Infrastructure Digital Twin Maturity: A Model for Measuring Progress

A Digital Twin Consortium White Paper

2021-08-04

Authors

John Turner (Gafcon), Richard Ferris (asBuilt), Salla Eckhardt (Microsoft).

Contents

FIGURES

TABLES

The world is talking digital twins, driving projections of market growth from $3.1B today to $48.2B in 2026.[1] That is a 1,455% increase in the next five years. It is therefore not surprising that if you are leading an infrastructure project you are interested in investigating and applying this approach.

You may be asked two key questions: What is a digital twin and where do I start? The next question you will be asked is, what business value can be delivered from this approach?

1 INTRODUCTION

The questions do not stop there. What are the risks? What should I do first? Is it enough to make incremental improvement of a conventional process, or should I invest in transformational approach? Is this about technology, or process or simply technology? Is this a technology bubble and should I run for cover?

Let's start with some phrases from some wise industry leaders who represent a wide range of disciplines, but with a common perception:

- Yogi Berra, "If you don't know where you are going, you'll end up someplace else."
- Lewis Carroll, "If you don't know where you are going any road will get you there."
- Henry Kissinger, "If you do not know where you are going, every road will get you nowhere.
- Steve Maraboli, "If you do not know exactly where you are going how do you know that you have arrived?"

This advice points to the requirement of a target, a place to aim for and to embark on the journey, one with the potential of multiple potential paths. In other words, you need to select a destination on a map and sometimes the destination is just the first one in the journey. Hence the need for a maturity model that defines the succession of destinations on the journey.

This is the purpose of this paper. It will help you understand where you are, set the initial destination, and offer assistance in making that journey. Our map is modelled using a Digital Maturity Model, shown below, specifically focused for the application of a Digital Twin to Infrastructure project.

infrastructure
Digital Twin
Maturity Model

- Understand where you are.
- Set your first destination
- Guide you in your journey.

1 *https://www.forbes.com/sites/jenniferhicks/2021/12/28/using-digital-twins-and-drones-to-capture-physical-enironments/?sh=7046d388556e*

2 KEY TERMINOLOGY

In order to read a map, we must determine, define and agree on key terminology. Every map has its legend so that the user can understand how to use it. Our map is no different.

To start, let us consider the definition of our target, to create a digital twin. We will use the one that has been adopted by Digital Twin Consortium:

A digital twin is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity.

- Digital twin systems transform business by accelerating holistic understanding, optimal decision-making, and effective action.
- Digital twins use real-time and historical data to represent the past and present and simulate predicted futures.
- Digital twins are motivated by outcomes, tailored to use cases, powered by integration, built on data, guided by domain knowledge, and implemented in IT/OT systems.

So, for a typical infrastructure project, the expectation is that we would normally have several virtual representations due to the complexity. Each of these are seamlessly connected into a single digital thread.

Digital Twin Consortium defines the digital thread as: a mechanism for correlating information across multiple dimensions of the virtual representation, where the dimensions include (but are not limited to) time or lifecycle stage (including design intent), kind-of-model, and configuration history; the mechanism generally relies on stable, consistent real-world identifiers.

A digital thread will:

- be populated with data flowing from upstream or previous time phases in the digital lifecycle, for example a digital twin focusing on operational use cases would need to be populated with data from Planning, Design, Procurement and Construction phases,
- communicate with other systems within the same phase of the digital lifecycle and
- pass data to downstream systems, which are systems that require the data in a later phase of the digital lifecycle.

Now that the target destination is set, the question of why we should travel that journey as a team is defined on the map itself. At each step, the value is derived from use cases that define how that business value will be unlocked and the processes and data required to support the use case.

The built environment is not delivered by a single entity, but by a supply chain of different stakeholders spread out by tens of years of collaboration based on legacy data. The quality of data you leave behind is your legacy to others. One aspect of the map is different, there are new roads to travel on, and this has been developed as infrastructure projects:

- are large, complex and high value,

- have a habit of running over budget and schedule,
- are approached from a one-off perspective project mentality, operating in siloes,
- bring together many different disciplines, over different time-based phases, from many different organizations, often with differing business drivers and
- operate in a traditional and conservative legal and contracting framework.

Overall, these characteristics are not conducive for success. But how can this be changed?

We analyzed the processes in practice and developed a different approach from the traditional way of mapping the lifecycle. The lifecycle processes are more aligned with automotive or manufacturing concepts such as a defined catalog of parts and systems that are being used to design, the concept that the site starts to become a factory floor, with assembly rather than create, and lastly reaches realization, when the virtual starts to become physical and the start of when data can be exchanged into the real-world object: the twin.

Extracting some key components of the process, leads to the following evolutionary process where we are managing the different traffic along these roads, and we advocate the Owner takes on a key role in orchestrating the process of managing the stages of the project lifecycle's evolutionary process as indicated in Figure 2-1.

Figure 2-1: The digital building lifecycle is led by the owner and increases the use of industrialization in the construction process.

This process evolution, shown in Figure 2-2, is reflected in the maturity model:

*Dinosaur (laggard)***:** Active and passive resistance of digital twins. Little or no digitization is found in many legacy projects.

Average: Passive observers of digital twins. Silos are first to digitize, often driven by architects automating the production of drawings or general contractors using models to coordinate and eliminate clashes in the field.

Leader: Active observers of digital twins. The Silos realize that there is mutual benefit in sharing, and this is often done without Owner involvement.

Evangelist: Active prototypes of digital twins. The Owners see the benefit and start to define the sharing of data between point solutions, often providing the technology platforms. This integration spreads across all phases controlled by the Owner internally.

Pioneer: Active adoption to digital twins in an entire organization. Eventually the integration encompasses the complete supply chain.

Reaching the Pioneer maturity level does not end the process. Change agents and industry innovators continue to evolve and adapt their processes to create new levels of maturity.

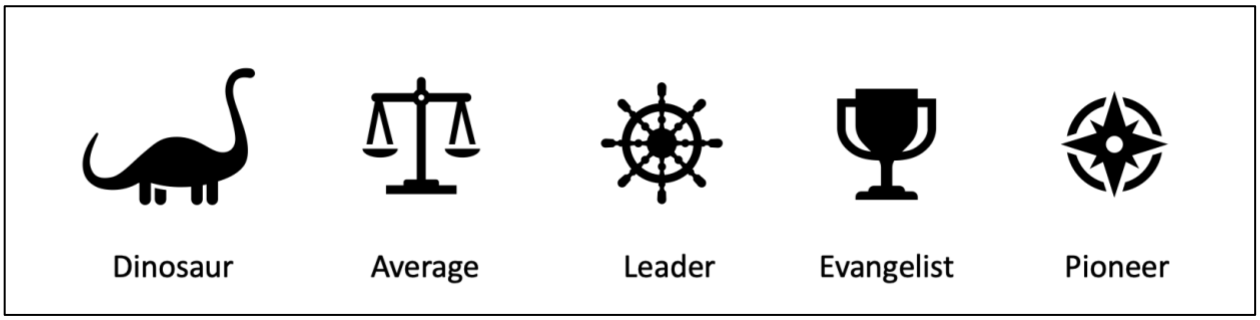

Figure 2-2: Digital twin process evolution.

3 THE MATURITY MODEL

All stages in the maturity model fall into these broad concepts but they also fall into five categories that are particularly applicable to Infrastructure projects.

- organizational structure,
- organizational performance,
- evolution of the digital thread,
- integration of business functions and
- use of catalog and repeatable design and construction elements.

3.1 DIMENSION STRUCTURE

The maturity model looks at the main participants in the overall digital building lifecycle and how they interact in the evolving world of digital twins. It defines not only the respective roles and responsibility of Owners, Architects, General Contractors and Trade Partners, but also of Vendors, Government, Standards Organizations, Authorities Having Jurisdiction from a permitting perspective and Society through driving sustainability and other targets. The organizational structure defines the data creators and the data consumers, bridging dependencies and strengthening organizational success.

	Dinosaurs	Average	Leaders	Evangelist	Pioneers
3.1.1 CONTRIBUTION OF OWNER	Minimal involvement. Not looking for an alternate value proposition. Reactive owner influence.	Minimal involvement. Owner wants to influence but unsure how to engage.	Some involvement in process improvement. Funding some proofs of concepts.	Complete involvement. Active pilots in progress. Desire to proactively influence process.	Driving involvement and influence. Evolving to a complete integrated delivery lifecycle for whole supply chain.
3.1.2 CONTRIBUTION OF ARCHITECT/ ENGINEER	Design Intent only. Paper-based deliverables.	Design Intent with some discussion. Introducing an independent digital approach.	Design Intent with increasing digital collaboration. May now be part of GC team.	Design incorporating catalog parts and DfMA approach.	Design by assembling catalog parts.
3.1.3 CONTRIBUTION OF GENERAL CONTRACTOR	Means and Methods, Interpreting design intent. Design bid build process.	Means and Methods, Interpreting Design Intent. Some design assist.	Means and Methods, Influencing design intent, design build prevalent.	Integrated approach introducing industrialized construction with some assembly of modules.	Integrated approach with complete adoption of fabrication/ assembly approach.
3.1.4 CONTRIBUTION OF TRADE PARTNERS	Reactive to GC. No ability to influence process. 2D process.	Some Design Assist but minimal ability to influence process. Some work digitally in 3D.	Starting to be engaged in the design process and in its digitization.	Complete involvement in the process and in its digitization.	Proactive Participation
3.1.5 CONTRIBUTION OF VENDORS	Manual shop drawings (2D) - everything is one off.	Some work digitally in 3D. Some integration to automate one off fabrication.	Working digitally in 3D. Some integration with wider team.	Providing digital catalog and manufactured components of some modules and systems.	Providing digital catalog and manufactured components of majority of modules and systems.
3.1.6 CONTRIBUTION OF GOVERNMENT	Historical perspective to the law - case law and legal precedent.	Electronic submission of documents is allowed.	Government starting to push a BIM mandate in design and construction.	BIM mandate extending to overall digital building lifecycle.	Law aligned with use of digital process and integrated project structure.
3.1.7 CONTRIBUTION OF STANDARDS ORGANIZATIONS	Reference basic standards required for regulatory compliance.	Former level, plus when beneficial to the current process.	Former level, plus design phase standards collaboration across some disciplines.	Former level, plus fully coordinated collaboration across design and construction phases.	Former level, plus owner-defined utilization of standards throughout the complete digital and physical lifecycle.

	Dinosaurs	Average	Leaders	Evangelist	Pioneers
3.1.8 Contribution of Authority Having Jurisdiction	Paper review by discipline.	Paper review by discipline.	Submission of PDF rather than paper, but process same.	Some disciplines may accept a model review. Electronic approvals of some processes.	All disciplines will accept an integrated model review and all decisions/submittals have an electronic equivalent.
3.1.9 Contribution of Society	No focus on sustainability. Minimal stakeholder and community engagement.	General lip service to sustainability, some community engagement.	Proof of alignment with sustainability initiatives, but generally not fully integrated.	Sustainability goals become integrated in the workflow.	Sustainability is an integral part of the process that would fail if removed.

Table 3-1: Dimension structure.

3.2 Dimension Performance

The focus is on measuring improvement in terms of process, results and the ability to predict improvements as the solutions are scaled and become more embedded in a different culture. It is expected that the outcomes derived from the outputs are different because the capabilities of digital twins are much broader than of the traditional tools and methodologies. While delivering results for one use-case, the digital twins are building readiness for several others.

	Dinosaurs	Average	Leaders	Evangelist	Pioneers
3.2.1 Use of Process Metrics (Efficiency)	Siloed Process. Limited, siloed metrics. No process metrics or published process. Low productivity.	Silos are prevalent but owner may ask for a project charter for each silo, which could be in the form of a BIM execution plan. Low productivity but a realization that it could be improved.	Evolving focus on a digital workflow. Metrics are more easily captured and reviewed. BIM-based review becomes a key part of the process. Owner starting to look at process and not just results. Key Performance Indicators are applied to silos.	Catalog of parts and systems of systems used in conjunction with bespoke design. Owner intimately involved. More focus on virtual and cloud enabling processes. Well-developed Key Performance Indicators.	Technology very integrated. Generative design developed from development brief using catalog parts and systems - validated by humans. Continuous improvement is metrics-based with owner driving improvements.
3.2.2 Use of Results Metrics (Outcomes/ Effectiveness)	The focus is rear view on cost and schedule metrics. Rear view reporting is common practice.	The focus is still on cost and schedule metrics, but they are now deeper. Near real-time metrics are being used.	Metrics are expanded to other areas that can be measured because of technology. Some predictive indicators are being utilized.	Results-based metrics are used throughout the process and compliment the process metrics. All metrics are predicted.	Metrics drive all visibility. Site visits become less important. Focus on dealing with exceptions, eliminating the bad and leveraging the good.

	Dinosaurs	Average	Leaders	Evangelist	Pioneers
3.2.3 Use of Predictive Metrics in Closed Loop Performance	Each project is one-off, so prediction is limited to cost and schedule.	Better use of historical data to predict the cost and schedule of a new project.	Prediction is used more widely across the process but is focused on project performance.	Prediction of building performance built into the process.	Prediction of peoples' interaction with the building build into the process.
3.2.4 Culture/ Knowledge Sharing/ Learning Organization	Confrontational, lowest bid, happy with status quo. No drivers to change.	Confrontational, lowest bid but unhappy with status quo. Starting to see that others perform better. Change introduced as point solutions.	Opinions from key stakeholder groups starting to be recognized together with the need to introduce change across the silos. Change is now more coordinated. POC activities are prevalent.	Focus on team and collaboration across the organization to mutual advantage. Focus on win-win.	Focus on stability of team and working together in a reproducible manner. Less focus of competitive bidding. More collaboration across the supply chain. Focus on win-win-win.
3.2.5 Scalability/ Consistency	One-off	One-off but with a focus of some standardization within the silos.	One-off but reproducible. Concept of standardization widespread in order to provide comparable metrics.	Reproducible at scale within the organization. Full standardization.	Focus on continuous improvement across the supply chain through the advanced use of KPIs and control charts.
3.2.6 Risk Profile	Transfer	Transfer	Reduce, transfer	Avoid, reduce, transfer	Assume, avoid, reduce

Table 3-2: Dimension performance.

3.3 The Evolution of the Digital Thread

The evolution of the digital thread starts with company and industry standards followed by the adoption of technology. Data is of little use unless it can be easily understood and so it needs to be clean and well defined. An initial digital thread can start narrow, with a focus on assets; virtual leading to physical. However, the real benefit comes with the broadening (more data inputs) and lengthening of the digital thread (use throughout more lifecycle stages) and the integration with business strategy supported by measurement and analytics.

	Dinosaurs	Average	Leaders	Evangelist	Pioneers
3.3.1 Use of Standards	None.	Few point standards.	Standards are widely used and cross functional.	Standards support the complete internal lifecycle.	Standards support the complete supply chain.
3.3.2 Adoption and Integration of Technology	Some point solutions used by vendors.	Owners asking for point solutions to increase efficiency.	Owners driving adoption and integration of point solutions and starting to provide the platforms.	Owners driving the use of technology to integrate the internal lifecycle and providing the end-to-end platforms.	Owners driving the use of technology to integrate the supply chain.
3.3.3 Coordination of Deployment of Technology	Too busy printing and writing to discuss. Design, bid, build process prevalent	Recognition that presents process is not working. Open to design assist.	Small scale but not continuous. More team-based / shared approach with Design Build options as applicable.	Continuous but not robust. May be held together with manual batch transfer. Distributed responsibility through Progressive Design Build.	Strong coordination by Owner across an Integrated Project Delivery process.
3.3.4 Data Stewardship	No concept.	Departmental data stewardship evolving.	Integrated data stewardship evolving.	Concept of Data stewardship well understood internally.	Concept of data stewardship integrated into the supply chain.
3.3.5 Width of the Digital Thread	No data flow.	Cost and schedule focused but not integrated.	Asset added to cost and schedule. Flows separate although there may be some integration of cost and schedule.	Cost and schedule are fully integrated with advanced work packages being modeled.	All data flows are integrated with advanced work packages.
3.3.6 Length of the Digital Thread	No data flow.	Construction phase only.	Design and construction phases only.	All internal phases.	Complete supply chain is integrated.

Table 3-3: The evolution of the digital thread.

3.4 The Integration of Business Functions

Infrastructure projects are complex and have evolving scope and external factors that can change over time with market and competitive factors. They all have metrics by which business success is judged, and how cost, schedule and assets are managed, but many projects may not fully utilize integration. They may not use simulation and closed-loop sensor feedback or focus on sustainability or even emphasize safety and security to the extent possible. Many organizations use a departmental focus on each of these categories, but the integration of all functions into a comprehensive and holistic information flow will provide many benefits.

	Dinosaurs	Average	Leaders	Evangelist	Pioneers
3.4.1 Management of Scope	High-level programing.	Programing decomposed and aligned with financial pro-forma.	Concept of decomposition of scope into advanced work packages in place for some disciplines.	Advanced work packages for management of scope incorporated into all disciplines.	Use of advanced packages used for all scope management and integrated into supply chain.
3.4.2 Integration of Financial Pro-Forms	Drives initial integrated budget only.	Initial budget may be decomposed and in alignment with the financial pro-forma.	Initial budget decomposed into full work breakdown structure in alignment with financial pro-forma.	Budget aligned with advanced work packages and in alignment with financial pro-forma.	Integrated decision-making process aligned with financial pro-forma with cost, schedule and assets linked.
3.4.3 Cost Management Processes	Cost plan, estimating using manual take-offs from 2D drawings, manual progress of measurement & payment.	Cost plan, estimating using automated take-offs from 2D CAD drawings and some BIM, manual progress of measurement & payment.	Cost plan, estimating using automated take-offs from BIM with regional estimating data bases: semi - automated progress measurement & payment with close comparison with parametric and detailed cost estimates.	Bill of Materials deliver bottom-up accurate cost estimates at planning submission; semi-automated progress measurement & payment. Some integration with schedule and work packages.	Bill of Materials deliver bottom-up accurate cost estimates at planning submission; automated progress measurement & payment
3.4.4 Schedule Management Processes	Completion milestone set together with major milestones.	Detailed schedule available together with critical path analysis.	Detailed schedule used various analysis including Monte Carlo simulation. Encouragement of the use of pull planning in Construction. Some 4D BIM analysis.	Schedule integrated with Cost and with advanced work package approach. Integration with BIM 4D analysis commonplace. Pull planning required.	Former level, plus supply chain integration. Full integration with advanced work packages.

	Dinosaurs	Average	Leaders	Evangelist	Pioneers
3.4.5 Asset Management Processes	Handover process is an afterthought. Individual assets are not tracked.	Some critical assets are tracked. Concept of OFCI for critical equipment.	Major disciplines such as mechanical and electrical will track assets through OFCI and CFCI. Concept of systems of assets being introduced.	All assets tracked by discipline and systems across OFCI and CFCI within organization.	All assets tracked by discipline and systems across OFCI and CFCI within supply chain, including commissioning from factory to operations.
3.4.6 Use of Simulation	None.	Some disciplines may be simulated in engineering calculations. Focus on LEED.	All disciplines may be simulated in engineering calculations to ensure compliance with building certifications required.	Former level, plus building systems the interaction of employees is simulated.	Full closed-loop prediction and verification in place for all disciplines and employees.
3.4.7 Measures of Sustainability	None.	Some alignment with LEED.	Better alignment with higher LEED or other similar certification.	Desire to be carbon neutral.	Desire to be carbon negative.
3.4.8 Safety and Security	No integration.	Some use cases around integrating modeling of safety components like fences and barriers as well as temporary fire protection.	Some integration of sensors and visual systems to monitor compliance with safety. Process simulation around hazardous work tasks.	Virtual training on the construction site and facility. Designing overall processes with a safety perspective. Increasing the ability of a wider workforce to be integrated in the process.	Safety and security totally integrated into the overall supply chain.

Table 3-4: The integration of business functions.

3.5 The Use of Catalog and Repeatable Design and Construction Elements

	Dinosaurs	Average	Leaders	Evangelist	Pioneers
3.5.1 Use of Design Standards	Architect will provide design standards for project if there are any.	Owner will provide design standards for the project.	Well-developed corporate design standards.	Design standards aligning with catalog and kit of parts approach and are open sourced.	Open-sourced design standards aligned with integrated supply chain.

	Dinosaurs	Average	Leaders	Evangelist	Pioneers
3.5.2 Use of Process/ Information Standards	Projects are one off and evolve under PM watchful eye.	Corporate Standards are applied but they may not be comprehensive.	Comprehensive corporate standards are available for all disciplines and systems.	Comprehensive corporate standards are used to drive internal integration of processes and systems.	Comprehensive corporate standards are used to drive integration of supply chain processes and systems.
3.5.3 Use of Design Authoring Template	One-off approach. Any templates will be provided by Architect/ Engineer.	Corporate design authoring templates may be available for some disciplines.	Corporate design authoring templates are available for all disciplines.	Corporate design authoring templates are closely aligned with catalog and kit of parts approach.	Corporate design authoring templates are developed in partnership with the supply chain.
3.5.4 Harvesting Design Components for Reuse	Projects are one off.	Some lessons learned but no formal process.	Some design components of repeat elements, such as electrical rooms or bathrooms are harvested.	All design components are harvested and aligned with Construction/ Fabrication strategy.	Design components are closely aligned with supply chain partners.
3.5.5 Alignment of Product Catalog with Design/ Construction/ DfMA/ Industrial Construction	None.	Some repeatable components may be provided but mode unlikely to support automation.	Repeatable components are packages in a form that will support automation and some integration with phases of project.	Components are well integrated into the internal lifecycle and provided in a form that supports automation and integration with data needed downstream.	Catalog is provided and updated by supply chain partners to support a full lifecycle approach.

Table 3-5: The use of catalog and repeatable design and construction elements.

4 What's Next?

The Digital Twin Consortium Infrastructure Industry Maturity Model has been published for broad industry adoption by building owners and their technology integrators. Making the maturity model publicly available is only the beginning. Ongoing activities will include alignment of maturity elements and levels related to continued improvement of overall business practices.

The Digital Twin Consortium *Infrastructure Working Group* is working on three ongoing initiatives to supplement this work and enable users to more easily measure and monitor their maturity. These projects are:

1. Developing a questionnaire with a scoring matrix so that organizations may be able to self-assess their level of maturity.

2. Mapping various use cases (by which business value is derived from the digital twin approach) to each cell in the matrix so that it is easier to understand the context of these use cases and their chance of a successful deployment.
3. Developing guides that can help organizations progress into a more mature deployment of Digital Twins.

AUTHORS & LEGAL NOTICE

This document is a work product of the Digital Twin Consortium Infrastructure Working Group, chaired by John Turner (Gafcon) and Salla Eckhardt (Microsoft).

Authors: The following persons contributed substantial written content to this document: John Turner (Gafcon), Richard Ferris (asBuilt) and Salla Eckhardt (Microsoft).

Contributors: The following persons contributed valuable ideas and feedback that significantly improved the content and quality of this document: Steve Holzer (HolzerTime).

Technical Editor: Dan Isaacs (DTC CTO) oversaw the process of organizing the contributions of the above Authors and Contributors into an integrated document.