Intelligent Simulations & the Circular Economy:

Using Digital Twins to Drive Sustainability and Cost-Efficiency in the AEC/O Industry

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Introduction

The architecture, engineering, construction & operations (AEC/O) industry today continues to find itself during a large-scale transformation, and one that is at once exhilarating and rife with potential barriers to success. On the positive side, critical advancements in IoT, Building Information Modeling (BIM), and real-time sensor technology are undergoing a rapid process of maturation alongside artificial intelligence (AI) and cloud computing. However, at the same time, the industry will not be permitted to leverage these new systems unencumbered by increasingly pervasive sustainability and cost-efficiency challenges.

Indeed, international scrutiny over the impact of built structures on the environment, as it relates to both their initial construction and ongoing operation, has never been so pronounced. Between the emergence of a variety of global initiatives and government regulations surrounding carbon emissions, energy usage, and overall sustainability, architects, builders, and facilities managers are under more pressure than ever before to enact urgent and measurable change.

Additionally, despite the accelerated pace of technological innovation throughout the sector, much of which should make the transition to sustainable practices considerably more efficient, parts of the AEC/O industry are still attempting to address the fallout from unprecedented supply chain disruptions and sky-high materials costs that have precipitated over the past few years. To make matters worse, the current trajectory of the international economic and geopolitical landscape remains anything but certain, and depleted expectations regarding cost stability may continue to sour the appetite of commercial real estate investors.

In light of all this, it would appear that the industry has arrived at somewhat of an impasse; despite the need to meet compliance with evolving global and regional sustainability initiatives, the cost

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of implementing such a wide-scale transformation in the current environment may seem altogether unfeasible for many professionals in the sector.

But what if the apparent difficulty of reconciling the cost of transformation with the imperative of sustainability was less a result of external factors, and more so of a broader strategic miscalculation? More specifically, what if AEC/O professionals could leverage a more holistic approach to digital transformation, one that not only solved for sustainability within all aspects of the built environment but also worked to reduce the costs associated with each stage in the process?

The Nemetschek Group believes that this can be accomplished through the refinement and utilization of digital twins alongside increasingly capable and data-rich AI models. In this eBook, we will provide an overview of the industry's myriad shared objectives as they relate to sustainability and cost-efficiency, before exploring how both external challenges and technological limitations might be overcome using a circular approach to the design, management, and optimization of all assets and processes across the building lifecycle.

SUSTAINABILITY & COST-EFFICIENCY IN THE AEC/O INDUSTRY: DEFINING THE OBJECTIVES

A Wide Range of Initiatives

According to the Global Alliance for Buildings and Construction, buildings accounted for 37% of global energy-related carbon emissions in 2021, with operational emissions reaching an all-time high (~10GtCO_2) and rising by nearly 5% from the previous year. Moreover, the same report reveals that the AEC/O sector continues to be responsible for the lion's share of global energy demand more broadly, at over 34%.

Understandably, the reality of its contribution to harmful emissions and excess energy consumption has placed the industry under increasing scrutiny over the years from international climate alliances, regulatory institutions, and national governments. As a result, AEC/O professionals around the world must urgently adapt their operations to align with global frameworks, such as the UN's Sustainable Development Goals, in addition to meeting enforceable reporting requirements laid out in the Paris Agreement, which aims to achieve net-zero carbon emissions across industries by 2050. Also, local authorities aim for a more sustainable construction by using materials that are lower in carbon emissions. The city of Amsterdam, for instance, has announced a new mandate for buildings to be built with timber.

Additionally, it's also critical to note that while the regulatory landscape around sustainability is still in its relatively early stages, the incentives to cut back on carbon emissions and reduce energy usage and waste are far from limited to strict compliance initiatives.

For example, due to the growing global emphasis on upholding Environmental, Social, and Governance (ESG) principles, stakeholders within the AEC/O industry are becoming increasingly reliant on ESG-based rating and scoring systems to prove sustainability and secure investments. Such incentives are even more pronounced for stakeholders operating within the EU, where sustainability directives and classification systems such as the Waste Framework Directive and EU Taxonomy are far more mature, and already becoming influential on how AEC/O companies operate and, in turn, on their overall ability to obtain funding from outside investors.

But pervading the culmination of outside pressure on AEC/O professionals is the fact that achieving sustainability is also an incredibly complicated and challenging task. And this is primarily because it doesn't require the transformation of just one system or process, but rather a wide range of processes related to each phase in the building lifecycle – from initial design and construction to daily operations, ongoing maintenance, renovation, and even demolition. More specifically, to meet the international community's expectations for the sustainable design, construction, and operation of the built environment, AEC/O professionals must solve the following:

- Sustainable construction methods that utilize low- or zero-carbon materials and processes to minimize upfront carbon impacts on the environment, as well as to prevent the future build-up of embodied carbon.
- Efficient design and operation allow for the inclusion and reliance on low-carbon energy sources, as well as an overall reduction of a building's daily and ongoing energy consumption needs.
- Intelligent and agile management solutions to optimize energy consumption in real-time, and more efficiently and accurately plan and predict maintenance and renovations/refurbishments to minimize waste.

The above is, of course, only a snapshot of what the AEC/O industry's transformation will entail, and it's critical to keep in mind that sustainability in the context of the built environment also relates to the health and well-being of a building's occupants.

This means, in addition to addressing carbon emissions and energy usage, the sustainable design, construction, and operation of buildings must also take into account factors such as ventilation and overall air quality, as well as lighting and acoustics. In fact, as research continues to reveal the compounding impacts of air pollution on human cognition, AEC/O professionals in the commercial real estate sector should expect sustainability directives to increasingly include demands for the optimization of occupant comfort and productivity.

The Rising Cost of Sustainable Transformation

For all that achieving sustainability requires in terms of upfront investment, most AEC/O professionals will already be more than aware of how important cost-efficiency is to the overall transformation. However, reconciling the need to leverage modern technologies with the cost of their implementation is only half the battle.

It is no secret that over the past few years, the AEC/O sector has been subject to an unprecedented rise in materials costs and persistent supply chain disruptions. This unfortunate turn of events was of course initially triggered by the impact of the global pandemic on shipping routes and the broader logistics of international trade, but has since been further complicated by the effects of macroeconomic uncertainty and the ongoing Ukraine-Russia conflict.

To put the industry's cost-efficiency crisis in perspective, e.g. the Building Cost Information Service (BCIS) found that the cost of building materials reached a 40-year high in 2021 in the UK alone, rising at an average rate of nearly 20% across all relevant categories, which included an astonishing 80% rise in the cost of both timber and steel for reinforcements.

In short, this means that AEC/O professionals will need to seek cost-efficient building and management solutions wherever possible, while at the same time accelerating their efforts toward improving sustainability across the entirety of the building lifecycle. Ideally, this would involve the implementation of strategies designed to serve both objectives simultaneously, such as:

- Minimizing energy costs through the optimization of consumption, reduction of waste, and utilization of alternative energy sources.
- Simulating supply chain scenarios to anticipate disruptions, optimize shipping routes, and reduce transportation costs.
- Monitoring systems performance in real-time to optimize energy use and detect maintenance issues as early as possible.
- Optimizing airflow and natural lighting to reduce heating and cooling costs while improving occupant comfort and well-being.
- Identifying materials for reuse to cut materials costs, minimize waste, and accelerate renovations and/or retrofitting.

While the scope of sustainability and cost-efficiency requirements facing the construction industry is nothing short of expansive, the positive side is that it comes at a time when the development of innovative, data-rich technologies and intelligent processing solutions within the sector is rapidly accelerating. Moreover, as the industry continues to leverage these solutions in new and creative ways, they significantly improve our ability to identify cost-efficient strategies and ease the overall path to transformation.

On that note, it is important to look at the benefits and limitations of two particularly useful technologies available today, before exploring how their utilization, alongside an increased emphasis on circularity across all phases of the building lifecycle, may be the construction industry key to achieving and maintaining sustainability and cost-efficiency into the future.

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DIGITAL TWINS, ARTIFICIAL INTELLIGENCE (AI), & THE IMPLEMENTATION OF THE CIRCULAR ECONOMY

Digital Twins: From Simulation to Performance

While the AEC/O sector has admittedly lagged behind other industries in terms of digital transformation, it now boasts a variety of advanced technologies that have already significantly improved the efficiency of critical processes related to all phases of the building lifecycle. Moreover, not only will the use and refinement of these tools continue to benefit construction professionals and shape the future of the industry, but it will also be crucial in the near term as stakeholders look to meet various sustainability initiatives while managing costs.

Importantly, the value created from virtually any technology used at any stage in the building lifecycle begins with the collection and distribution of data. For example, using a combination of data related to the physical composition and lifetime performance of a built asset and data from real-time sensors and IoT devices, we can create a virtual replica of that asset, known as a digital twin, and leverage the twin to run simulations, make predictions, and ultimately optimize its performance.

What makes the digital twin such a powerful tool for the AEC/O industry is the richness and diversity of the data it contains, and that it is sourced from Building Information Modeling (BIM) techno-logy leveraged from the earliest stages of a building's design and throughout its construction. This provides the historical context needed to replicate the asset with incredible accuracy from the outset of the operations phase. Moreover, the real-time connectivity established when integrating the twin with IoT sensors allows for additional, more immediate context to be introduced into the model, which facilitates the continuous optimization of both the physical asset and its replica over time.

In their most ideal forms, digital twins are created and leveraged alongside an open-source-based Building Lifecycle Intelligence system (BLI), which enhances the accessibility, analysis, and management of all integrated data throughout the lifecycle. This includes historical data sourced from BIM, as well as real-time operational and contextual data gathered from multiple sources.

Put simply, BLI integrates all project-relevant data into a centralized system, establishing a single source of truth from which insights can be easily accessed and exchanged between stakeholders at different phases, optimizing how the information from one stage is used to inform the next. Most importantly, the seamless exchange of insights from across the building lifecycle allows BLI to produce a much more robust, accurate, and reliable digital twin based on all available and relevant information.

To understand more clearly how this technology can be leveraged to drive sustainability and cost-efficiency, let's take the example of a digital twin used to replicate a building envelope. After creating a data-rich virtual model of the critical barrier between a structure's conditioned and unconditioned environment, the building envelope's digital twin can be used to:

- Analyze sensor data and simulate insulation scenarios to adjust insulation levels and optimize energy consumption.
- Identify ideal glazing levels for reducing energy consumption and improving occupant comfort.

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- Optimize the operation and placement of shading devices to reduce heating and cooling costs.

- Simulate airflow scenarios to identify optimal ventilation strategies, reduce energy consumption, and improve indoor air quality.

- Monitor and predict performance and maintenance needs across the building envelope in real-time to promote early detection and reduce repair costs.

- Simulate retrofitting scenarios using both historical, real-time, and relevant contextual data provided by the digital twin to identify cost-efficient designs and reduce CO_2 emissions.

Of course, it’s critical to note that most digital twins that exist today are not without their limitations. Most notably, despite the considerable advantages of BLI, a digital twin may still require additional information to simulate outcomes with accuracy and achieve the desired result. For example, if a building operator wanted to achieve certain humidity levels through the optimization of a building’s insulation system, the digital twin-powered simulation would need to take into account data related to external factors such as regional environmental trends and climate forecasts.

What often happens as a result of insufficient or incomplete information is that a notable gap emerges between the outcome projected by the simulation and the actual performance of the building or asset. And in some cases, this can lead to the kind of frustrating, costly errors, and miscalculations that the simulation had actively been trying to avoid.

In order to close this gap and accelerate progress toward sustainability and cost-efficiency in the AEC/O industry, we will need to continue to lean into the use of digital twins, but also adjust how we refine digital twin simulations to include the use of increasingly powerful artificial intelligence (AI) and machine-learning technologies (ML).

Moreover, in addition to the technology itself, we will need to rethink our overall strategy in achieving sustainable outcomes, moving away from a more fragmented treatment of individual processes, and toward a more holistic approach that establishes a circular economy around which all phases of the building lifecycle revolve.

Integrating AI and the Circular Economy

While the broader advantages of AI have only recently taken the world by storm, the benefits of artificially intelligent technologies and processes for optimizing the building lifecycle have been of interest to the Nemetschek Group for quite some time.

The existing and potential use cases of AI for the AEC/O industry are vast, from more accurate forecasting of built asset performance and generative design to manual process automation and the enhancement of decision-making through the more rapid and efficient analysis of outcomes. In the unique context of digital twins, we also see no shortage of opportunities, including the potential to close the performance/simulation gap, and ultimately accelerate the transformation to more sustainable and cost-efficient solutions across the project lifecycle.

However, current iterations of AI systems share some of the same limitations as digital twins. More specifically, just as digital twins need additional information to produce more accurate and reliable simulations, AI needs to be trained on increasingly large volumes of historical and contextual data to expand its capabilities.

But it isn’t just more data that AI needs in order to become transformational, it’s the right data presented in the appropriate context, and within the parameters of a clearly defined strategy. The simple fact is that while AI is impressive, and in many cases nothing short of astonishing, the capabilities of these systems are ultimately the product of how we design and guide them toward a specific outcome. And this is where circularity, or the implementation of the circular economy, comes into play.

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Although it might sound complicated, what is meant by the circular economy is actually fairly straightforward: Whereas we have traditionally regarded the building lifecycle as a straight-through process, beginning with design and construction, moving into operations and management, and ending in demolition, the circular economy frames it as an indefinite feedback loop, in which the optimization of one phase serves that of the next, and even the "end" stage of one building or project is optimized to serve the design and construction phase of another.

In the context of sustainability and cost-efficiency, this simply means that each stage of the project lifecycle is optimized around these two mutual objectives, and in a way that directly supports the other stages, thus contributing to the circular economy. Even more specifically, this means introducing the strategic goal of circularity into the use and development of digital twins, asset simulations, and assistive AI and ML-powered technologies.

For example, in addition to focusing on how the design of a building informs its initial construction, digital twins and AI could be used to simulate and evaluate different retrofitting scenarios, making it easier to identify the optimal material choice for longevity and reuse. Similarly, during operation, these technologies might help optimize energy use and occupancy comfort not just for existing structure and its tenants, but in a way that designedly factors in long-term cost-savings and sustainable renovation scenarios.

Going forward, the overall key to realizing these use cases is to approach the limitations of current digital twin and AI models with a keen eye toward establishing circularity. Because when we stop to consider the ability of AI and machine learning systems to continuously improve based on the addition of new information, and the fact that systems like BLI have the unique capacity to integrate new functionality across the building lifecycle, the task of achieving sustainability and cost-efficiency begins to look less like an insurmountable barrier, and more like an exciting opportunity to create positive outcomes for the environment, as well as a new source of value for building owners, occupants and the AEC/O industry at large.

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