# An Overview of State-of-the-Art Technologies for Data-Driven Construction

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**Abstract.** The Architecture, Engineering, and Construction (AEC) community has been implementing actions that address the significant productivity and efficiency problems that are common in on-site construction. In spite of the many advantages of introducing emerging technologies, the industry continues to rely on hard copy documents. However, the recent advent of new technologies such as AI, Blockchain, IoT, and 5G-communication is leading the built environment into a modern data-driven environment. This data-driven environment can be described as having five phases based on the data utilization criteria: data acquisition, data highway (mobile), data security, data analysis, and data realization. The AEC community can apply IoT, 3D laser scanning, and drones to the data acquisition phase. These technologies can provide the AEC community with fast, affordable, and robust data collecting methodologies. 5G-communications technologies can allow participants to communicate enormous quantities of data in seconds among the various stakeholders. Blockchain enables the AEC industry to share, secure, and store data in distributed ledgers, establishing transparency, immutability, traceability, and decentralization. It also utilizes artificial intelligence (AI) and machine learning (ML) algorithms for data analysis. AI and ML analyze big data collected from the acquisition phase and give a prediction about models or improve decision making by clustering or categorizing data. Finally, by introducing speech recognition technology, virtual and augmented reality, the designer can provide customers with a customer-centered environment. This study presents an overview of state-of-the-art technologies for data-driven environments, use cases, and the impacts of these technologies on the AEC industry productivity and efficiency.

**Keywords:** State-of-the-art technology · AEC industry · Data-driven construction


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# 1 Introduction

The AEC industry has been taking high impact strategies to address many of the significant productivity and efficiency problems that are common in on-site construction. The AEC needs to increase productivity annually by about 1% because it has only been growing by one-quarter of the rate of manufacturing productivity over the past 20 years. In spite of the many advantages of newly introduced strategies, it uses the same hard copy documents as it used for decades. This reluctance to adopt state-of-the-art information technologies is one of the main reasons that AEC's productivity growth has been stagnant. However, the recent advent of new technologies such as IoT, 5G-communication, Blockchain, AI, Automatic Speech Recognition (ASR), is leading the built environment into a modern data-driven environment. This data-driven environment can be described as having five phases based on the data utilization criteria: data acquisition, data highway (mobile), data security, data analysis, and data realization. Figure 1 explains the relationship between categories and technologies. This paper presents these five criteria's state-of-the-art construction technologies, use cases, and discussions.

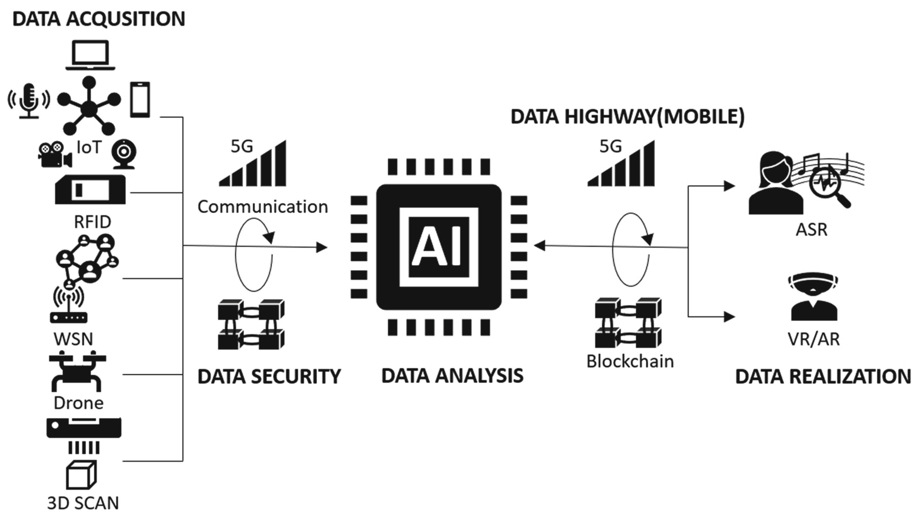


**Fig. 1.** An overview of state-of-the-art technologies for the AEC industry.

# 2 Methodology

This study conducted two tiers of analysis. One tier was general category analysis that extracted broad technological areas. The authors used "Google Scholar" and "Web of Science" to find articles related to "the state-of-the-art" and "data-driven" technology for the AEC industry. Several web and journal articles were found and general categories such as data acquisition, data analysis were extracted by the trends, clustering of technologies reported. On top of that, the other tier research conducted is to pick up specific technologies and use-cases of each technical group by googling. Since state-of-the-art technologies are nascent, just introduced to the market, the authors could get the related data mostly from web articles.

# 3 An Overview of State-of-the-Art Technology for Data-Driven Construction

## 3.1 Data Acquisition

Data acquisition of the project progress is one of the most critical managerial activities for decision making, undoubtedly relies on precise and useful monitoring systems in the architecture, engineering and construction (AEC) projects (Son et al. 2015). AEC industry has been developed data acquisition technologies for decades, and most of the advancements in data acquisition involve automated works. The purposes of the automated data acquisition are as follows: reducing human error through unmanned devices, securing large amounts of data faster, more accurately, and cheaply which was previously hard to get.

These purposes can be achieved by the following automated data acquisition technologies: Internet of Things (IoT), Radio Frequency Identification (RFID), Wireless Sensor Networks (WSN), Unmanned Aerial System (UVA, other words: Drone), 3D scanning, to name but a few. Subsequent paragraphs, however, are indented.

**Internet of Things (IoT):** Internet of Things (IoT) has appeared as a significant research area in construction management recently as a method of collecting data from materials manufacture to installation and inspection in building construction (Maghsoodi et al. 2020). The IoT was defined as "the interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications" (Gubbi et al. 2013). In a construction project, four system blocks comprise the IoT networks: sensors, communication nodes, servers, and user interfaces (Lam et al. 2017).

**Radio Frequency Identification (RFID):** RFID uses electromagnetic fields to automatically identify and track tags attached to objects (Atzori et al. 2017). Two types of tags are used for different functions in data collection: passive tags collect the energy of radio waves from a nearby RFID reader, while active tags have a local power source and get energy from further RFID readers and locate more flexible (Jia et al. 2019). Tags are embedded in tracked objectives. RFID is widely used in supply chain management such as transportation tracking, and material and components assembly in construction (Gubbi et al. 2013). Near field communication chip is applied for site safety and material delivery process management (Swedberg 2015).

**Wireless Sensor Networks (WSN):** WSN contains a large number of different-function sensors communicate wirelessly, such as through Wi-Fi, Bluetooth, Ultra-Wideband (UWB) and ZigBee (Shen et al. 2008). WSN contains three main components namely: sensor node, communication node, and gateway (Frei et al. 2017).

Sensor node measures and storage different type of data, communication node transfers data to the gateway. Gateway receives and forwards data to the data analysis terminal wirelessly. Different kinds of sensors can be installed in an existing building in collecting data of indoor temperature, humidity, air quality, brightness, etc. (AL-Mousawi and AL-Hassani 2018). It is widely used in smart building and building energy control.

**Unmanned Aerial System (UVA, Drone):** UVA system is a type of WSN that any aircraft or drone that works without a human pilot onboard. It uses devices such as drones or small crafts onsite collecting 3D point cloud and transfers data through a wireless network to a user terminal. Point clouds are sets of data points in some coordinate system. The drone is widely used in data collection of site surveys, which saves cost, time and labor compare to traditional survey methods. It can also be used in building façade inspection, construction progress monitoring, and safety inspection (De Melo et al. 2017).

**3D Scanning:** Laser scanning and photogrammetry are two types of 3D scanning technologies. Laser scanning collects point cloud data of real-world objectively to develop an accurate 3D model on its shape and appearance. It is done by shooting laser beams followed by a distance measurement at every pointing direction. The collected data can then be used to construct digital 3D models. Photogrammetry is a science of making measurements from photographs, especially for recovering the exact positions of surface points. Point cloud technique can be used for surveying, mapping, inspection, progress monitoring, and clash detection (Kovacs et al. 2006).

As seen above, the technologies in the data acquisition phase aim at collecting big data without any human interference and errors. These technologies help to establish the foundation of data-driven circumstances.

## 3.2 Data Highway (Mobile)

It is evident that communication is essential in the advancement of every industry (Bailey 1953). Wireless communication is arguably the most critical segment in the global Information and Communication Technology (ICT). Notably, the data mobile highway has been in demand and growing exponentially as more people and machines use this technology to support daily activities. From the second generation 2G communication system which was introduced in 1991, it has been followed rapidly by advanced versions such as 3G and 4G and as of today, 4G LTE (Long term Evolution) has taken a shift in how data is transferred. (Wang et al. 2014). In spite of these technologies, there is a need for way faster and more effective mode of data highway which gave rise to the evolution of next-generation technology known as 5G.

5G is the next generation of mobile data highway technology that will have the capacity to replace all other mobile broadband systems. It operates on three different bands of spectrums, unlike LTE (Looper 2019). It promises to foster a more significant impact by connecting edge computing, autonomous vehicles, higher efficient industries, internet of things (IoT) and analytics infrastructure with least latency (Bayern 2019). Unlike LTE, 5G will be as fast as 20Gbps over wireless networks which is a major technological breakthrough and can revolutionize all other industries to run faster, efficient and reliable (Nordum and Clark 2017).

The advantages of 5G communication are as followings: 1) spectral efficiency with multiple frequencies allowing larger bandwidth to be extended to longer distances, 2) energy efficiency by leveraging the technological gains for both transmitters and servers, 3) enhanced mobile broadband which will allow serving densely populated metropolitan centers, 4) machine to machine type communication which enables IoT applications to be much faster and efficient, 5) ultra-reliable and low latency communication which would address the autonomous vehicle industry, 6) better satellite access and wireline coverage (Fulton 2019).

With these technological advancements on data and network management, blockchain will be able to operate on multiple networks (Bayern 2018). It has the potential to be the platform where all businesses are conducted, and 5G will be the network and data highway it will run on. It has the strength to solve many issues of the world and the way we interact with others financially (Gurnani 2019). This can be a significant revolution in the construction industry. Using smart contracts, payment methods existing in decentralized blockchain networks, the process can be much faster, transparent and much-needed automation (Johnston 2018).

A study by IHS Markit analyzed the adoption, diffusion cycle, and long-term economic contribution of 21 expected use cases. These are categorized into three main categories which are Enhanced Mobile Broadband (EMBB), Massive Internet of things (MIoT) and Mission Critical Services (MCS) (Campbell et al. 2017). Through EMBB, augmented and virtual reality can be broadly utilized. MIoT becomes an infrastructure of smart homes, cities. Finally, MCS encompass applications such as an autonomous vehicle, drone, automation, smart grid which used in the AEC industry now.

Through the 5G communication technology, people can share big data such as video footage which sizes are more than 1 GB in seconds. It means that the AEC industry provides clients with more detailed, realistic, two-way communication, attracting clients' attention, and being easy to reflect clients' ideas.

### 3.3 Data Security

As well known to people, Bitcoin is cyber money that is traded through the Internet in a distributed security system utilizing a publicly-opened ledger named the blockchain (Swan 2015). Blockchain is a catalog of blocks that got validated, each connecting to its precedent block and ultimately to the genesis block. A block is a data module that saves transactions for integration in the distributed ledger, the blockchain. (Antonopoulos 2014). Blockchain can be achieved even from long distant or numerous sites if the network participant has their public and private key. Since all entities can share the same copy of data in the ledger, any tampering is reported and updated in all blockchains in less than 10 min. The data varies from financial, electronic, to energy consumption, to name a but few. The data is secured cryptographically by the cyber key set (UK Government 2016).

Subsequent A smart contract utilizes codes that are autonomously carried out by the trigger of specific situations. In the perspective of the blockchain, smart contracts refer to blockchain transactions that not only trade financial assets but also possess more comprehensive specifications in them. In a more official description, a contract is an approach of utilizing blockchain platforms such as Bitcoin or Ethereum to establish agreements among people. Indeed, three characteristics of smart contracts that render them outstanding are autonomy, self-sufficiency, and decentralization (Swan 2015).

AEC industry has been trying to adopt the blockchain technology into their business processes. A supply chain is a representative area that blockchain can be an excellent solution for its complexity. Project management can apply the blockchain to secure all the data produced in the construction project. For example, HerenBouw, Amsterdam-based company, is utilizing a blockchain-embedded project management system on a commercial building construction project. The system helps project participants have in-just, precise communication, and fewer mistakes. Furthermore, in the completion of the project, blockchain can handover the project related information right away. "digital twin" blockchain system, developed by the Gardner Builders with Briq, delivers all the data such as paint colors, light bulb types, door silvers, maintenance documents, warranties, to name a few (Hegemen 2019). On top of that, the construction manager is able to get reputation data for subcontractors by blockchain. "Yeeyi," a community platform in Australia, initiated a digital reputation ledger for a second-hand marketplace with a plethora of Chinese expatriates (Lee 2018). Life-cycle ledger is another example of blockchain use cases. Building maintenance involves an end-to-end cycle of the construction project, asking data that can be traceable when needed. "Blocxs" of OSIsoft, Amsterdam-based startup company, provides Process Intelligence (PI) system for building assets with blockchain. Blocxs shares building equipment life cycle data such as production company, logistics partners, commissioning partner, service department, and recycling partner with building owner and occupants. This application enables participants to respond to an issue from the building maintenance efficiently and reduces the cost of building operations (Mulder 2018). "Synapse" from Brickschain that located in California is an artificial intelligence and blockchain platform for the built environment. It provides the construction industry the prediction of project bidding, execution, and risk management (Talton 2018).

### 3.4 Data Analysis

Machine learning (ML) and pattern recognition discover the regularities automatically in data by the adoption of computational algorithms and make a decision such as data classification into different categories by using the routines found (Bishop 2006).

AEC industry has been applying ML technologies to the following areas: prediction, irregularity detection, handling system complexity. For example, the ML algorithm can forecast building energy consumption following historical weather data and occupancy details. Furthermore, it can improve building equipment's anomaly detection, which determines whether there are issues with the facilities and responses to those issues automatically. On top of that, since building management is becoming more and more complicated, ML can help establish a better indoor quality of building systems (Primex 2020).

There are several use cases in the AEC business market. In the planning and design phase, "GenMEP" by Building System Planning, located in California, is an automated tool to create the mechanical, electrical, and plumbing (MEP) automatically, adding-on to Autodesk Revit. In the construction phase, "Building Information Modeling (BIM) 360 IQ" by Autodesk is a managerial tool that utilizes connected information and ML to forecast and focus on high-risk problems or predict subcontractor hazards. "Compact Assist by Volvo Construction Equipment (2015)" helps generate passes that the compactor draws and record asphalt mix temperature maps for the area automatically, calibrating to the final pavement requirements. "SmartTag by Smartvid.io" developed a technical photo and video platform. It involves a "SmartTag" engine that can label pictures and videos of the job field autonomously by utilizing ML, voice, and image recognition technologies. SmartTag uses a deep learning model to classify vision and voice to name the construction information, and predictively proposes safety strategies for the project participants. "SMART CONSTRUCTION" by Komatsu and NVIDIA developed an AI reinforced safety tool for job fields. It models 3D visualizations and traces the whole construction area with live interaction among workforces, equipment, and materials in the project site. Doxel, an AI-based software, argues that it improves construction productivity by adopting robots and drones with multiple sensors to track the project progress. In the operational phase, "Comfy" by Building Robotics, a startup headquartered in Oakland, is an application for building automation management. It helps users change thermostat settings indoors on-demand and apply it over time (Bharadwaj 2019a). "CogniPoint" is a building management software developed by Israel-located company, "PointGrab." CogniPoint system run by AI optimizes the lighting, HVAC for space purposes. IBM also provides the "Watson IoT Platform." It improves energy efficiency in buildings and delivers personalized/occupant-friendly spacial experiences based on data analytics. "Verdigris," a California-located company, provides software for IoT energy metering and platform for data analyzation. "Bidgely" delivers software that can help electricity businesses collect information concerning measurement and the cost of energy utilization by various home devices. The system sends customers visual data to attract attention by using the machine learning algorithm (Bharadwaj 2019b).

### 3.5 Data Realization

This section will deal with Automatic Speech Recognition (ASR), Augmented Reality (AR) and Virtual Reality (VR) in terms of data realization. To do that, it will also mention a definition, case studies in various fields, and the development direction for the future about automatic speech recognition.

**Automatic Speech Recognition (ASR):** The ASR can be determined as the autonomous, computer-conducted decoding of oral communication into a legible script instantly. Briefly, ASR is a system that enables a machine to recognize the words when a person talks into a voice recognition device, currently a smartphone, and to transform them into written scripts (Stuckless 1994).

Thanks to the popularization of Automatic Speech Recognition (ASR) with the advent of smart devices, it can be easy for people to use these systems daily. Besides, according to the 2018 Smart market report, the global automatic speech recognition market valued approximately $9.12 billion in 2017. In various areas such as finance, retail, health care, and even the AEC industry, they have tried to apply ASR systems to provide more convenient services to consumers (Bernstein et al. 2018).

In the case of the field of finance, Royal Bank of Canada (RBC) announced in 2017 that consumers can now pay their bills using Apple's Siri. Sean Amato-Gauci, vice president of the bank, said that it has become possible for RBC to provide not just more convenient solutions to clients by offering bill payments but also simple and innovative solutions by giving clients the ability to seamlessly and conveniently bank using voice commands. At the same time, the United Services Automobile Association (USAA) announced that Amazon Alexa helped USAA members to access information about account balances, transactions, and spending patterns. US Bank also announced its embracing of voice-technology. Customers can now check their account balances, hear due payment dates and the amount, obtain account transaction history, and make payments by speaking to an Amazon Alexa (Aspa 2017).

Healthcare is a sphere where speech recognition has put down deep roots as just like other areas as well. Long ago, the Healthcare Information and Management Systems Society (HIMSS) called voice recognition an "aggressively" expanding market with a 20% growth rate per year. A KLAS Enterprises report says that in spite of 50% of physicians' resistance to adopt the technology, 9 out of 10 hospitals plan to expand speech recognition use (Yelina 2017).

**Augmented Reality (AR):** As an emerging technology, AR integrates images of virtual objects into the real world. By inserting the virtually simulated prototypes into the real world and creating an augmented scene, AR technology could satisfy the goal of enhancing a person's perception of virtual prototyping with real entities (Whyte et al. 2000). Park et al. (2013) combined AR and BIM technologies as an inspection system that enables managers to inspect and control costs and time for more efficient job performance (Park et al. 2013). To improve the efficiency of facility maintenance management, Cheng (2016) developed a framework of a BIM-based location-aware system collaborated with AR (Cheng et al. 2016). Users can share real-time location information by Wi-fi fingerprinting and data source of BIM.

**Virtual Reality (VR):** The fundamental concept of virtual reality (VR) is to generate a simulated environment based on users' experience and unique insights with computers, software, and peripheral. The setting may be simulated as a real or an imaginary environment (Whyte et al. 2000, Sacks et al. 2013). The use of VR in the construction industry has expanded rapidly since the late 1980s.

VR is widely used in the AEC design in multiple aspects, including communication, safety management, information, and change tracking, and cloud-based modeling in both design and construction phases (Bouchlaghem and Liyanage 1996). Sacks et al. (2013) used VR for safety training and got a better result in safety testing data to examine, comparing to conventional classroom training (Sacks et al. 2013). Kim and Kano (2008) compared VR images with construction photographs taken by a fixed-point camera in the same direction and locations (Kim and Kano 2008). The comparison was valid for the visual assessment of construction progress in a job site. Matching VR images and construction photographs corrected the deviation angle from a 3D viewpoint.

## 4 Discussion

The technologies investigated in this paper improves not only construction data management but also enhances adaptability to the increasingly changing market circumstances. To gain a competitive edge in a competitive market environment, individual technologies are eliminating human involvement and are pursuing faster, more accurate, and less expensive data processing. These data-driven technologies provide critical information not only to project managers but also to clients quickly and at the right time and can help them make agile and accurate decisions. Furthermore, data-driven environments can cause a significant challenge in the AEC industry. It is the shift from a professional-oriented market to a client-oriented market.

The AEC industry has been a market that professionals have the power in decision making since, in most cases, project owners do not have professional knowledge. At best, with help from owners' representatives, owners can have leadership in the general direction of the project, and most of the details are left to the expert. However, as the state-of-the-art technologies begin to replace the realm of specialists, substitute expert decisions, and create an environment that delivers the vast amount of data needed for decision-making in real-time, the experts-oriented market quickly transforms into a client-oriented market. For example, in the stock market, AI systems have almost replaced fund managers' positions, and with the help of AI, customers can make investments with ease. The construction industry is no exception. The IT industry is taking the initiative over the traditional construction industry. Katerra, a Los Angeles-based construction company, was funded by Softbank and was founded in 2015. The company's management staff consists of mostly IT professionals, not architects, and offers customized, customer-oriented services. The AEC industry seems to need to develop a platform that accommodates market changes. It's a time of day when customers can decide a lot about the building design by using their laptops, ASRs and VRs, without any help from experts.

## 5 Conclusion

Industry 4.0 has become self-evident not only in information, computing, and telecommunication communities (ICT) but also in manufacturing, even in construction industries recently. Although the AEC community is slower to apply state-of-the-art technologies than other industries, it has been trying to embrace them, and its efforts are paying off in many ways. In the data acquisition phase, Sensors, chips, and networks such as IoT, RFID, WSN, Drone, and 3D scanning collect the information faster, more precise, and cheaper than ever before without human interference. The collected big data are transferred to the partner in seconds through the 5G mobile network, enhancing a fast and appropriate decision making. The blockchain system secures the data acquired in a distributed, transparent manner. The Smart contract through blockchain accelerates getting rid of intermediary in the transactions, decreasing cost and time. AI system delivers decision making, substituting experts' role. The data processed by AI are offered to clients through ASR, VR, AR vividly. The combination and collaboration among these technologies enhance the transition of the AEC industry's data-driven processes.

Despite the advance of individual technology, it is stagnant to integrate state-of-the-art technologies for the AEC industry's project and procedures. Moreover, these new technologies have a disruptive characteristic that may move the center of the AEC industry to the IT industry. And in the process, many construction experts may lose their jobs. Thus, further studies of these issues are needed.

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