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Construction 4.0

Key Points

- The potential of Construction 4.0 is tremendous.
- The transition to Construction 4.0 is challenged by the industry's tradition of custom-made projects and one-off designs.
- Product repetition in Industry 4.0 is replaced by process repetition in Construction 4.0.
- Construction 4.0 driving principles mirror those of Industry 4.0 and are summarized.
- Significant Construction 4.0 technologies are highlighted.
- Opportunities and barriers of Construction 4.0 are identified.

Introduction

This Executive Insight looks at the emerging nature of Construction 4.0. It provides an overview of what comprises Construction 4.0. We will examine some of the opportunities it may create and the challenges it will likely face. We start by defining Industry 4.0, which provides the framework for Construction 4.0. We also relate how Industry 4.0 is evolving from Industry 3.0 Similarly, we will define the scope and attributes of Construction 4.0 and discuss how it has evolved from Construction 3.0.

Industry 4.0

Increasing sensor content, big data generation, and AI (artificial intelligence) analytics are the core technologies behind Industry 4.0, which focuses on intelligent and perceptive systems. 5G will be a major boost to Industry 4.0 as it evolves from single machine-to-machine connectivity to having real-time control, smart supply chains, predictive maintenance, and ultimately ubiquitous visibility and intelligence.

Industry 4.0 is changing the roles of people and technology in industry and consequently is shifting customer expectations. Smarter hardware serves as the technological foundation for Industry 4.0. Driving Industry 4.0 to the next level of performance are big data and AI analytics. Industry 4.0 is not a future trend. It is currently providing advantage to early adopters. The roadmap for transitioning from Industry 3.0 to Industry 4.0 is increasingly becoming well-developed.

Construction 4.0

With construction accounting for nine percent of global GDP (and around six percent in the U.S.), the potential of Construction 4.0 is tremendous. The transition to Construction 4.0 is challenged by the construction industry's custom-made projects and one-off designs. Product repetition must be replaced by process repetition in Construction 4.0.

Despite the many existing definitions and the lack of a clear standard, there seems to be consensus to consider Construction 4.0 as "the application of Industry 4.0 to the construction sector." In other words, and in a broad sense, Construction 4.0 is the application of construction digitalization.

Construction 4.0 may be defined more specifically as:

- An innovative construction management technique, driven by Industry 4.0 technologies, that allows for the creation of a smart construction site.
- A process of implementing cyber-physical systems to encourage the digitizing of the construction industry with the intention of achieving optimum performance of the sector.[1]
- A combination of cyber-physical technologies that supports a smart construction site, digital modeling (Building Information Modeling (BIM); digital twin – a digital replica of potential and actual physical assets, processes, people, places, systems, and devices), simulation, and virtualization.

Construction 4.0 is founded on four design principles[2]:

1. Interconnection and interoperability
2. Information transparency (Virtual Reality and Augmented Reality)
3. Decentralized decisions (BIM, the Cloud)
4. Technical assistance (drones, robots, 3D printing)

Construction 4.0 and the technologies that comprise it will not be successful if we do not simultaneously address other performance issues facing the industry today. These include, for example, strengthening project foundations and dramatically improving stakeholder engagement. Other performance issues exist as well.

Construction 4.0 Driving Principles

The underlying principles of Construction 4.0 often mirror those of Industry 4.0. These include:

- **Horizontal integration** – linkage between a given resource and the relevant information within the expansive value chain. Global demand for key materials of construction such as iron ore for steel or various rare earths together with evolving supply chains and intermediate fabrication and processing capabilities and capacities weigh into today's procurement strategies.
- **Vertical integration** – linkage between various components and systems at a construction site, including those associated with customization. These may include linkages to smart

[1] O. Temidayo, A. E. Oke, C. Aigbavboa, M. Liphadzi (2018)
[2] M. A. Hossan, A. Nadeem (2019)

manufacturers on a discrete basis. BIM enables close coupling between designers, builders, and key suppliers, providing a level of planning and granularity not previously available.

- **End-to-end supply chain integration** – multi-level connectivity providing value-add to different links along the supply chain. Allows material tracing and tracking; real-time monitoring of intermediate steps in the production process; vendor performance assessment (shop load; rework; quality test results); logistics chain management; and customized management reports and tools. Examples include early warning of potential supply chain delays due to late availability of key supplier subcomponents or accelerated reordering of commodities as drawn down from onsite stocks.
- **Real-time capability** –this includes a full range of site performance characteristics and capabilities.[3] Also included are sensor informed, model-based assessments, alerts, and action initiation. *Examples are real time safety, monitoring ever-changing construction environments and operating modes, interfacing with worker specific, location specific data, and fostering worker safety.*
- **Virtualization** – enabled by digital twins, this allows both optimization offline as well as in real time. The latter is enabled by the Internet of Things (IOT). Construction-focused digital twins are increasingly providing a foundation for living enterprise asset management.
- **Modularity** – based on agile supply chains, a systems perspective, flexible processes, and modular decision-making processes and procedures. Physical modularization at various scales is increasingly complemented by "knowledge assemblies," improving and accelerating project design and scope completeness.
- **Decentralization** – facilitates coordinated and aligned action among otherwise autonomous elements with localized decision making. Cyber-physical systems are enablers of decentralization. *COVID-19 has highlighted one element of decentralization: remote working has become more common.*
- **Interoperability** – ability to exchange information, conduct transactions, and work in tandem. Aided by semantics[4]. Interoperability of data is essential for IOT to be successful. Smart contracts and even AI-enabled predictive project analytics rely on the contextual use of words and ideas (semantics).
- **Smart products** – utilize embedded sensors to report their current condition (operating performance parameters; location and other geospatially related data) and forecast their future performance characteristics based on an assigned task. They may be networked together as part of a larger smart process or contextually operate as an integrated element of a smart site. Onsite construction equipment is capable of self-monitoring and reporting their current operating performance and maintenance condition. Linked to planned utilization schedules derived from updated construction plans, they can predict when maintenance may be required and recommend actual maintenance events considering construction demands placed on them. In large base camps with multiple networked diesel generators, micro-grids aid in optimizing economic dispatch, recognizing that diesel performance improves with load factor.
- **Smart site** – a cyber-physical environment operating within model-based parameters but availing themselves of a distributed sensor and execution capability that can be dynamically

[3] Real Time Safety Systems; Patent number: 9082284 and 8754768; Prieto

[4] Semantics is the study of the relationship between words and how we draw meaning from those words. It considers context.

optimized for performance. Enabling technologies include sensors on people, equipment, materials (such as radio frequency identification or RFID), and the site more broadly; real-time monitoring by drones and cameras; wearables; and construction robots. BIM models, digital twins, communication bandwidth and channels (5G enabled), and a common data environment are all enablers of a smart site.

- **Smart processes** (including project management) – smart construction may include use of construction robots connected to Cloud data. Project management processes incorporate real-time site performance data with big data analytics to predict performance trends and to develop optimized responses. Construction robotics are advancing rapidly and will benefit fixed module and fabrication sites the most in the short term, but specialized construction robots (bricklaying) are already finding use in general construction environments. Advances in anthropomorphic robots are evident, but generalized robotic workers remain in the future. The greatest challenge will be integration of humans and robots in the same construction environment.
- **Systems integration** – deals with new capacities and their integration with each other as well as integration with the installed base. It addresses all aspects affecting Construction 4.0, recognizing that different elements of the industry will be at different levels of maturity for an extended period. Brownfield projects still represent a significant portion of the construction industry and systems integration must focus on bringing more recent technology advances and practices to what is typically a custom-made environment.
- **Corporate social responsibility** (workers obligations; stakeholders; carbon) – Construction 4.0 impacts multiple dimensions of existing social contracts and responsibilities. These include likely new legislation and regulation; new jobs and skills; new work rules geared to a cyber-physical environment; new business models and platforms; and emergent risks. *Issues related to social justice, greenhouse gas emissions, and embedded carbon will grow in importance in the short term, and will create new markets for the construction industry such as that currently represented by green hydrogen.*
- **Customization** (to reflect site and project constraints/requirements) – will be enabled by a growing library of knowledge objects and an ability to assemble specialty capabilities through enhanced interoperability and Cloud computing. The construction industry must create a data commons if it is ever to achieve step-changes in levels of productivity and performance.

Construction 4.0 + Advanced Technologies + New Project Management Models = Construction Industry Optimization

Construction 4.0 Technologies

The realization of the Construction 4.0 underlying principles is supported by a range of technologies that is being deployed more broadly as part of Industry 4.0. This range of technologies, however, has mixed maturity in the Construction 4.0 context.

Each of the following technologies will have one or more manifestations within an engineering and construction setting. The greatest power will arise from a "network" effect, with added value being created with each new instance of a deployed technology[5]:

- **Internet of Things (IOT)** – object-to-object communication, coordination, and model-based shared decision making. Distributed sensors link their information with smart machines and backend analytics and information systems. (Networked sensing; near field communication and control)
- **Internet of Services** – enabler of Product as a Service (PaaS) business models. These can include software upgrades to smart equipment operating systems based on actual site conditions experienced; usage-based expense versus capital outlay (for example, a diesel generator charged on run time and load factor); and post-construction predictive maintenance.
- **Internet of People** – people not just as point provider/consumer of data and information, but rather as a node in a dynamic information mesh. This information includes physical attributes (location, direction, and rate of travel); personal attributes (health of individual, sleep time, and quality); and sociological profile (social media).
- **Cyber-Physical Systems** – integration of data, including real-time sensor and human data; models and algorithms; and physical systems. These can include smart machines, processes, and even an entire construction site. The increased digitalization in the sector, including the growing use of digital twins, may be occurring faster than our focus on cybersecurity. We must ensure that SMART ≠ VULNERABLE. Exposure is amplified by long supply chains and the preponderance of stakeholders.
- **Simulation and Modeling** – facilitates design optimization including life-cycle design. This is an essential element of construction means and methods planning in Construction 4.0 and in real-time management and control of a smart construction site. Used in conjunction with BIM and augmented reality.
- **Augmented Reality (AR)** – visualization of computer graphics and models in the real environment. This creates the opportunity to interactively experience the real-world environment and aids in decision making.
- **Virtual Reality (VR)** – provides a platform for virtual objects that can be used for construction and for operations and maintenance (O&M) reviews. Also used to facilitate design and construction reviews and decision making. Serves as a platform for augmented reality.
- **Mixed Reality** – merging of real and virtual worlds to produce new environments and visualizations where physical and digital objects coexist and interact in real time. Mixed reality does not exclusively take place in either the physical or virtual world, but is a hybrid of reality and virtual reality, encompassing both augmented reality and augmented virtuality via immersive technology[6].
- **Big Data Analytics** – Big data analytics is the complex process of examining big data (that which contains greater variety arriving in increasing volumes and with ever-higher velocity) to uncover information such as hidden patterns, correlations, trends, and preferences that help make informed decisions.

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[5] Executive Insight, Convergence of Construction Technology
[6] Wikipedia

- **Cloud Computing** – data collaboration and sharing are becoming well established in Industry 4.0, but are still maturing in construction. Cloud-based analytics will complement software as a service model.
- **Internet of Data/Common Data Environment (CDE)** – management of exponentially growing data associated with Construction 4.0. The British Standards (BS) PAS 1192-5:2015 Specification (for security-minded building information modelling, digital built environments, and smart asset management) has largely overlooked BIM data contained within a CDE.[7]
- **Blockchain** – also known as distributed ledger technology, this is an essential element of data security and, importantly, is part of establishing a single version of the truth. It is an enabler of automated, frictionless transactions that are essential in Construction 4.0. One example is a smart construction robot that entrusts data feeds from a third-party sensor. This technology is a core opportunity in overcoming cybersecurity risks.
- **Cybersecurity**[8] – far less understood in Construction 4.0, this faces unique challenges associated with the multiplicity of actors, long supply chains, and vulnerabilities associated with the growing use of common data environments. The extension of BIM models and digital twins into the operating period further elevates these risks.
- **Additive Construction** – has a similar definition to that of "additive manufacturing" in Industry 4.0. It is the process of joining materials to create constructions from 3D model data. This means that the design, production, and assembly processes are digitally controlled to some extent. Recent efforts on 4D printing[9] warrant longer term monitoring.
- **Automation/Construction Robots** – offer the potential for higher quality and reliability with lower waste. These are especially beneficial for hazardous or highly repetitive operations. Construction's custom-made environment is more challenging than that encountered in Industry 4.0. Multi-functional robots and multiple robot applications offer future potential.
- **Semantic Technology**[10] − provides an abstraction layer above device information that facilitates interoperability. Semantic information in BIM models may represent an increased cybersecurity vulnerability.

Opportunities Created

Construction 4.0 offers the industry many new opportunities. The benefits can be analogously seen in Industry 4.0 in the manufacturing sector. These include:

- Enhanced safety through the use of robots for hazardous, repetitive, and stressful work.
- Enhanced safety through greater safety awareness in a cyber-physical setting.
- Dynamic awareness of construction operations performance and overall site status.
- Identification of emergent construction risks (safety, performance, supply chain, and others.).

[7] E. Parn, B. Garcia de Soto (2020)
[8] Executive Insight, Cybersecurity
[9] $D printing creates materials that can respond to changes in their environment
[10] Semantic technology encodes meanings separately from data and content files and separately from application code. This enables machines as well as people to understand, share, and reason with them at execution time. With semantic technologies, adding, changing, and implementing new relationships or interconnecting programs in a different way can be as simple as changing the external model these programs share.

- Productivity improvement from better information flows (transparency, trust, timeliness).
- Predictive analytics that learn from application.
- Enabler to address given industry process issues as part of industry restructuring.
- Extension of digital models into the operating period strengthens focus of life-cycle performance.
- Increased simulation of means and methods and simulation testing and development of workface plans.
- Population of a data-rich library of knowledge objects.

Barriers to Acceptance and Implementation

Construction 4.0 adoption will be challenged by a combination of:

- Fragmented industry structure (wide variation in scale and maturity levels).
- Historically poor technology adoption rates in the industry.
- Differing value perceptions between the executive and workface levels.
- Added hurdles imposed by custom-made, one-off projects.
- Existing weak information transparency and transmission.
- Political and social acceptance.
- Technological challenges, given the nature of construction and the construction environment.
- High technological maintenance cost.
- Limited relevant skills base in the construction industry.
- Inadequate industry mechanisms and investments in R&D.
- Challenges posed by systemic innovation.
- Lack of industry standards and slow extension of existing Industry 4.0 standards to Construction 4.0.

Summary

Industry 4.0 will drive the same step-changes levels of transformation that each of the first three industrial revolutions did. The expansion into the virtual world and the growing intersection of the cyber and physical realms will create a future we can only imagine today. If history is our guide, however, the resulting transformations will be profound and enduring.

Industry 4.0 will create new opportunities for construction as well as new challenges. The skills Construction 4.0 will require will differ from those required today. How we create and shape the environment around us also will be dramatically different. Much of what we do and how we do it today may give way in this transformation, but those who can make this transformation—integrating the potentials of Industry 4.0 into the construction environment—will be tomorrow’s leaders and the future members of the National Academy of Construction.

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