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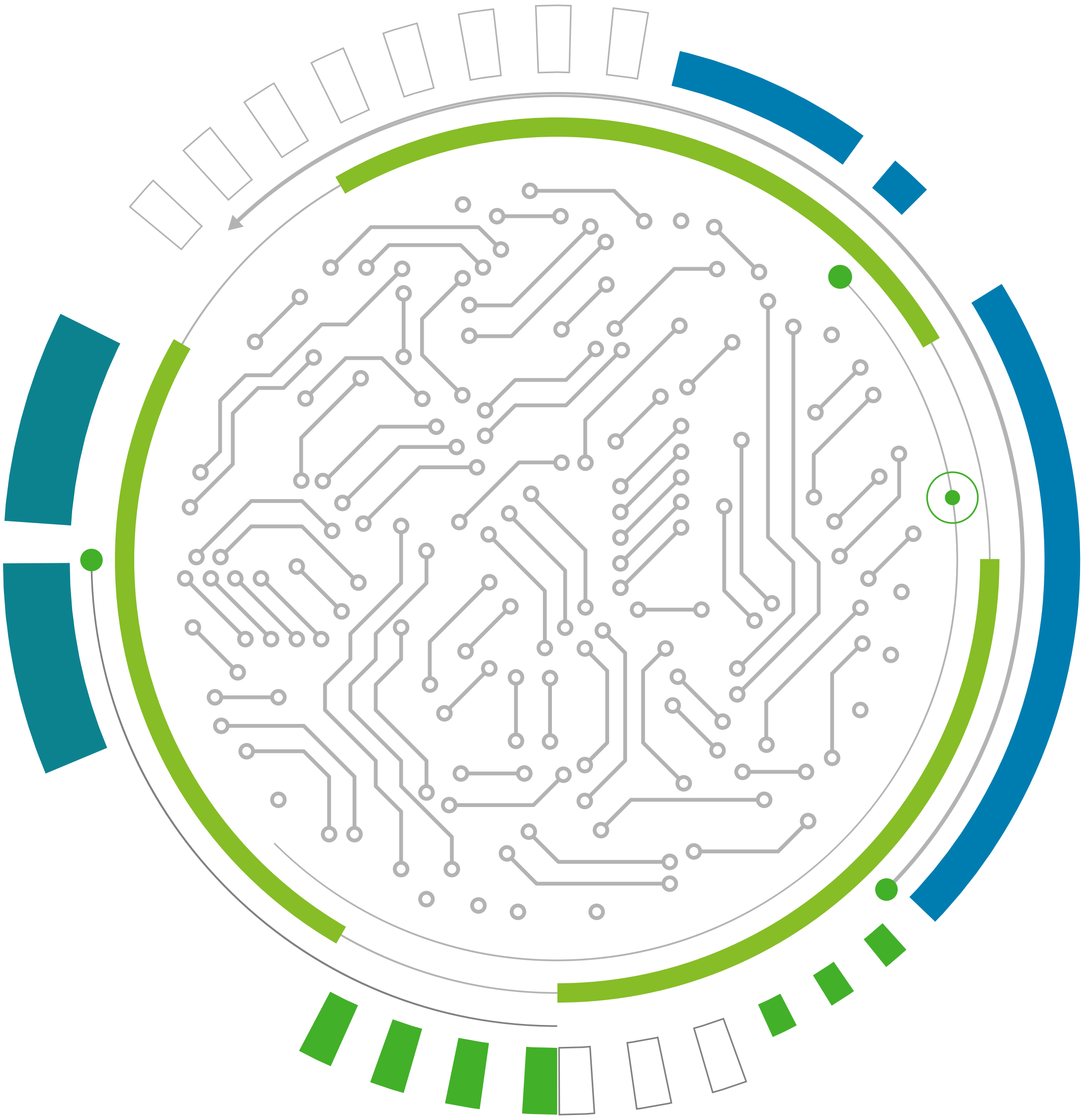

Digital Twins as Warehouse Operating Systems

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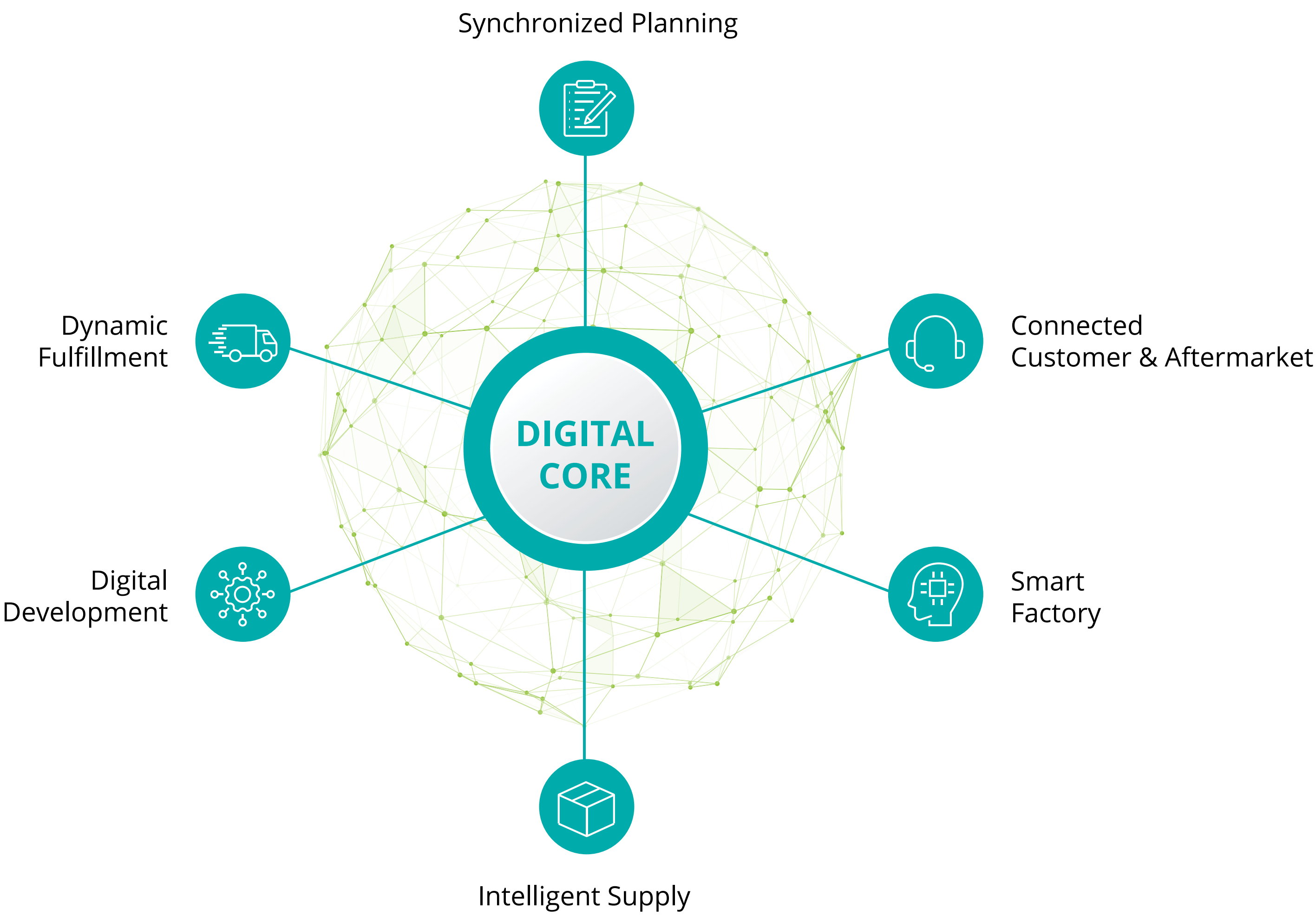
Supply Chain realities as ingredients for Digital Twin applicability

The rise of digital technologies and Industry 4.0 is transforming the landscape of warehousing and supply chain management, as companies seek to optimize their operations and keep up with the demands of a rapidly evolving market (economic realities and customer behaviors) and emerging technologies to improve efficiency, agility and cost-effectiveness.

Trends impacting the warehousing as a whole

In today's strategy and operations, there are several trends impacting warehousing. The first is the evolution from a traditionally linear and sequential supply chain to a digital supply network (DSN). DSNs are characterized by real-time (digital) visibility into each node of the supply chain network and are powered by an interconnected flow of information, thus transforming the way that goods are produced, transported and delivered.

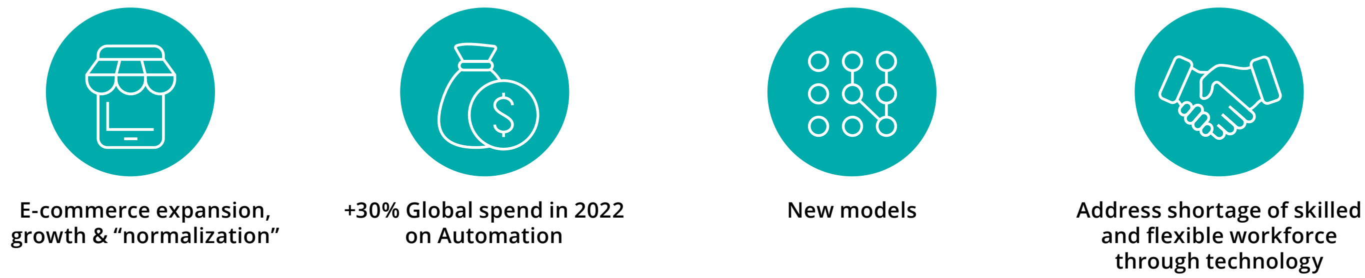


Another key trend impacting a company's warehousing function is the focus on supply chain Agility, Efficiency and Resilience, which has become increasingly important in the wake of the COVID-19 pandemic and the widening geopolitical risks. With disruptions to global supply chains and unprecedented demand volatility and variability, companies are seeking ways to build more flexible operations, by keeping the aforementioned Agility, Efficiency and Resilience in balance with the more "established" core targets of Service, Cost and Sustainability. This balance can be achieved by means of several tactics and systems, of which Digital Twins are at the center of gravity of the resulting ecosystem, given their unique ability to clone and integrate holistically.

Applying the strategic lens now to warehousing, we can identify several notable macro-trends at this level as well. One of the most significant is the growth and, in particular, the "normalization" of e-commerce, which has led to increased demand for faster, more accurate, and more efficient order processing and delivery. Globally, B2B and B2C e-commerce is currently estimated to add more than 100 million m² of new warehousing space every year, with over 50 thousand warehouses to be built globally before the turn of the decade.

Another important trend is the (fast) increasing spend on automation , recording double-digit growth up to 30% globally last year. This is further accelerated by the rise of new warehousing models such as e-grocery, co-warehousing or micrologistics, as means to fulfill customer expectations of increasing complexity, as well as the availability of space.

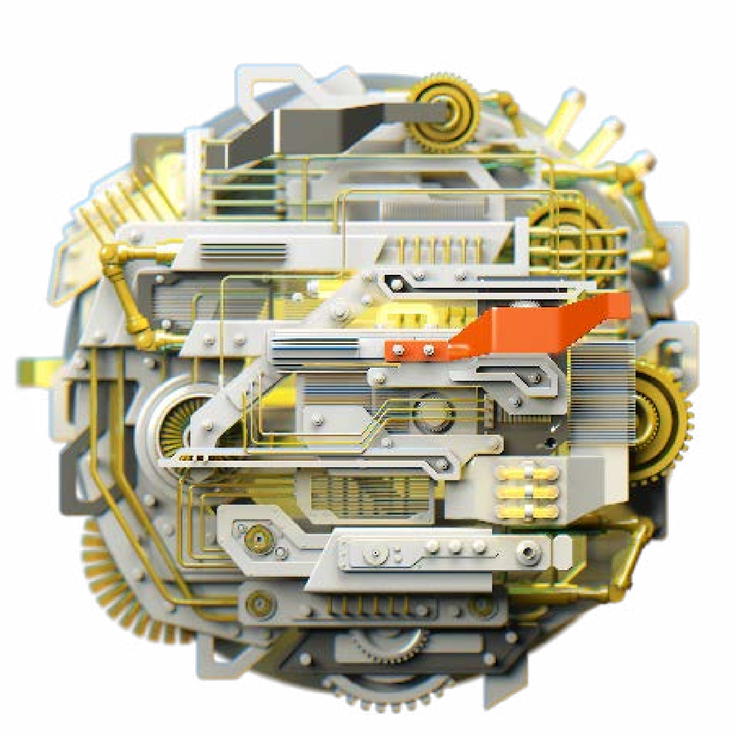
Last, and by no means least, the global shortage of Talent is a reality the industry is acknowledging. We must also acknowledge that this is also heavily generational, as the young professionals of today's expansive digital world find the average warehousing practices (more than often as a late adopter of technology) unattractive and incompatible to their expectations.



The need for a smart warehouse operating system

The dynamics of digital supply networks, the normalization of e-commerce, along with a constantly increasing amount of available automation technologies (today at more than 80!) are impacting warehousing by reshaping the intralogistics landscape. Warehouses are facing faster, more varied volumes and order mixes, packaging and vehicle types, respectively less and less negotiable customer expectations around delivery times and sustainability.

This phenomenon of increased complexity is however "natural" and known in physics as **"entropy"**: a property that refers to the number of ways in which a system can be arranged, entropy is a thermodynamic function to measure uncertainty, randomness, or the disorder of that system - the higher the entropy the more disordered the system will become.
If we reflect on all the moving parts described above, we easily deduce that warehousing is in a state of entropy. This, however, is not at all new for this discipline and is, in fact, quite normal and expected – entropy continues to grow and does not show signs of decelerating.



The intrinsic (and expanding) nature of "warehouse entropy" is thus driving the need for a "Warehouse Operating System". As a fundamental definition, an Operating System (OS) controls, manages and acts as the interface between all (hardware, software, users) resources and operations. The scope of a Warehouse OS is thus the continuous control of present entropy by "looking into the future" – identifying and navigating any and all issues before they occur and capturing and executing on opportunities our human mind would likely miss in the myriad of systems, data and logic, with the constant goal to improve business outcomes, ideally autonomously.

By leveraging the full "cyber-physical" power of Industry 4.0, Digital Twins are the key construct for enabling a Warehouse OS.

Digital Twins explained – what they are and why we should pay attention

The basics

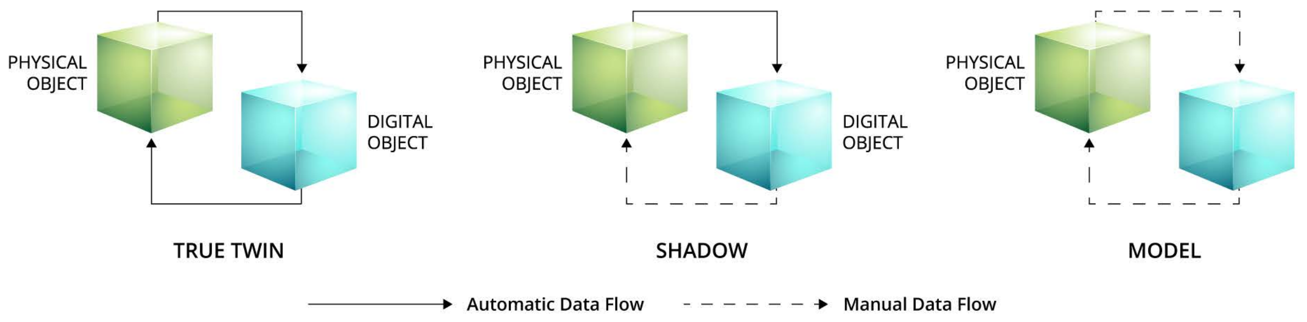
Digital Twins (DTs) are real-time, digital images (or models) of physical objects and business processes and are always connected to these by a bi-directional flow of data and information: the "real" item transmits transactional data and real-world measurements across various dimensions, while the virtual counterpart returns decision-supporting information.

The key to understanding the concept of a Digital Twin lies it its name – "twin" i.e., always two parts are involved in this construct: one real, physical, and another virtual - a multi-dimensional, hyper-intelligent algorithm-based model of the ideal state of its physical counterpart. As such, any change in the state of the physical object leads to a change in the state of the digital object, and vice versa.

The main objective of DTs is to provide real-time predictive insights that allow for informed, effective decisions and enhance the value of business outcomes by avoiding issues, split-second identifying intolerable deviations from optimal conditions and leveraging unseen opportunities. These remarkable capabilities to predict and optimize, respectively orchestrate and execute, drive benefits in terms of cost savings, improving quality, and superior overall efficiencies. In Logistics, Digital Twins provide real-time insights into inventory levels, order volumes, and shipping status. A great example comes from a global leader in container freight ports, where DTs scenario-simulated the effect of new transshipment strategies and informed the team on how close to optimal their current resource allocations on equipment were and how that could evolve short and long term.

When discussing Digital Twins, it is essential to understand that there are different "levels" of Digital Twins, a fact which often drives imprecisions in the definitions used widely (and freely) on the market today. The difference between these loosely called Digital Twin "levels" lies in the degree of connectivity between the physical world and its digital counterpart.

In this article, we focus on "complete" DTs, as defined above and seen in Figure 1, leftmost representation, with fully automated, always-on data flows in both directions.



A level of connectivity below, a "Shadow" has an automated one-way data flow between the physical object and its digital clone i.e. a change in the state of the physical object leads to a change in the state of the digital object, but not vice versa. Thus, a Shadow receives real-world data automatically, yet does not actuate changes back into the physical reality autonomously.

In comparison to a "complete" DT, a digital shadow is thus easier to implement and, in (risk-averse) fact, it is by far the best option to start on such a transformational journey. As the intelligent algorithms (often, yet not always Machine Learning) powering the digital clones require a training phase to learn the characteristics and behaviors of their physical equivalents, and this type of learning in turn is equally often supported via human interaction, shadows are the most risk-averse entry point into digital twinning at its finest – "human-in-the-loop".

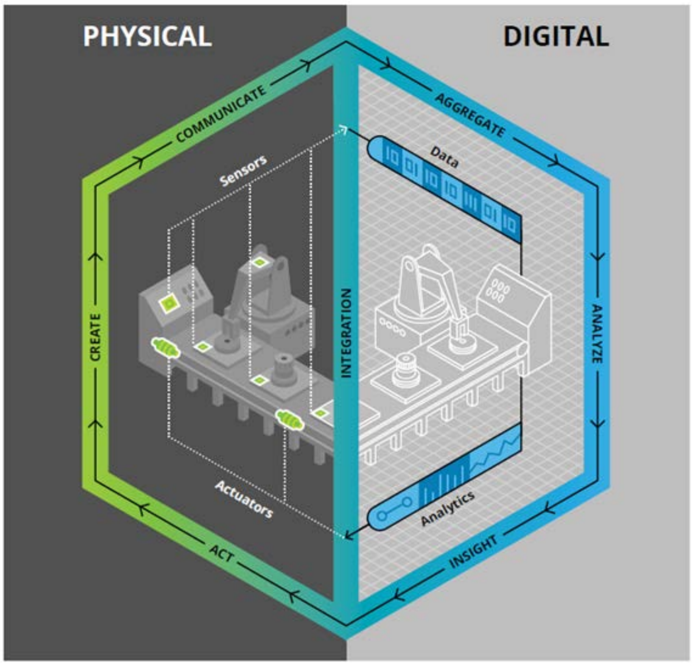
The market's preferred misuse of Digital Twin terminology - the model, or simulation, is a digital representation of an existing or planned physical object that does not use any form of automated data exchange or integration between the physical object and its digital clone. A change in the state of the physical object has thus no direct effect on the state of the digital, and vice versa, and thus a model would need to be manually updated regularly to avoid discrepancies.

The architecture

In a "complete" Twin, the data flows dynamically between physical and digital, making these fully integrated in both directions, in what is called the "physical-digital-physical loop"

The loop's architecture further substantiates the term of "cyber-physical systems". Sensors strategically placed throughout the physical assets and processes generate signals that allow the Twin to capture real-world machine, operational and environmental data, which in turn can be combined with enterprise data, such as bills of materials, data from transactional systems such as Warehouse Management Systems data lakes, as well as external data feeds (traffic, weather, economy etc.).

All aggregated data is analyzed by the smart algorithmic simulations of the Digital Twin, producing valuable insights such as unacceptable trends in actual performance compared to ideal ranges, to optimize processes, reduce downtime, and enhance overall performance. In consequence, should an action be necessary in the physical world, the Digital Twin triggers the process through actuators, which can also accept human intervention (such as the confirmation or correction of the intended action, for DT learning/training purposes). The integration between the tangible and virtual plays a crucial role in this construct, ensuring a bidirectional layer of communication interfaces and cybersecurity.



Source: Industry 4.0 and the digital twin technology | Deloitte Insights

The typology

This generic cyber-physical architecture of DTs scales across diverse levels of focus and granularity, from individual assets to processes (several assets connected by business logic), then entire facilities (several processes connected by new data streams), to end-to-end supply networks (several facilities connected strategically) and finally entire ecosystems (several companies or an entire industry combining their supply networks).

We already stated that Digital Twins as Warehouse Operating Systems enable companies to look into the future to optimize their operations – what does this factually mean in the context of the first three of the layers mentioned above – assets, processes, and facilities, as they refer directly to the "four walls" of distribution centers?

In terms of Assets, DTs provide a comprehensive view of their lifecycle, from component and part design, to testing, commissioning and operation and have several use case possibilities on the strategic, tactical and operational levels:

• Strategic: key, real-time reporting insights into performance, such as Mean Time Between Failure (MTBF) and Total Cost of Ownership (TCO, when coupled to a financial data stream).

• Tactical: predictive maintenance capabilities, as incoming functional data is continuously benchmarked against that ideal digital model. By leveraging the sensing capabilities of the Digital Twin, enterprises can monitor and control individual assets, products, and systems in real-time, ensuring they operate at peak efficiency. Solving the root cause of problems helps firms identify and address issues before they become reality, improving overall efficiency and reducing downtime.

• Operational: a platform for prototyping and testing new technologies, enabling companies to stay ahead of the curve and innovate their operations. By leveraging the multiple features of a Digital Twin, including real-time monitoring, predictive analytics and continuous improvement tools, organizations can increase performance and asset efficiency and thus gain a competitive edge in today's fast-paced business environment at lower costs.

With several assets combined within a net of business logic, Process Twins enable dynamic analysis, adaptation, are key to high efficiency and thus operational excellence. Process Twins impact strategic, tactical and operational use cases:

• Strategic: scenario-based "what-if" simulations which can analyze and adapt to changes in material flows, product recipes, order patterns, available resources and technologies used.

• Tactical: advanced process control and dynamic analysis, to optimize operations and achieve lower process run costs, reduced production/delivery costs per unit and decreased resource costs.

• Operational: dynamic adaptation resulting in real-time continuous improvement by identifying issues as they occur, making it possible to immediately (and autonomously) address them and minimize (ideally remove) downtime.

Combining multiple processes with even more additional data sources and layers result in Facility Twins. The predominantly tactical use case of a Facility Twin lies in the enablement of the orchestration and optimization for an entire site at a time – a complete "digitally-enabled living organism", optimized end-to-end based on the same principles described above for individual processes.

Data layers

The twins in each level of granularity can receive, besides the basic transactional data and logic they are originally built on, additional layers of complementary data (from various sources), enabling them to achieve new feats of prediction and maximize their potential. For example, adding a financial data layer to an operational DT enables it to function as a scenario-based business case calculator, that can help firms assess the cost-benefit impact of process changes on their operations and make informed, sound investment decisions. By synchronizing maintenance and production scheduling data layers, operations can identify optimal maintenance windows with no impact to critical delivery timelines, while at the same time ensuring that the former are performed (and not continuously rescheduled) to in turn guarantee maximum uptime and efficiency for the latter.

Another notable example of DT data layer resides in a site's Sustainability-related sources, such as machine, facilities and IT infrastructure data, for the real-time control (assess and reduce) of the warehouse's multi-dimensional CO2 footprint, by optimizing material flows and IT-OT (Information Technology & Operational Technology i.e. Automation) asset utilization, respectively waste management.

Digital Twins can thus orchestrate and optimize facilities, analyze and improve processes, and sense and actuate assets. By working across all these layers, organizations can gain valuable insights and make informed decisions to enhance their performance and strive for "automated and autonomous" continuous improvement.

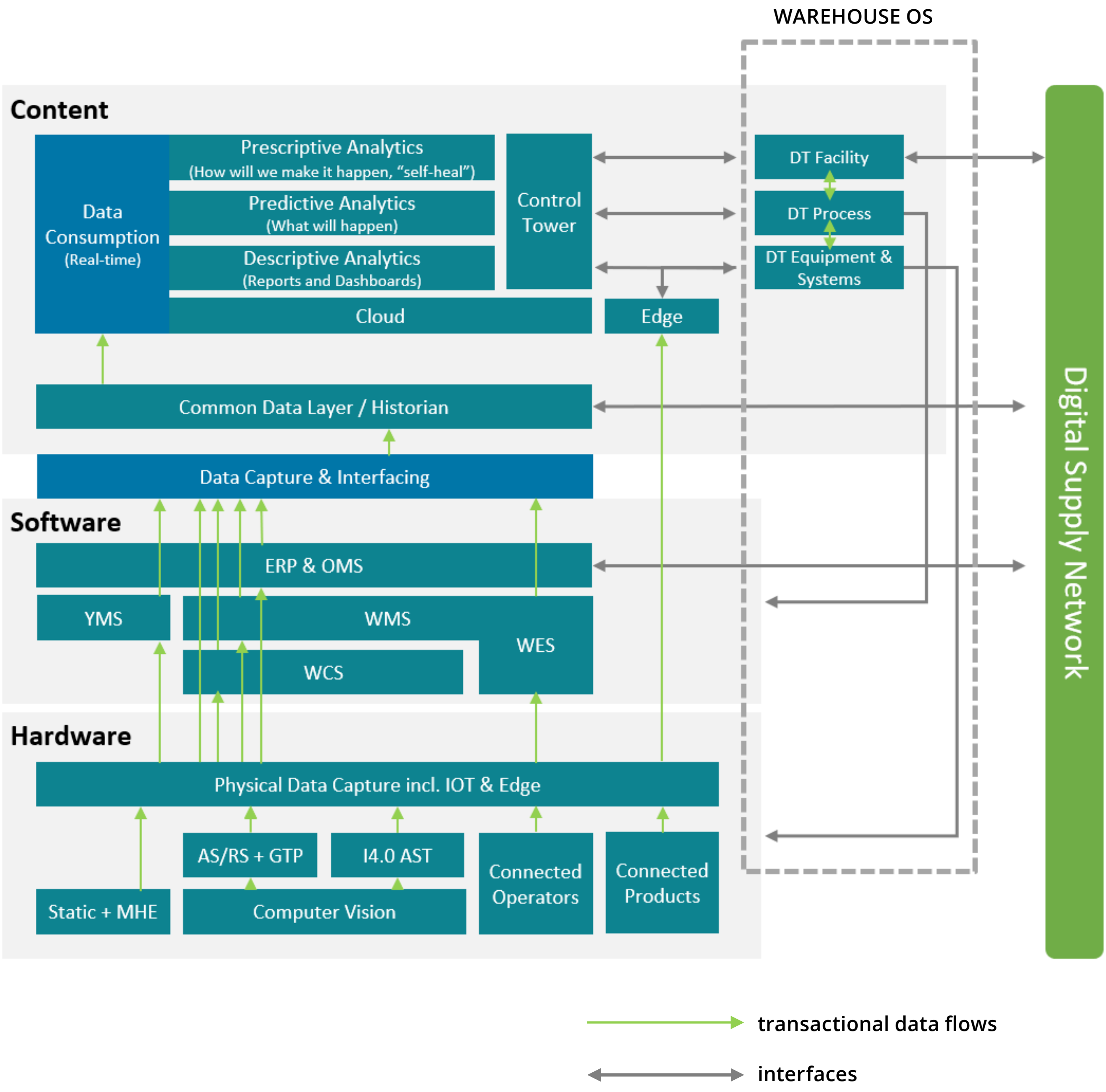
A comparison worth making is between Digital Twins and Control Towers. The latter enable organizations to monitor and control processes and operations; they do so via digital means (dashboarding, reporting) consumed in a physical environment. At their inception, Towers had the scope to provide real-time data-driven visibility to human decision makers and have since also fast adopted predictive capabilities, based on the same concept of "peeking into the future" in order to take the best operational decisions in the present.

This fact may seem to blur the line between the technical concepts of Tower and Twin, however nothing is further from the truth – the reality is that Twins enable Towers (and thus one Tower can make use of the outputs from several different Twins), by making available a plethora of predictive optimization scenarios based on the same live operational data Towers regularly consume (and more), and provide them with unprecedented levels of detail and decision-making across all assets, processes and the entire warehouse itself. Thus, one Control Tower can be equipped with multiple Digital Twins, of multiple types and at multiple levels of detail.

To learn even more on the link between Towers and Twins and how AI transforms how businesses make and execute real-time supply chain decisions, please access [Deloitte and Aera alliance | Deloitte Belgium.]

The journey to Digital Twin as the new operational standard

Where does the DT Operating System fit in the Warehousing Systems Stack?



We documented before that an OS controls, manages and acts as the interface between all resources and operations; if we analyze the adjacent figure, we can see that DTs, which are logical manifestations of content, interact continuously with transactional / process-driven and process-executing systems and link these with broader Digital Supply Networks.

The orchestrated goal of all these interactions and links, encapsulated in an OS, is to recurrently identify, reach and maintain continuous optimal positions on all KPIs of an operation, respectively of its role and impact in the broader supply chain.

Laying the foundation for deployment

When implementing Digital Twins, there are several prerequisites that organizations must meet to ensure success. ”Step zero” is to identify the burning platform which can be resolved by digital twinning: challenges, opportunities – the problem at hand, respectively the business value the solution has to deliver. The scale of the application, especially if the technology is new to the company, must be determined with caution, by combining the well-known ”think big, start small, scale fast” mindset with a “learn fast” approach (notice here we did not write “fail fast”, as we believe we can learn about impeding failure before its actual occurrence).

The next step is to have a comprehensive data strategy in place. This involves identifying all relevant data sources for each DT application (short-term, to start and also longer term as additional Twin layers for new Twin capabilities), collecting and integrating data from various systems, and ensuring data quality and accuracy (to prevent the classical situation of “garbage in, garbage out”). With a solid data strategy, enterprises can leverage the full potential of the Digital Twin and make high-precision decisions based on correct and complete data.

The following phase refers to a Digital Twin “maturity-build” journey i.e. the aforementioned start with a Shadow, to establish a solid, risk-averse learning foundation for the system and its users, which can subsequently be bidirectionally integrated (we note here that, with regard to the value impact of such a deployment, companies may see sufficient return in operating at Shadow level, with an unattractive cost-benefit situation for upgrading to a “complete” twin – each project must assess this in detail). This involves creating a digital (mathematical and logical) model of a warehouse asset of process, including all relevant data sources and key governing performance indicators (KPIs), and ensuring continuous receival of data from the live operation.

Considering that the “visual” part of a DT is a software user interface, a key factor is the User eXperience (UX), which both software and business representatives should agree can make or break a digital project. UX is a crucial element that defines how a user interacts with and experiences a product, system, or service. It encompasses various factors such as a person's perception of utility, ease of use, and efficiency.

To successfully design and implement a Digital Twin, it is essential to focus on professional inclusion, which involves continuously capturing design insights and then usage feedback from users. This helps in co-creating the solution based on the most pristine knowledge of real and best processes, and as such ensuring user-centricity in the design process. It will enable users to in turn adopt and co-own the outcome of Digital Twin design and implementation – change management at its finest.

Furthermore, by placing the user at the center of the technology, Digital Twinning enters Industry 5.0, which refers to user-centric, highly collaborative, interconnected and intuitive systems.

Finally, it is essential to develop Talent to work with, maintain and grow Digital Twin setups and practices within organizations. New roles and new mindsets are thus needed; a non-exhaustive list would be: DT data architects to design and implement the complex data infrastructure, DT software engineers to develop and maintain the intelligent software applications that power DTs, working closely with infrastructural specialists and automation engineers (and maintenance staff) to close the physical-digital-physical loop together, supported by IoT specialists focused on integrating sensors and other data capture devices within assets and processes, UX designers for intuitive and user-friendly human interfaces, respectively process owners capable of business understanding and accountability transcending real and virtual planes. While the types of expertise listed may not be new while taken in isolation, the key and novelty on the Talent front lies in their synchronized operation in service of a cyber-physical construct which can reach remarkable scale and impact.

To close, the ability of Digital Twins to probe the future in intellectual ways far surpassing our own and thus, in way less than a blink of an eye, avoid high-impact challenges and tap into hidden opportunities we would likely miss, and doing so in a highly collaborative, advisory way, enables us to state that DTs, unlike any other technology to date, have the unique likelihood to become THE golden standard of world-class Warehouse operations.

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