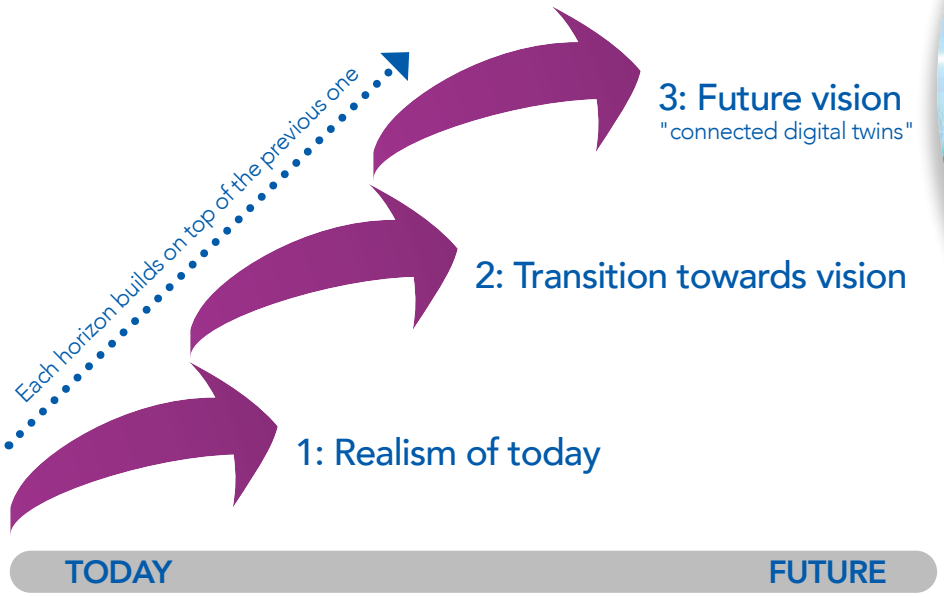
However, there are promising developments. We increasingly recognize the imperative for public and private collaboration during this transition. The mandate for digital regulations and permits by public authorities serves as a catalyst for digitizing the value chain. We also notice that in major projects around the world, international front runners in the industry actively collaborate to incorporate the prerequisites for ecosystems of digital twins, such as open standards. The Accelerator Program initiative from buildingSMART international has been developed to support major projects.

Yet, despite progress, our efforts remain insufficient to tackle the formidable challenges ahead. By studying our existing systems and understanding their interconnections, we glimpse the possibilities for intervening and reshaping the built environment for the better—a crucial step toward our second horizon in the framework. The route to improving outcomes is via understanding our built and natural systems better and intervening more effectively.

The Three Horizons Model



Source: www.visionforbuiltenvironment.com

Part 2:
Opportunities are Emerging

Two critical themes are emerging: advancements in data and digital technology, and the maturing of the industry. The interplay between these two is pivotal. While data enables key insights that can inform better decisions, it is the practical tools built on technology that harness and leverage this data. Without the industry maturity to adopt and use these tools, addressing the socio-economic challenges we face would be impossible.

From a technological standpoint, we've witnessed remarkable acceleration in recent years. This progress extends beyond digital twins and robotics, encompassing the decreasing costs of sensors that provide dynamic data about assets and the growing accessibility of artificial intelligence.

One notable example is Singapore's development of a digital twin of the entire city, known as Virtual Singapore. This platform integrates data from various sources to create a dynamic 3D model of the city, used for urban planning, disaster management, and infrastructure maintenance. By simulating the impact of new construction projects on traffic, ventilation, and noise levels, Virtual Singapore allows for better decision-making and planning. The system also enables predictive maintenance of infrastructure, potentially reducing downtime and extending the lifespan of assets.

Such technological advances have made the application of these technologies possible on a national scale. AI, for example, has demonstrated its potential to increase productivity significantly. A growing school of thought suggests that AI will further enhance digital twins by enabling advanced data analysis, predictive maintenance, and decision-making. This will turn them into intelligent systems that can learn and improve over time. AI-based modelling can revolutionize the models that sit at the core of many digital twins, generating simulations and providing insights faster and cheaper than the physics-based models that are used to train them. This can make digital twins more accessible and valuable contributors to the system.

Another example of this application is in energy grid management, where enhanced intelligence is improving system-level decisions. The energy grid includes power generation plants, transmission networks, distribution systems, and consumer usage data. Renewable energy sources like solar, alongside traditional power plants, are integrated into the grid to ensure reliable energy delivery. By using real-time data from sensors and smart meters, the grid can dynamically balance energy supply and demand. For instance, when solar generation is high, the system can reduce power output from coal plants or store excess energy in batteries, thereby reducing carbon emissions and improving grid resilience. However, challenges remain, particularly in cybersecurity and ensuring seamless data flow during critical times, which have led to some high-profile incidents.

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The Role of openBIM

For a few years, there has been a growing acknowledgement that openBIM will play a crucial role in the ecosystem of digital twins and broader systems thinking, providing a foundation for structured, interoperable and accessible data across the built environment. buildingSMART International has been developing effective standards and services for the industry. Notably, the publication of IFC 4.3 as an established ISO standard has solidified its importance. Recent developments such as Information Delivery Specifications (IDS), BIM Collaboration Format (BCF), and the buildingSMART Data Dictionary (bSDD) service are bringing significant benefits to stakeholders across the built environment. Additionally, there is a growing trend of governments and clients recognizing the value of IFC and openBIM, leading to an increase in IFC mandates.

If you consider the topic of Building Information Modelling (BIM), there has not always been a consensus that this is applied in a way which contributes to more productive outcomes. A recent study found that "the organisational and contractual frameworks that are being used to deliver BIM projects only partially support collaboration" [6]. This adds weight to the importance of openBIM, which can add more value through greater interoperability, enhanced collaboration and improved productivity. To support this, bSI is advocating far greater use of open standards to, unlock these positive outcomes across the built environment ecosystem.

These ongoing developments are enabling an ecosystem of digital twins. To support these ongoing developments, buildingSMART International is expanding a mixture of new open services and standards to address growing demand. As an industry, we must focus on the system as a whole, not as an isolated entity.

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Part 3:
A Systems Perspective

The built systems that sustain our society come in many forms. They are complex, interdependent and essential. Therefore, it is time to perceive the built environment differently, not as a series of construction projects, but as a system of systems whose explicit purpose is to enable people and nature to flourish together for generations [8].

The key value proposition of this systems perspective is that it can deliver better outcomes for people and nature at a lower overall cost. And it is a necessity if we are to address the system-level challenges that face us, like addressing climate change, providing resilience and developing a circular economy. Such an approach would be outcomes-focussed, systems-based and community-enabled. A clear example of this has been done at a national scale in Singapore. The CORONET X platform aims to streamline regulatory governance by following a clear open standard through which submitters need to adhere to an IFC format for building works. This system-level approach will improve collaboration, streamline submissions, and give clear guidance to all who use it.

In the paper, "Enabling an Ecosystem of Digital Twins – An Update", published in September 2023, the DTWG introduced the seven perspectives [8]. These perspectives play an essential role in the transition of the industry, and a systems perspective connects them all.

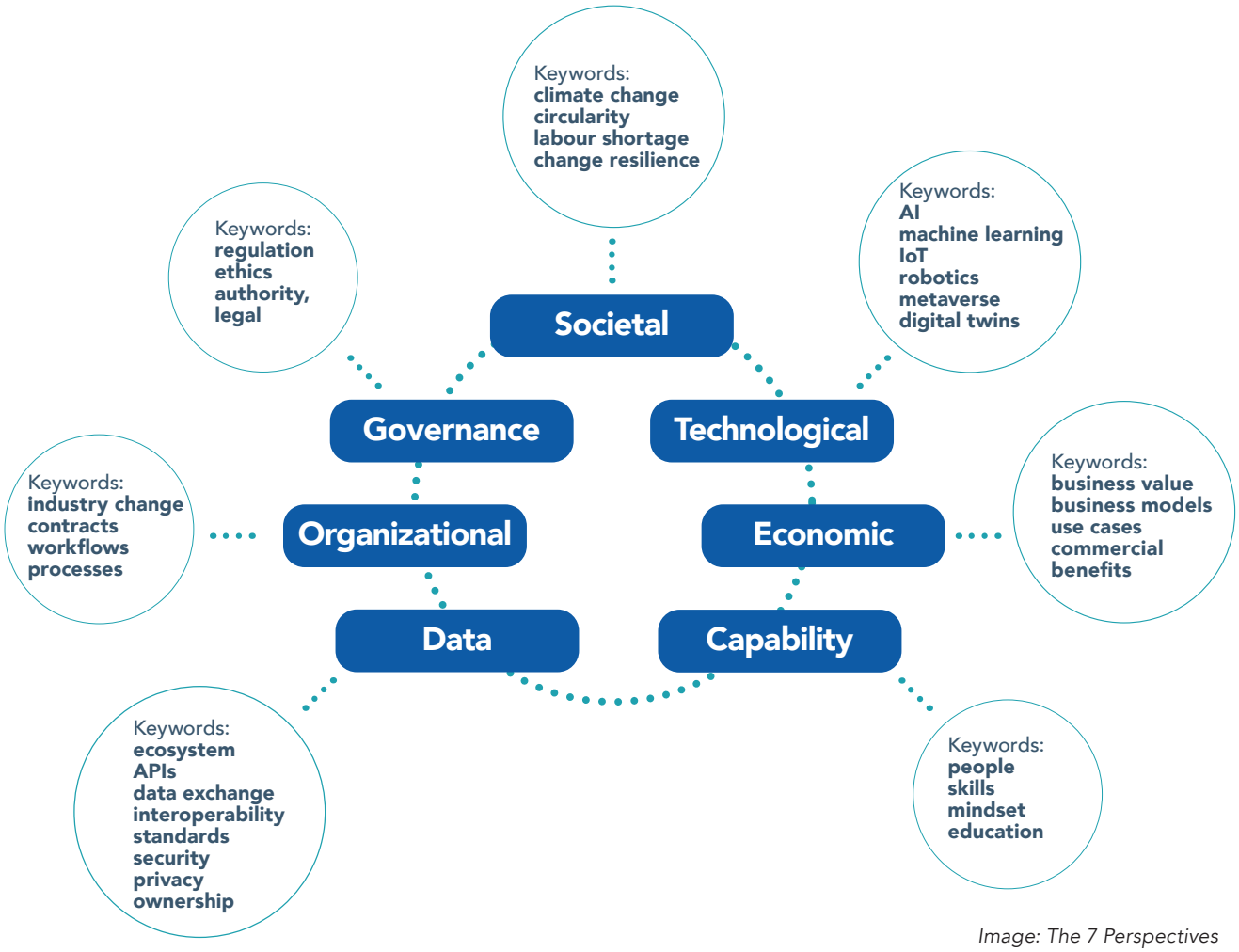

Image: The 7 Perspectives

Together, these perspectives provide a coherent framework for considering the built environment, highlighting the interdependencies. For example, "Governance" can provide regulations to foster more consistency, transparency, and accountability in a system. For the "Capability" perspective, we see a big gap in awareness and skills relating to system thinking, including what impact engineering decisions are having.

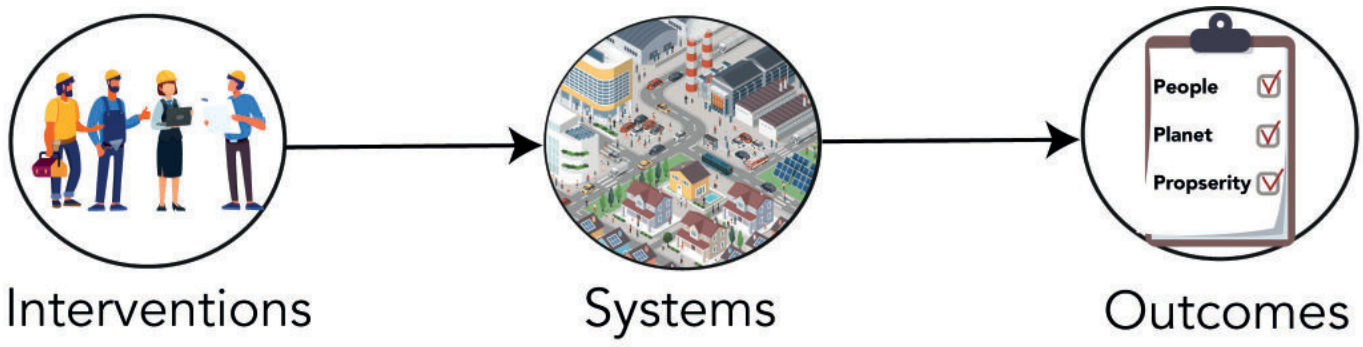

Image: Interventions into a system can lead to better outcomes

As the diagram above illustrates, the route to improving outcomes is through enhancing the performance of the systems. In this context, projects are 'interventions', adding new assets or modifying existing ones to have a positive impact on the overall system. Therefore, we must use all the means at our disposal to understand our built and natural systems better and to intervene more effectively. This includes making much better use of data and digital approaches such as developing ecosystems of connected digital twins and cyber-physical infrastructure.

A key goal should be transforming these systems into truly cyber-physical entities. Leveraging digital twins, GIS, sensors, big data, and other emerging technologies can enhance the understanding, operation and performance of these systems. Additionally, embracing open standards can drive innovation and gain support from the software industry.

However, this shift requires more than just technological advancements; it necessitates a change in mindset, industry norms, and governance. The ultimate goal should be to improve the quality of life for people. Only by adopting a systems perspective can we do this.

Leveraging digital twins, GIS, sensors, big data, and other emerging technologies can enhance the understanding, operation and performance of these systems

Conclusion

As we navigate the complexities of our modern world, the need for a systems perspective has never been more pressing. The interconnectedness of the systems that sustain our society demands a holistic approach, where every intervention is considered in the context of the broader network of systems it impacts. The challenges we face—ranging from climate change and demographic shifts to technological advancements—cannot be addressed in isolation. Instead, they require a coordinated, systems-based approach that integrates social, economic, and environmental considerations.

The transition towards cyber-physical systems represents a significant opportunity to enhance the efficiency, resilience, and sustainability of the built environment. By harnessing the power of digital twins, GIS, sensors, big data, and other emerging technologies, we can create systems that are not only more effective but also more adaptable to the evolving needs of society. Open standards will be crucial in this transformation, fostering innovation and enabling seamless collaboration across different sectors.

However, this transformation is not solely about technology. It demands a shift in mindset, a re-evaluation of industry norms, and a reimagining of governance structures. To achieve meaningful progress, we must focus on improving the quality of life for all people by addressing urgent challenges such as climate change, environmental degradation, and social inequality.

In conclusion, the journey towards an effective system of systems is both a challenge and an opportunity. By adopting a systems perspective and leveraging the tools and technologies at our disposal, we can create a future that is more sustainable, equitable, and resilient.

In short, we are an industry in transition with a brighter future.

Having established a coherent conceptual framework, the DTWG will in the next months now work with specific use cases to translate the conceptual framework in this and previous papers to practice.

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