DIGITAL TWINNING AUSTRALIA

WHITE PAPER

Cyber Physical Systems [CPS]
the next generation of Digital Twins [DTw]
to implement Industry 4.0 [4IR]

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ABSTRACT

The continuing rapid pace of change for Industry 4.0 technology, means that some organisations termed “digital natives” are the early adopters taking advantage of this new digital technology, while more traditional organisations are falling behind.

An enhanced combination of technologies allows organisational transformation across the whole of the organisation’s processes, structures, and business models. These early adopters increasingly gain significant advantage. Previous integration and interoperability challenges are rapidly being addressed so it is not too late for organisations to begin their journey.

The evolution from digital twin/s (DTw) into cyber physical systems (CPS), which connect DTw and data, is readily explainable to less technically savvy audiences. A Minimum Viable Product (MVP) is a great way to prove the feasibility of DTw technology and identify future opportunities and options, bringing tangible and intangible benefits to the organisation as it is, and for future capability and development.

Some examples from various industries follow:

INDUSTRY 4.0 (or 4IR)

A McKinsey report on manufacturing *("Manufacturing's Next Act, 2015)* indicates that Industry 4.0 is not marketing hype, but powerful emerging currents that will change the way we operate and open up new opportunities.

In summary it will impact manufacturing and industrial sector due to:

- Very significant rise in data volumes, computational power, and connectivity
- Emergence of advanced analytics and business intelligence capabilities
- New forms of human-machine interaction and integration
- Improvement in transferring digital information to the physical world.

Since 2015 these trends are far more pervasive and have expanded to encompass many diverse industries.

In a more recent report in 2022 *("The data driven enterprise in 2025")* McKinsey lists the following seven characteristics of the emerging data-driven enterprise:

1. **Data is embedded in every decision, interaction, and process.**
2. **Data is processed and delivered in real time.**
3. **Flexible data stores enable integrated, ready-to-use data.**
4. **Data operating model treats data like a product.**
5. **The Chief Data Officer's role is expanded to generate value.**
6. **Data-ecosystem memberships are the norm.**
7. **Data management is prioritized and automated for privacy, security, and resiliency.**

While we might think this is somewhat futuristic, they also report on the Lighthouse Network (Launched in 2018, the Global Lighthouse Network is a World Economic Forum initiative in collaboration with McKinsey & Company), which in 2021 had 90 sites globally. Their report notes that "The frontrunner companies that comprise this network continue to demonstrate the true potential of the Fourth Industrial Revolution **(4IR)** technologies to transform the very nature of manufacturing."

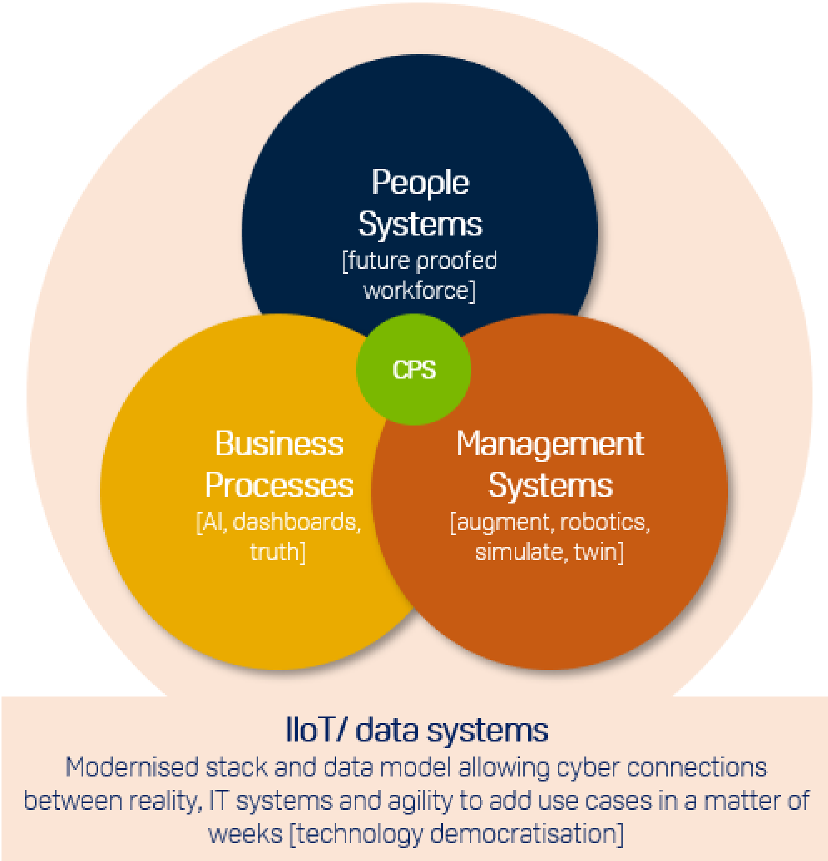

Figure 2. Cyber Physical System Positioning Adapted from McKinsey& Company report.

Cyber-physical systems sit at the heart of this fast-moving transformation as shown in the two diagrams (Figure 1 & Figure 2), taken from McKinsey reports. The key take away is that this transformation is happening now and providing tangible immediate benefits to early adopter participants.

McKinsey reported [2020] that industry fast-movers are building on their head start and are now able to generate more value across the entire enterprise. As highlighted in Figure 1 Cyber Physical System technology is the connector across the people, business, and management systems.

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Then in 2021, McKinsey reported "lighthouses unlock sustainability through 4IR technologies". Again, it is the evolution of DTw into CPS that enable accelerated development. In Figure 2, McKinsey illustrate that technology, performance and sustainability are intrinsically linked. CPS, sitting at the apex is the connector of DTw; the enabler.

The recent exponential shift in technology is driving significant market based transformational change - e.g., energy is an example of where the priority has shifted from infrastructure supply to consumers as key generators. The shift is paradigm-like and prioritises design for operational combined with consumptions optimisation across the asset's life cycle.

A well-publicised example of Industry 4.0 would be smart autonomous cars, which, while still evolving, will bring together several technologies, including electric power for transmission, connection to the factory for condition monitoring, as well as software for passenger interaction, routing, driving and collision avoidance. In a recent quote, one automobile company executive indicated that today they were hiring as many software engineers as automobile engineers. There are significant changes taking place in this industry right now.

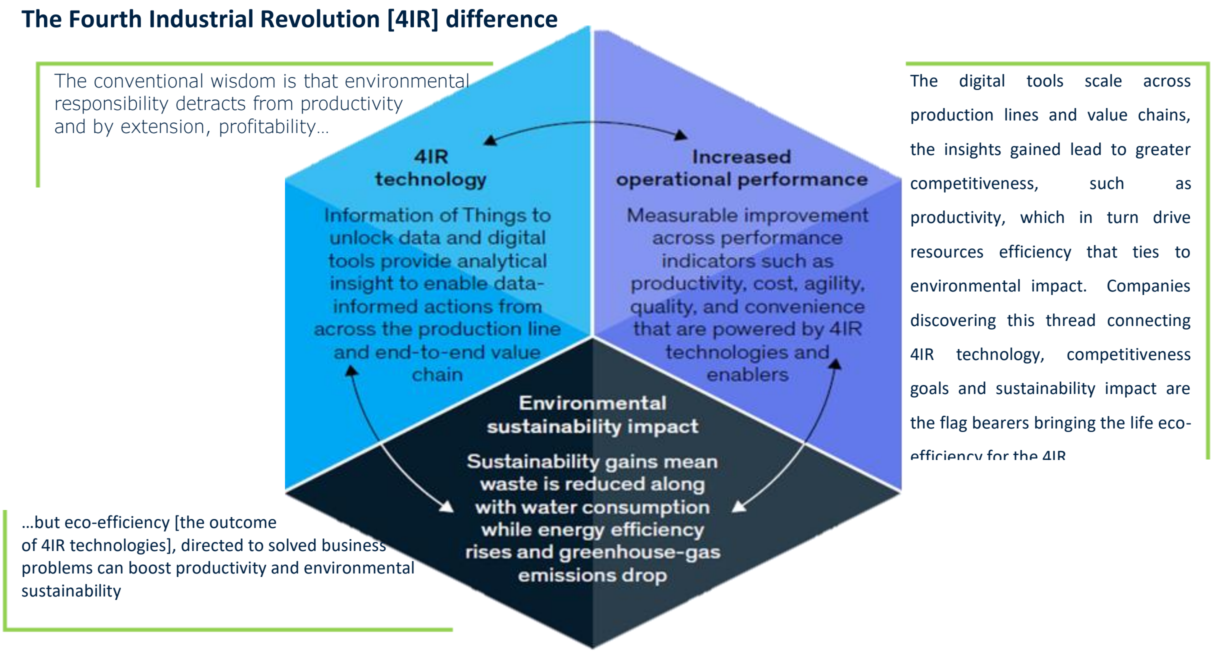


Figure 2. Cyber Physical System impact [Image source: McKinsey 2015]

DTw DEVELOPMENT

Digital Twins emerged in the 1970's with NASA space shots (very rudimentary). The actual term was coined in 2003 by Dr Michael Grieves and has developed since then. There are many definitions today of what a DTw comprises, but the one we will use is

> ***"the ability to connect critical physical asset with their historical, current and forecast data, in a curated form derived from various data/ information storage solutions, {the edge and live?], enabling am expanded group of users and participants to collaborate, explore, prove and improve solutions to complex problems."***

DTw contain numerous layers, represented simplistically in a singular process at Figure 3. This diagram shows how information from the physical layer passes through the data layer, using machine embedded sensors into a data/ knowledge base to inform the model layer where virtual models allow analysis and visibility, resulting in actionable insights and human intervention.

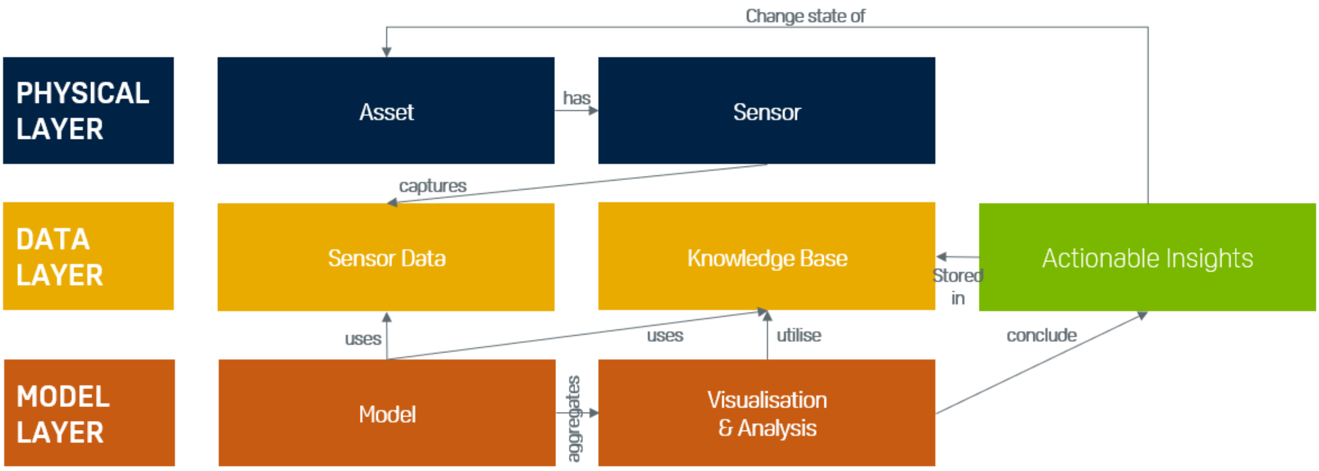


Figure 3. DTw ontology model. (Singh et al, 2021)

Digital Twinning Australia (DTA) product *Cooee* (call response and isolate) has extended the singularity concept illustrated in Fig 4. to the next level, being the shift from singular component to whole of system or plant levels. If we consider one pump, Fig 4. makes sense. Now consider ten pumps whose function is to drive flow at prescribed levels with pre-defined tolerances and accessing data from above and downstream and making sense of a system. The diagram becomes increasingly difficult to conceptualise.

DTA's Cooee enables the contextual visualisation of systems operating and interacting with other systems to encompass the plant or organism. Cooee is able to deliver this at Industry 4.0 levels of interoperability.

Maturity

Considerable discussion is occurring today about maturity levels of DTw, and Table 1 below is one version. Evolving from the simplistic Level 1 to the most complex current systems (Cooee) at Level 5. Levels 4 and 5 are new developments and are less common right now but certainly are in development and like Cooee, in operation. At Level 4 we would call that the DTw has evolved to a CPS.

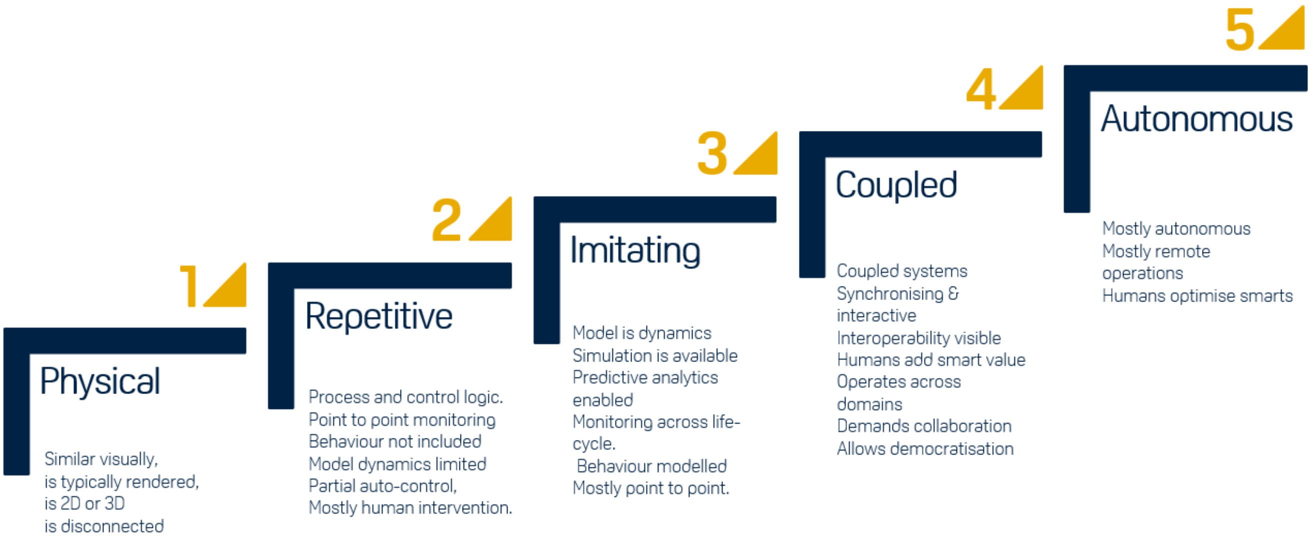


Table 2. Maturity level of DTw

HISTORY OF CPS

The term CPS emerged in 2006 but related concepts existed earlier, as with DTw. There appears to be some overlap between DTw and CPS, but the emerging view today is that a CPS combines several synchronising DTw. A CPS, therefore, unites single DTw to achieve enhanced information and associated benefits, and will regularly operate across and link disciplines, as these following examples show.

Mining A mine with a cyber physical mine system enables conceptual visualisation and system interoperability allowing operational problems to be resolved in the context of strategic asset lifecycle optimisation. This allows a focus on critical operational elements that are essential for managing assets aging or utilisation, whilst balancing indirect issues like decarbonisation and social license issues.

Smart building - Consists of multiple interconnected DTw's covering equipment, inclusive of energy systems, space utilisation, transport efficiency, security, and a raft of operations.

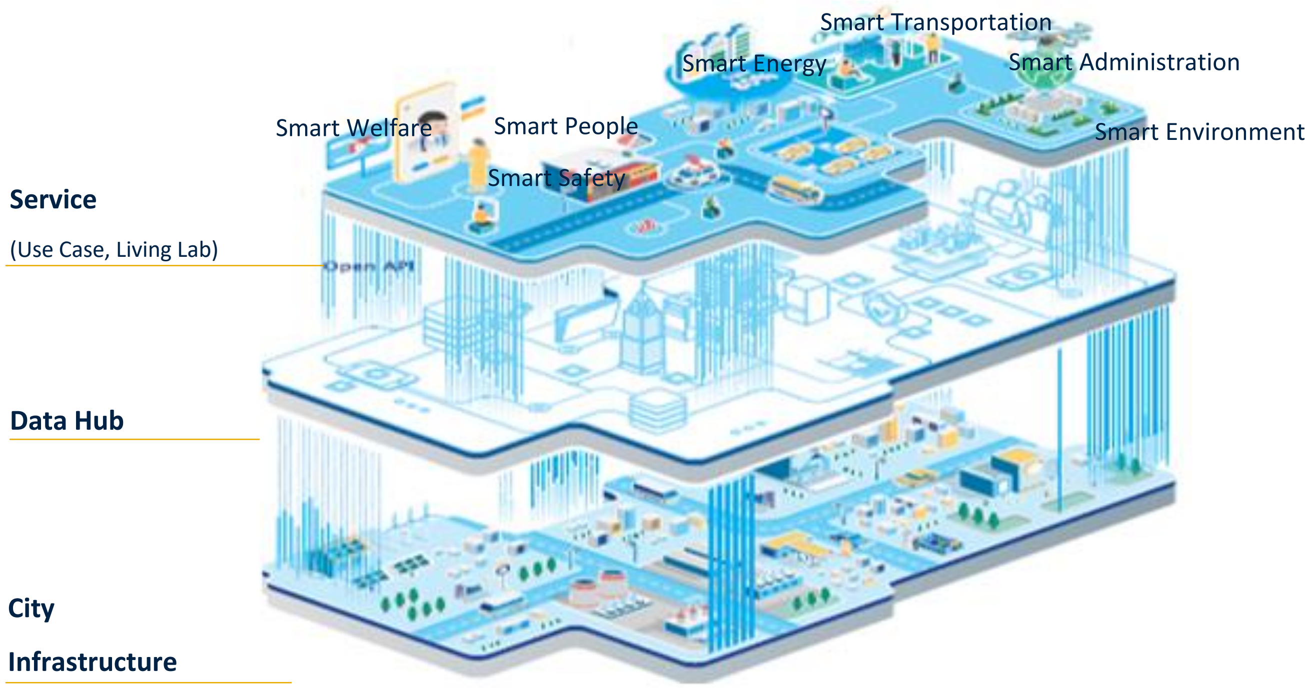


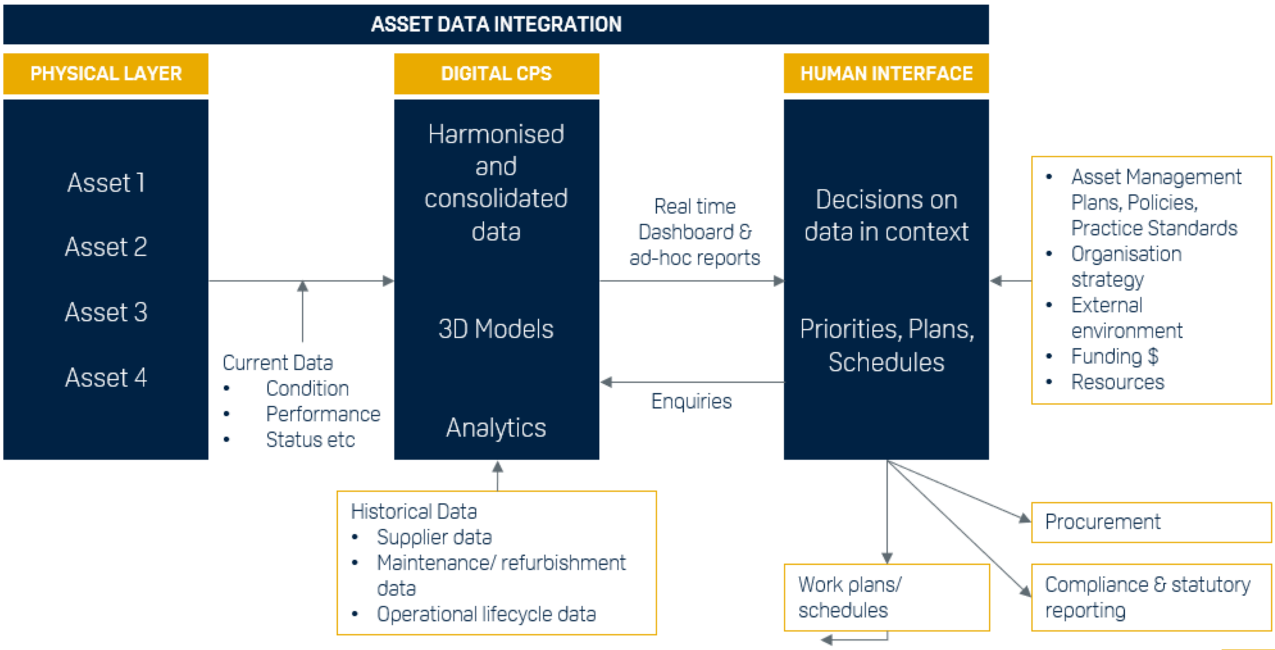
Figure 4. Smart City illustration (Korea Agency for Infrastructure Technology Advancement, 2019)

A smart city - as per Figure 4, will lead to improved urban planning, traffic and utilities management, sustainability, cooperative governance and quality of living or use for citizens / occupiers, and achieve this through collecting, analysing and understanding data and its many inter-connections. [i] When a number of DTw connect forming a CPS, this increases the overall capability and business value of the model through connected data and advanced analytics.

CPS ISSUES TO BE RESOLVED

With DTw or the next generation CPS like Cooee there remain several ongoing issues currently being investigated and resolved across operations and research.

- Interoperability. Data from various sources is often in different formats and these differences need to be integrated and the data retained by the user not the vendor. DTA's data harmonisation approach (Cooee) resolves this to allow immediate progress towards a CPS - see Figure 5. on page 6.
- Standards for interoperability are continuously under development as is the R&D associated with Cooee, which will permit future enhanced integration, but this will progressively occur over time. Cooee's data harmonisation creates a usable working skeleton now.
- CPS takes data integration beyond the simple Business Intelligence **(BI)** and its near static dashboards on the 2000's to allow learning by reuse of past data, and the embracing experiential data, identifying new insights and opportunities (e.g., how to speed up production processes, or maintain quality in changing conditions)
- Asset interoperability is supported. Data on assets from various sources can be integrated for significant effect – for example upon acquisition the plant can be modelled of as built drawings and asset specifications (including supplier data), on-going maintenance and be watches assessed and modified efficiently, actual physical changes during the life cycle are monitored and adjusted, and long-term asset planning can be optimised) – see Figure 5 below.
- Human and CPS interaction issue, where careful design is required to ensure personal safety



when interacting with autonomous machines.

Figure 5. CPS Interoperability

BENEFITS OF A CPS

Benefits will include those that are more tangible and quantifiable, alongside those that are desirable but harder to measure. The following brief list is a mixture of both:

- Reduces operational costs due to the impact of contextual visualisation and interoperability
- Aids human decision-making on assets, by providing live data in context and historic comparison, whether that be about maintenance requirements, refurbishment, replacement and/or disposal decisions.
- Supports more accurate modelling and simulation of future scenarios
- Assists in transcending what is traditionally a silo approach
- By bringing together data, it facilitates collaboration across various functions and disciplines plus real time management information.
- Reframes how business processes and models are identified, planned & achieved
- Opens new revenue sources - e.g. Removing intermediaries in the value chain, emerging ecosystem across industry boundaries, allows the commercial use of data for alternate benefits.
- Enhances both personal and infrastructure safety, and resilience.
- Provide relevant data for aggregation and summary on ESG reporting.

Experience increasingly shows that fast movers are rewarded in this digital and data age, and we have seen that with large technology-based companies that are able to pivot quickly in response to changing circumstances and dominate rivals. A CPS with integrated data and analytics provides industrial companies with physical assets more flexibility and agility to change.

HOW TO PLAN FOR AND IMPLEMENT CPS

A CPS is an essential part of the transformation to efficient digital and data utilisation as described in this paper. The examples indicate this has a profound effect on organisations, their business models and mode of operation. For some of the newer technology-based companies that we hear about regularly, these “digital natives” continue to be very quick to respond to changes and adapt new technologies more easily than their competitors. Older and more established companies with legacy systems and procedures, and often find it more difficult to adapt, however DTw can enhance even these more static businesses providing cost of production savings and management enhancements.

The capabilities that organisations require for digital transformation and the progression to the adoption of CPS can be summarised as:

- Board direction/Mindset change – able to see technology as an enabler and move beyond legacy systems and processes
- Cultural evolution - foster enhanced collaboration across functional and operational groups
- Skills enhancement - upskill the organisation both management and workforce, aiding retention of key workers, and greater efficiency, critical to the evolving data driven enterprise.
- Allow greater flexibility to pivot and change to address emerging situations.

The implementation of these capabilities will not be instantaneous, but will be a thinking board and management journey of discovery, growth, and development. This can include for example:

- Starting small and learning by introducing a MVP, not just as a prototype but a learning experience which demonstrates specific working solutions in one area of the business, which will assist the organisation in identifying best payoffs for future development. As this is understood and embraced change becomes less turgid and enjoyed.
- Once and MVP is in place it can be enhanced to add to the initial data harmonisation and integrate data from various sources in support of the MVP. This requires limited investment and enhances the learning opportunity and profitability dollars and useful information to guide further development. Full interoperability can come later.
- New governance models across the organisation can be implemented for this initiative, since there will be improved predictability, and each step will build on the previous step based on ongoing learning and the regular review of the initial goals, the objectives, their implementation plans and evolution.

It should be noted that there is considerable material being developed and it is now available from the Centre for Digital Built Britain (hosted at the University of Cambridge) and the Construction Innovation Hub. These ventures are collaborations between UK Government, industry, and academia to produce publicly available guidance to enhance the journey of digital transformation through digital twins and cyber physical systems.

While your organisation may or may not be "digital natives", they can become a "fast follower" and still gain significant benefits by using the proven technology. This paper has explained some key issues at a high level but each of key item can be expanded upon in greater detail as required.

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[i] *Source: National Strategic Smart City Program, Korea Agency for Infrastructure Technology Advancement, Korea https://smartcity.go.kr/wp-content/uploads/2019/08/Smart-city-broschure ENGLISH.pdf accessed 25/2/2022*