TRENDS IN CONSTRUCTION TECHNOLOGY – THE POTENTIAL IMPACT ON PROJECT MANAGEMENT AND CONSTRUCTION CLAIMS

A RESEARCH PERSPECTIVE
ISSUED BY THE
NAVIGANT CONSTRUCTION FORUM™

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Building on the lessons learned in construction dispute avoidance and resolution.™

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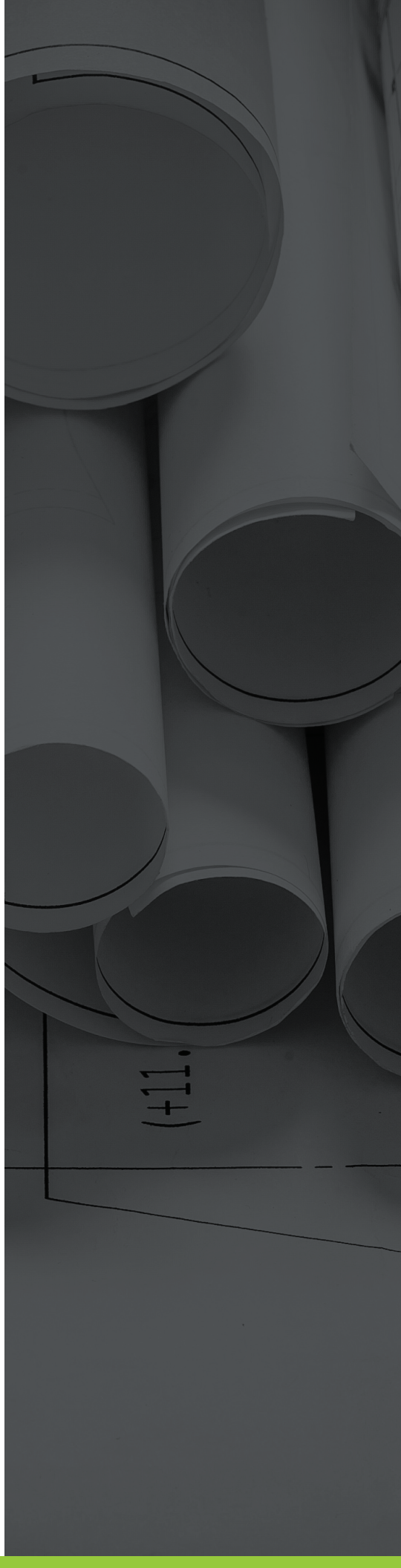

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PURPOSE OF RESEARCH PERSPECTIVE

The construction industry has long been singled out as an industry with declining productivity and a strong resistance to change.

"Innovation and cutting edge are not words frequently associated with the U.S. construction industry, at least not in comparison to industries like robotics or aerospace, but even more unfortunate is that the industry's poor image may be deserved. Data from federal agencies shows U.S. construction industry productivity has a long history of decline that continues today."[1]

1. "Construction Productivity in Decline," *Professional Engineer*, National Society of Professional Engineers, June 2014.

"Like all industries, the construction industry is seeing rapid advancements in technology, but unlike most industries, the construction industry has relied on age-old techniques for a very long time. Nobody likes change, but I think we all agree that our industry in particular is pretty resistant. Simply put, we're on the verge of something big. It's the kind of shake-up that has the potential to revolutionize the way that people perform their jobs on a daily basis."[2]

"Although the construction industry is well positioned for technological disruption, a mindset shift among practitioners remains the biggest challenge. In its survey, KPMG found that most construction firms are waiting for competitors to take the first step toward the adoption of technologies to streamline their workflows and improve their data collection – including integrated project management information systems, earned value management, remote monitoring, smart sensors, and robotics and automation."[3]

The purpose of this quarterly research perspective is to identify and explore ***some*** of the advances in construction technology in order to identify their potential impact on project management as well as construction claims management and dispute avoidance. Technology has transformed the world radically over the last few decades. Computers, the internet, the internet of things ("IoT"), solar and wind power generation, and much more have made substantive changes in our personal and professional lives as well as in the overall economy. Likewise, there have been a number of technology changes impacting construction, with even more on the way.

Navigant's Global Construction Practice recently identified 21 "early stage startups" that are working on technologies – both software and hardware – that are oriented at changing the construction industry insofar as how projects are planned, designed, and constructed. The Navigant Construction Forum™ was asked to research the topic of how technology is in the process of changing the construction industry. While performing this research the Navigant Construction Forum™ also examined how some of these technology changes have the potential to avoid or mitigate construction claims.

INTRODUCTION

Starting the research for this report, the author thought back on the changes observed over the last four decades the author has been involved in the construction industry. At a minimum they include the following:

- From paper drawings to Computer Aided Drawings ("CAD") to Building Information Modeling ("BIM")
- From handwritten to typewritten letters sent via the U.S. Postal Service to faxes to e-mail to text messages, Twitter, and other instant-messaging applications
- From hand-drafted construction schedules using the Arrow Diagramming Network ("ADM") to Primavera P6, version 16.2
- From mainframe computers to "luggables" to laptops to handheld computers
- From a large number of handwritten project logs to very sophisticated project management software systems
- From large files of payment applications, addenda, change orders, Requests for Information ("RFIs") or Clarifications ("RFCs"), and Shop Drawings / Submittals to online systems where all parties on the project can electronically access such documents in real time.

Other changes to construction industry technology encountered by the author include:

- The use of Radio Frequency Identification ("RFID") for tools, equipment, stored materials, etc.
- The use of Light Detection and Ranging ("LIDAR") devices to create 3D models, as-built drawings, etc.
- The use of Unmanned Aerial Vehicles ("UAVs") or Drones
- The use of Ground Penetrating Radar ("GPR") for the purposes of subsurface investigations
- 3D printing
- 4D scheduling
- Object detection technologies such as backup cameras and pulsed radar object detection
- Fatigue detection technology that monitors pupil size, blinking and how long eyes stay shut in order to detect fatigue
- Smart wearables that utilize RFID, sensors and biomonitors
- Grading technology such as GRADE with Assist to make excavators, bulldozers and motor graders more efficient, cut grading time, reduce excavation rework, and reduce the cost of staking and grade checking

2. http://www.isqft.com/start/blog-future-trends-construction-industry/
3. Hallie Busta, "Construction Dive – KPMG report: Construction industry slow to adopt new technology," Sept. 14, 2016 http://www.constructiondive.com/news/kpmg-report-construction-industry-slow-to-adopt-new-technology/426268/

These and many other changes to the technology associated with the construction industry have the potential to substantially change the way owners, designers, construction managers, contractors, and subcontractors perform their work. Once these technological changes are more widely adopted in the industry, it is believed that construction productivity will ***increase***, construction costs will ***decrease***, and site safety will ***improve*** substantially.

As noted in earlier research perspectives issued by the Navigant Construction Forum™, including the ***Delivering Dispute Free Projects*** series and ***A Crystal Ball – Early Warning Signs of Construction Claims & Disputes***[4] the Navigant Construction Forum™ has determined that there are five requirements necessary to deliver a successful project as shown below.

In addition to researching how such technological advances will impact projects and project management, the Navigant Construction Forum™ has also considered how many of these technology advances ***might*** contribute to the prevention or mitigation of construction claims and disputes, thus contributing to the ultimate goal for both owners and contractor – ***delivering successful projects.***

The Navigant Construction Forum™ took a high-level look at 14 advances in construction related technology in order to get a robust picture of the trend in construction technology. These 14 advances are presented in this research perspective in alphabetical order, ***not*** in order of significance or the potential impact on projects and claims. This research perspective describes and discusses each technology in a summary fashion and forecasts the potential impact of each on construction and project management. Additionally, the Navigant Construction Forum™ offers observations on how each technology ***may*** impact construction claims and disputes.

TRENDS IN CONSTRUCTION TECHNOLOGY

3D PRINTING

3D printing (also referred to as "additive manufacturing") is a construction process that fabricates three dimensional solid objects from a digital program file. The fabrication of a 3D printed object is accomplished by laying down layers of a specified material until the object is totally fabricated. Each layer of the material is a thin horizontal cross section of the fabricated object. By way of analogy, 3D printing is somewhat like glue laminated timber, also called "glulam," in that each thin layer laid down by a 3D printer bonds to the previous thin layer to fabricate an entire object. 3D printed objects can take on any shape. The fabricated objects are produced from a virtual design of the desired object. Virtual designs can be created by a CAD file using a 3D modeling application, a digital model, a 3D model or an Additive Manufacturing File ("AMF"). A 3D model may also be created by use of 3D scanners that generate a 3D model that feeds into 3D modeling software to create the needed 3D model.

Potential Impact on Construction, Project Management, and Claims Mitigation – Assuming that a project design is accurate and sufficiently complete, the Navigant Construction Forum™ anticipates that 3D printing ***should*** allow for pre-fabrication of various components needed to complete the constructed project. For example, in the early 2000s, Cornell University undertook a large student housing project (approximately $170 million). In an effort to save cost and time on this program, Cornell pursued the idea of "prefabricated" bathrooms for the new dormitories.[5] Although 3D printing did ***not*** exist at that time, commercially at least, such prefabricated components could ***reduce*** construction duration, ***increase*** construction quality and ***decrease*** the need for rework, thus saving time and cost for the contractor.[6] It is well recognized in some sectors of the construction industry that prefabrication and/or modularization of selected components offsite will aid in onsite productivity. 3D printing can help spread the concept of prefabrication for the benefit of projects and their stakeholders. However, it is also recognized that prefabrication and modularization will require more careful attention to procurement chains and processes than is now common on most construction sites.

4. See "Delivering Dispute Free Projects: Part I – Planning, Design & Bidding," Oct. 2013; "Delivering Dispute Free Projects: Part II – Construction & Claims Management," March 2014; "Delivering Dispute Free Projects: Part III – Alternative Dispute Resolution," June 2014; "A Crystal Ball – Early Warning Signs of Construction Claims & Disputes," June 2015, and "Delivering Dispute Free Projects – Does Partnering Help?" March 2016, Navigant Construction Forum™, Boulder, CO.
5. Barbara White Bryson and Canan Yetmen, *The Owner's Dilemma: Driving Success and Innovation in the Design and Construction Industry*, Greenway Communications, Atlanta, GA, 2010.
6. Nigel Hughes, Jason M. Dougherty, and James G. Zack, Jr., "The Impact of Rework on Construction & Some Practical Remedies," Navigant Construction Forum™, Boulder, CO, 2012.

Another example of how of how 3D printing ***may*** also impact productivity onsite was highlighted by the American Association of Mechanical Engineers ("ASME"). An industrial-scale robot working in conjunction with a 3D printer was able to fabricate and lay bricks approximately four times ***faster*** than a human bricklayer.

"The robot arm rapidly and precisely builds the entire outer shell of a small house, laying about 225 bricks per hour. To compare, a human bricklayer lays about the same amount of bricks in half a work day."[7]

As 3D printers become more common in the construction industry the impact ***may*** help decrease productivity loss and delay claims as prefabrication and increased productivity of onsite work should result. Additionally, 3D printing should also help ***decrease*** the need for rework on projects that, in turn, should ***reduce*** costs and delays.

4D BIM

4D BIM is a term widely used in the CAD industry. The term refers to "an intelligent linking of individual CAD components or assemblies with time or schedule related information."[8] As such, the term 4D BIM refers to the "fourth dimension" – time. Thus, 4D BIM is 3D BIM plus the schedule. The idea of 4D BIM or 4D scheduling is somewhat akin to a time machine. The concept is to allow project participants to visualize all schedule activities and events in advance of when these activities or events are underway. Being able to visualize both the design as well at the construction plan well in advance of actual construction should help superintendents, foremen, and craft labor see what it is they are to construct, in what order, and allow them to gain confidence in the plan. Further, seeing the project being built visually should allow project participants to foresee and avoid problems such as having multiple trades working in the same small space at the same time – something that is difficult to spot when reviewing a typical critical path method ("CPM") schedule. As one of the author's previous senior managers used to frequently comment, "Bad news delivered early is useful information. Bad news delivered late is a disaster." In the context of 4D scheduling, if the visualized model shows conflicts or pinch points in the construction plan and these are discovered early in the process, the plan can be modified to avoid such problems before such issues actually impact work in the field.

Potential Impact on Construction, Project Management, and Claims Mitigation – A recent article in a well known construction industry publication discussed 4D BIM in the context of 4D scheduling. Some of the comments in this article highlight the impact of 4D scheduling on both construction and project management as follows.

"4D visualization is a dress rehearsal for the foremen, and catching [conflicts] weeks ahead of time means you can be that much more efficient when the labor and the foremen are on the jobsite. It's the human equivalent of clash detection. … The process of animating the model from the schedule forces an attention to detail that is often missing from schedule reviews. … 4D visualization … supports lean principles and pays huge dividends in safety, efficiency and quality. … As the team reviews the 4D model they believe that the work can be done as the schedule and model show. … We are going to see some major efficiency gains."[9]

The Navigant Construction Forum™ believes that as 4D BIM and 4D scheduling become more prevalent in the construction industry, the ability to spot conflicts built into the baseline schedule should be identified much earlier than is now common during traditional schedule reviews. Quick reaction rescheduling and workarounds should become much ***less*** common, thus saving time and money on the site. Additionally, productivity in the field should ***increase***; delays due to schedule conflicts and interferences should ***decrease***; and the result should be a ***decrease*** in productivity loss and delay claims.

AUGMENTED REALITY

Augmented Reality ("AR") is a view of the real world environment that has been augmented or supplemented by computer generated input such as graphics or video. The concept behind AR is to enhance the user's perception of reality.[10] AR is ***not*** new, having been employed in military, industrial, medical, commercial, and entertainment arenas for years.[11] The most common use of AR today is, probably, in the videogame arena. However, with respect to the construction industry, AR can assist in the planning and design process in that AR can help in visualizing building projects.

"Computer generated images of a structure can be superimposed into a real life local view of a property before the physical building is constructed there; … AR can also be employed within an architect's work space, rendering into their view animated 3D visualizations of their 2D drawings.

7. http://www.3ders.org/articles/20160728-this-brick-laying-3d-printer-robot-can-build-a-house-four-times-faster-than-a-human-bricklayer.html, July 29, 2016.
8. Fred Mills, "What Is 4D BIM?" www.TheBIM.com, The BIM Limited.
9. "Seeing is Believing – Interest Heats Up for Risk Reducing Tools that Marry Highly Detailed Schedules to Design and Construction Models," *Engineering New-Record*, May 30/June 6, 2016.

Architecture sightseeing can be enhanced with AR applications allowing users viewing a building's exterior to virtually see through its walls, viewing its interior objects and layout."[12]

During construction, AR has also shown itself to be extremely useful.

"With the continual improvements to GPS accuracy, businesses are able to use augmented reality to visualize georeferenced models of construction sites, underground structures, cables and pipes using mobile devices. Augmented reality is applied to present new projects, to solve on site construction challenges."[13]

Using AR and 3D BIM models, designers, construction managers, and contractors "can view a complex structure as if it were a 3D model placed on a table, or zoom in for a 1:1 view that simulates what it would be like to move through its structural framework."[14]

Potential Impact on Construction, Project Management, and Claims Mitigation – When fully implemented on a project, AR can aid project participants in visualizing the complex details of the project in much more detail than 2D drawings or even 3D BIM models. The Navigant Construction Forum™ believes that the use of AR may help avoid encounters with differing site conditions and spot design defects and errors before they are encountered in the field, thus avoiding changes and reducing delays attendant to such situations.

AUTONOMOUS CONSTRUCTION

The term "autonomous construction" today generally refers to construction equipment that is navigated, maneuvered, and operated by a computer, without the need for human control or interventions under ordinary, planned conditions at the site. There are three levels of autonomous construction currently being worked on by equipment manufacturers and construction contractors.

*"With **automation**, a function of the machine is operated by independent means. For instance, while a dozer itself retains an operator, the blade is controlled by preprogrammed data.*

*With **semi-autonomy**, equipment and other site operations are controlled remotely from a nearby office or even an offsite location.*

*With **autonomy**, equipment essentially operates on its own, thanks to sophisticated technologies that enable machines to work safely with minimal inputs."*[15]

A review of current literature shows that fully autonomous construction equipment is **not** yet common on the vast majority of construction sites. However, fully autonomous equipment is currently in operation on some large mining sites. Autonomous mining truck fleets are operating at some iron ore mines in West Australia and autonomous large bulldozers are being employed at mining sites in Wyoming. Semi-autonomous underground loaders are likewise being employed in mines in Nevada. As the mining industry works out issues with autonomous and semi-autonomous equipment, and as the cost of such equipment falls, the use of such equipment will become more common.

Potential Impact on Construction, Project Management, and Claims Mitigation – The use of autonomous and semi-autonomous equipment on construction sites should result in huge improvements to job site productivity and an increase in site safety. Should this come about, the Navigant Construction Forum™ anticipates a ***reduction*** in lost productivity and delay claims.

BIM and VDC

BIM and Virtual Design and Construction ("VDC") are becoming more common in the construction industry – perhaps more on vertical and technically complex projects than on horizontal and less complex projects. BIM is a process – ***not*** an end point or a product such as the completion of paper-based 2D drawings.

"A Building Information Model (BIM) is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM process to support and reflect the roles of that stakeholder. The BIM is a shared digital representation founded on open standards for interoperability."[16]

10. Mark Graham, Matthew Zook, and Andrew Boulton, "Augmented Reality in Urban Places: Contested Content and Duplicity of Code," *Transactions of the Institute of British Geographers*, 2012.
11. "Augmented Reality Landscape," http://augmentedrealitybiz.com/augmented-reality-landscape/ August, 2012.
12. Devina Divecha, "Augmented Reality (AR) used in architecture and design," http://www.designmena.com/inspiration/augmented-reality-ar-part-architecture-design, *designMENA*, Sept. 8, 2011.
13. Jason Churcher, "Internal accuracy vs external accuracy," http://www.augview.net/News/Blog/archive-7May2013.html May 7, 2013. See also, "Augmented Reality for Architecture & Construction," http://www.augment.com/augmented-reality-architecture/
14. Greg Aragon, "AECOM and Trimble Use Mixed-Reality Technology for Engineering and Construction," http://www.enr.com/blogs/12-california-views/post/39681/, June 24, 2016.
15. Mike Anderson, "Being Automatic, Autonomous ... Or Somewhere In Between," *Engineering News-Record*, July 25/Aug. 1, 2016.
16. Jason M. Dougherty, *Claims, Disputes and Litigation Involving BIM*, Routledge, New York, 2015.

VDC has been described as follows:

"Virtual Design and Construction (VDC) is the management of integrated multi disciplinary performance models of design and construction projects, including the product (i.e., facilities), work processes and organization of the design, construction, and operation team in order to support explicit and public business objectives.

The theoretical basis of VDC includes:

- Engineering modeling methods: product, organization, process
- Analysis methods: Model-based design, including quantities, schedule, cost, 4D interactions, and process – these are termed Building Information Modeling (BIM) tools
- Visualization methods"[17]

In the simplest terms, BIM is the computer model of the project available to all project participants for their information, their input, and/or extraction of information throughout the life of the project, while VDC is the electronic version of the plan for construction of the project.

Dodge Data and Analytics recently performed a survey of larger (i.e., US$50 million or more in annual construction value) general contractors, construction managers, and trade contractors to determine how these firms engage with BIM. The following table shows a comparison of how general contractors and trade contractors use BIM.[18]

Construction Modeling Activity on Projects as Reported by General Contractors and Trade Contractors

BIM USES	GENERAL CONTRACTORS	TRADE CONTRACTORS
Crew Locations and Workforce Planning	14%	57%
Temporary Works	24%	45%
Construction Work Packaging	16%	38%
Safety Rule Packaging	8%	18%

Despite the different uses of BIM by general contractors and trade contractors, this survey indicated overall agreement that BIM produces the following results, all of which benefit projects using BIM:

- Decrease in RFIs and RFCs
- Better construction documents
- Reduction in material waste
- Reduction in scheduling cost
- Reduction in final construction cost
- Reduction in reportable safety incidents
- Improved information mobility
- Improved collaboration on the project
- Reduction in unanticipated problems
- Fewer paper documents
- Improved productivity

17. John Kunz and Martin Fischer, "Virtual Design and Construction: Themes, Case Studies and Implementation Suggestions," Stanford University Center for Integrated Facility Engineering (CIFE) Working Paper #097, Version 14, January 2012.
18. Steve Jones and Donna Laquidara-Carr, "New Survey Reveals How GCs, CMs and Subs Engage in BIM," *Engineering News-Record*, CBQ 16 ENR Contractor Business Quarterly, Summer 2016.

It is noted, however, that BIM and VDC are being employed primarily by larger firms and owners in the industry, as the cost and the difficulties of implementing BIM and VDC are high hurdles for medium and small sized design and construction firms to overcome. Additionally, there are myriad other challenges associated with the use of BIM in the design and construction processes that are also difficult to overcome.[19] However, BIM is being required by many owners and as this preference grows from the owner's side of the equation, the cost and the current challenges of using BIM on projects should decrease, thus allowing smaller firms to use this project delivery method.

Potential Impact on Construction, Project Management, and Claims Mitigation – As the use of BIM becomes more widespread, the Navigant Construction Forum™ believes that project management will become ***more*** proactive and ***less*** reactive as problems should be identified earlier and resolved more easily. As a result, the number of changes, delays, and claims should be ***reduced***, for the benefit of all project participants.

DIGITAL FUTURE

McKinsey & Company published a report in June 2016 that addressed a potential digital future specifically for the construction industry.[20] The term "digital future" covers a huge array of technology changes, all of which seemingly will have positive impacts on the industry. This report notes that "large projects" in the mining, infrastructure, and oil and gas sectors typically take 20% longer than initially scheduled and are up to 80% over budget. The McKinsey study compares somewhat favorably with the SmartMarket Report issued by the Navigant Construction Forum™ in December 2011, which concluded the following.[21]

Impact of Risks on Large Infrastructure Projects

IMPACTS	% OF RESPONDENTS EXPERIENCING IMPACT	AVERAGE % OF PROJECTS IMPACTED	AVERAGE IMPACT
Delayed Completion	84%	24%	17%
Over Budget	86%	19%	14%
Disputes and Claims	76%	11%	$3.1 million

The McKinsey study started by taking a broad brush to paint a fairly dismal picture of the construction industry with respect to productivity, mainly due to a lack of adoption of technology innovations.

"While the construction sector has been slow to adopt process and technology innovations, there is also a continuing challenge when it comes to fixing the basics. Project planning, for example, remains uncoordinated between the office and the field and is often done on paper. Contracts do not include incentives for risk sharing and innovation; performance management is inadequate, and supply chain practices are still unsophisticated. The industry has not yet embraced new digital technologies that need up front investment, even if the long term benefits are significant. R&D spending in construction runs well behind that of other industries: less than 1 percent of revenues, versus 3.5 to 4.5 percent for the auto and aerospace sectors. This is also true for spending on information technology, which accounts for less than 1 percent of revenues for construction, even though a number of new software solutions have been developed for the industry."

This report goes on to summarize a number of digital technologies that are currently available in the marketplace or close to becoming available, but which are **not** yet widely used in the construction industry. A synopsis of these digital technologies follows:

- **Higher definition surveying and geolocation** – Under this heading the report lists electronic distance measurement; more accurate Global Positioning System ("GPS") and Geographic Information System ("GIS") applications; high resolution photogrammetry; LIDAR; improved GPR and magnetometers used with LIDAR; and high resolution cameras small and light enough to be mounted on drones. Technologies such as these can develop both above ground and underground 3D images of project sites and can be uploaded to other analytical and visualization systems for use in project planning and construction.

19. Christopher L. Nutter, "Common Challenges Associated With Design and Construction Delivering Using Building Information Modeling," *Insight From Hindsight*, Issue No. 18, Navigant Construction Forum™, Boulder, CO, May 2016.
20. Rajat Agarwal, Mukund Sridhar and Shankar Chandrasekaran, "Imagining Construction's Digital Future," McKinsey & Company, June 2016.
21. McGraw Hill Construction, Navigant Consulting and Pepper Hamilton, *Mitigation of Risk in Construction: Strategies for Reducing Risk and Maximizing Profitability*, McGraw Hill, New York, December, 2011.

- **Next generation 5D building information modeling** – 5D BIM is a five-dimensional representation of the physical and functional characteristics of a project. This system considers both the cost and schedule of a project, as well as such other characteristics as geometry, specifications, aesthetics, thermal, and acoustic properties. The system allows owners and contractors to record the impact of changes to project cost and schedule. Additionally, 5D BIM gives project participants the ability to identify risks earlier, thus reducing "surprises" on project sites.
- **Digital collaboration and mobility** – Process digitization means moving away from paper and toward online, real time sharing of information to assist with project collaboration, timely progress tracking, risk assessment, quality control, and, it is anticipated, better and more reliable project outcomes. Replacing paper processes with digitization should enhance and speed up information sharing and make information sharing more accurate. Digitization of project information is intended to improve:
  - Design management
  - Project scheduling
  - Materials management
  - Crew tracking
  - Quality control
  - Contract management
  - Performance management
  - Document management
- **The internet of things and advanced analytics** – Construction project sites are complex by their very nature, are often very dense with labor, equipment, materials, subcontractors, vendors, etc., and projects generate large amounts of data, much of which is ***not*** captured and retained, ***nor*** even measured and processed. IOT is already available and in commercial use. Electronic sensors and wireless technology are available that could make equipment and other project assets "intelligent." This technological advance combined with the use of near field communication ("NFC") devices and RFID tags can help monitor productivity and reliability of both staff and assets in the following areas:
  - Equipment monitoring and repair
  - Inventory management and ordering
  - Quality assessment
  - Energy efficiency
  - Safety

Potential Impact on Construction, Project Management, and Claims Mitigation – The Navigant Construction Forum™ anticipates that increased use of new digital technologies will improve the accuracy, reliability, and speed of project communications, which is likely to ***decrease*** changes and delay claims. New digital technologies ***may*** help reduce encounters with unknown underground conditions, thus ***decreasing*** the likelihood of differing site conditions. Other technological advances should help improve onsite equipment maintenance and improve material procurement that in turn helps ***decrease*** the amount of project delay.

DRONES IN CONSTRUCTION

One of the most visible and frequently mentioned changes in construction is the use of UAVs – more commonly known as "drones." The construction "industry is finding a multitude of benefits from aerial photography and the collection of data with laser, infrared and other sensors than can be used to produce 3D maps for earthwork calculations, thermal imaging for inspection, and point clouds for BIM models."[22] This survey found that contractors are already using UAVs for:

- Tracking job progress
- Logistics and production planning
- Inspection of areas difficult or impossible to access
- Safety monitoring and support
- Land surveying, thermal imaging, laser scanning, and other data collection

The chief executive officer of a drone manufacturer was recently interviewed and offered the following observations concerning the use of drones in the construction industry.

"A large development site, like a highway or an apartment complex, needs to be meticulously mapped by a team of surveyors. Depending on the project, this can take weeks or even months. But a drone that is operating on highly sophisticated software and that has state of the art cameras onboard can do even the most complex job in a fraction of the time, sometimes in minutes … Aerial mapping is a huge cost saver. But it is also a tool that propels construction into the future by giving developers information they previously had no access to. … Knowledge is power. Knowing what needs to be done, and precisely how it needs to be done. It is something that every project manager dreams about. Getting rid of the guesswork brings a construction project into the 21st century, something that is long overdue."[23]

Another recent article highlighted the potential cost savings resulting from the use of drones on a construction project in the following manner.

"When it comes to paving roads, mistakenly adding a quarter inch of extra material over 10 miles can boost the final bill by a quarter million dollars. To avoid such mistakes, managers are increasingly seeking to improve the overall precision and accuracy of construction projects with automatic machine guidance ("AMG"). AMG links construction equipment with onboard computers that use data from 3D models and GPS to guide operations – saving time and money as well as improving safety and quality."[24]

This particular article explains how drones are currently carrying and using RGB cameras.[25] However, the article notes that the drone is capable of carrying small LIDAR sensors also. Unlike many other drones that are manually operated by someone on the ground with a radio-control device, drones such as the one discussed in this article navigate by use of GPS Real Time Kinetic ("RTK") technology and are designed to be controlled by a robotic total station.

22. ConstructionPro Network, "Drones in Construction – 2015 Survey Report," ConstructionProNet.com, WPL Publishing Co., Inc., Rockville, MD, 2016.
23. Joe A. Kunzler, "Drones Have Brought the Construction Industry Into the Future," TECH.CO, http://tech.co/drones-construction-future-2016-9, Sept. 6, 2016.
24. Charles Choi, "Drone Surveys Improve Automated Road Construction", http://insideunmannedsystems.com/drone-surveys-improve-automated-road-construction/, Nov. 7, 2016.
25. An RGB camera delivers the three basic color components (red, green, and blue) on three different wires. This type of camera often uses three independent CCD sensors to acquire the three color signals. RGB cameras are used for very accurate color image acquisitions. A charge coupled device ("CCD") is a device for the movement of an electrical charge, usually from within the device to an area where the charge can be manipulated, for example conversion into a digital value. This is achieved by "shifting" the signals between stages within the device one at a time.

The biggest holdup to the widespread use of drones has been, until quite recently, the lack of Federal Aviation Administration ("FAA") rules and regulations resolving the legal status of operating drones commercially. This issue has been resolved in the main by the issuance of FAA rules concerning the use of commercial unmanned aircraft systems ("UAS") or drones on June 21, 2016. These rules outline the following:

- The weight of commercial drones allowed (55 pounds)
- The maximum height at which drones can be flown (up to 400 feet)
- The maximum speed drones can be flown at (up to 100 miles/hour)
- Requires the use of anti-collision lights on drones after twilight
- Requires that drones can only be flown within the line of sight of the operator
- Sets the minimum age of drone operators (must be at least 16 years old)
- Requires that all operators obtain Remote Pilot Airman Certification from the FAA that requires passing a written aeronautical test and undergoing a background security check

These FAA rules have a large amount of additional discussion, information, and detailed requirements, as this Final Rule is 624 pages long.[26] FAA has announced that they will be looking at issuing further rules for larger drones but these additional rules have ***not*** yet been set forth. However, Secretary of Transportation Anthony Foxx appears to recognize the value of drones for use in inspecting utility towers, antennas, bridges, power lines and pipelines in mountainous areas. When these new rules were issued earlier this year, Foxx was quoted, in the previously cited article, as saying:

"This is a major milestone for safely integrating unmanned aircraft systems into our nation's airspace. … These aircraft truly have the potential to transform the way we fly and they offer many potential benefits to society … in many cases, unmanned aircraft can perform these activities with much less risk than a manned aircraft that might have to fly into dangerous terrain or in bad weather."

Drones, combined with artificial intelligence, are also being looked at as a major way to improve productivity on construction sites. A recent news article from the Japan Economic Newswire reported the following:

"The [Japanese] government unveiled plans … to raise productivity at construction sites by 20 percent from current levels by 2025 through the use of drones and artificial intelligence in the construction industry … Prime Minister Shinzo Abe vowed to wipe out the image of construction work as being dangerous, dirty and demanding, and 'drastically' change the working environment. The [Japanese] government envisions using drones to carry out surveying at sites of public works such as tunnels, bridges and dams. The use of artificial intelligence is aimed at dramatically reducing the time required to carry out land surveys."[27]

One takeaway concerning the use of drones was highlighted in a recent issue of Engineering News-Record.[28] This article posed six questions that contractors should address before they begin using drones on their sites. The questions are the following:

- Have you applied for and received your FAA approval?
- Have you developed a plan on exactly how you intend to use drones or UAVs, including risk management and safety procedures?
- Have your operators passed the aeronautics test required for them to serve as a pilot?
- Are you aware of the surroundings the drones will be operating in?
- Have you considered the insurance implications for using UAVs or drones in your business?
- Have you considered the reputational risk your firm could face if your drone/UAV was found operating too close to others' property, especially if you accidentally (or intentionally, due to a rogue operator) film something that others didn't want taped and it was released to the public?

Potential Impact on Construction, Project Management, and Claims Mitigation – The Navigant Construction Forum™ believes that the use of drones can improve project management in a number of ways – surveying and mapping; creating 3D maps for earthwork calculations; inspection purposes; providing detailed, accurate information for BIM models; tracking job progress; aiding in logistics and production planning; safety monitoring; thermal imaging; laser scanning; and controlling equipment operations. Some have speculated that drones, at some point in the future, ***may*** even be used to deliver materials to construction sites. However, the Navigant Construction Forum™ was unable to locate information indicating that any construction company currently using drones is pursuing this potential use. Perhaps, once the FAA issues new rules on larger drones, this potential use will be realized. Considering the

26. Office of the Secretary of Transportation, U.S. Department of Transportation, Federal Aviation Administration, 14 CFR Parts 21, 43, 61, 91, 101, 107, 119, 133, and 183, June 20, 2016.
27. Kyodo, "Government Eyes Raising Construction Site Productivity with Use of Drones," ENR Digital Wire http://www.enr.com/external_headlines/story?region=enr&story_id=u4pRrjFtCvID9HNews, Sept. 21, 2016.
28. Tom Boudreau, "Six Questions to Ask Your Construction Clients Before They Begin Using Drones," Engineering News-Record, Oct. 31, 2016.

information located concerning the use of drones in construction by the Navigant Construction Forum™ in preparing this research perspective, the Forum has concluded that drones may be very successful in reducing claims and disputes. The ability to deliver real time information on project progress and more accurate data for use in surveying, inspections, safety monitoring, etc., should ***decrease*** errors and omissions in drawings, changes or constructive changes during the performance of the work, etc. Finally, the Navigant Construction Forum™ acknowledges that there is some degree of risk accompanying the use of drones that contractors must be aware of and be prepared to deal with.

GEOSPATIAL TECHNOLOGY

Much has been written about the use of BIM in design, construction, and operations and maintenance. However, it is noted that:

"When one designs a building, typically one never designs specific to the actual location where it would be built. There's a virtual reference point and everything in the design is relative to that reference point. It is only now there has been the need to fix this piece of infrastructure to a 'location' on the planet as people want to perform. Structures can no longer be designed in isolation; sustainability requires that buildings and other structures be designed in the context of their geolocation. This is driving the convergence of geospatial and 3D technologies."[29]

So what exactly is "geospatial technology"? One of the earliest articles the Navigant Construction Forum™ could locate on this topic defined the term in the following manner:

"Geospatial technology refers to equipment used in visualization, measurement, and analysis of earth's features, typically involving such systems as GPS (global positioning systems), GIS (geographical information systems), and RS (remote sensing). Its use is well known and widespread in the military and in homeland security, but its influence is pervasive everywhere, even in areas with a lower public profile, such as land use, flood plain mapping and environmental protection."[30]

In its simplest terms, harnessing geospatial technology to BIM provides more detailed and accurate information to the project participants through the planning, design, and construction process. As a result, BIM plus geospatial technology improves collaboration among the project participants by enabling better communication with the project owner through accurate 3D visualization of the proposed design.

The geospatial technology process for a project has multiple steps that have been described in the report entitled "Geospatial + Building Information Modelling: Enhancing Productivity, Efficient, Compliances and Mechanisation for the Construction Industry," and are outlined briefly below:

- GIS inventory of all existing geospatial data of the proposed site and surrounding area
- Satellite remote sensing to create satellite images
- Total station to measure horizontal distances, slope distances, angles, vertical height differences, three dimensional coordinates and other positional features
- GPR to geolocate underground infrastructure
- Photogrammetry to project objects on the terrain (the project site and surrounding area)
- Laser scanning and LIDAR for reality capture at the outset of the project and during construction
- Scan to BIM to incorporate all data into the BIM model
- Point cloud data, 3D modeling and visualization during the design phase;
- Machine control and automation using the global navigation satellite system ("GNSS") positioning technology and digital design files to steer construction equipment and communicate with other equipment on site
- Positioning systems to aid in asset and material management for the project (e.g., to track the location of a dump truck and plan efficient routes for the truck's tasks)

To make all of the above happen requires compatibility and complementary standards. Quite recently, the International Organization for Standardization ("ISO"), BuildingSMART and the Open Geospatial Consortium ("OGC") developed a compatible BIM/Geospatial standard entitled the OGC LandInfra Conceptual Model. Now that the value proposition of connecting geospatial technology and BIM is known and there is a recognized standard to provide for this interconnection, what is holding up the adoption of this technology in the construction industry? The answer appears to be the following:

"The three biggest hurdles in the adoption of geospatial are the lack of expertise … resistance to change … and cost."[31]

29. "Geospatial + Building Information Modelling: Enhancing Productivity, Efficient, Compliances and Mechanisation for the Construction Industry," Geospatial Media + Communications, www.geospatialmedia.net, 2015.
30. Marlene Cimons, "Geospatial Technology as a Core Tool: Impacts Everything from Navigating to Law Enforcement," www.usnews.com, May 11, 2011.
31. Luke Abaffy, "Trends of Building Information Modeling and Geospatial Use in Construction," Engineering News-Record, http://www.enr.com/articles/39980-trends-and-prospects-for-geospatial-and-building-information-modeling Aug. 3, 2016.

Potential Impact on Construction, Project Management, and Claims Mitigation – The Navigant Construction Forum™ believes that as these three hurdles are overcome in the construction industry the use of geospatial technology will expand. Once this occurs, project managers will have access to accurate, real time data and information, making their jobs easier. Likewise, communications on the project will improve given the enhancement of project data that will likely result in a decrease in claims and disputes such as differing site conditions, changes, delays, etc.

RADIO FREQUENCY IDENTIFICATION TECHNOLOGY

RFID is ***not*** new technology but appears to be spreading more widely across the construction industry. RFID technology has demonstrated its value in the following areas on construction sites.

- Logistics and supply chain visibility
- Inventory tracking
- Personnel tracking and timekeeping
- Materials management
- Access control
- Asset and equipment tracking
- Tool tracking
- Real time location systems ("RTLS")

Such uses can help increase site productivity by making it easier to locate stored materials in the laydown area and track where tools and equipment are stored.

Potential Impact on Construction, Project Management, and Claims Mitigation – The Navigant Construction Forum™ believes that any technology that helps ***increase*** labor productivity is good for projects and will likely ***decrease*** productivity loss claims.

REALITY CAPTURE TECHNOLOGY

Very basically, "reality capture" is the use of various technical tools to capture a 3D model representation of a real world object. More technically:

"Where traditional 3D modeling techniques are slow and only as accurate as the artist or designer makes them, reality capture can capture detailed, accurate digital representations in minutes. Reality capture can be achieved by techniques such as LIDAR, where lasers take detailed scans of a subject, taking measurements and creating point cloud data in an xyz axis. This point data is reconstructed into a 3D model. While accurate, LIDAR only captures 3D data leaving color out. Photogrammetry is another method by which reality capture is achieved. This type of reality capture uses photographs to reconstruct a 3D image. While this method can require multiple photos to complete a model (typically with a minimum of 2), it can also capture the colors of the subject, translating them into the texture map of the model to further save time in creating assets … Photogrammetry can also be used to recreate motion paths of subjects. Even 3D cameras … can be used for reality capture."[32]

Reality capture can save laborious modeling of background assets. Reality capture is fast and convenient and can reduce the need for human effort. A case study concerning reality capture was highlighted in a recent article concerning a brownfield redevelopment planning project.

"In Coatesville, Pa., a depressed, rust-belt town about 40 miles west of Philadelphia with a population of 13,100, the city manager and the town's consulting engineers are using 3D reality capture to help prospective developers see a diamond in the rough. … In just a few minutes, a drone captured more than 750 aerial photos of 'The Flats,' a rugged, 30-acre former steel-mill site. The … software processed the drone's photos, combining them with old survey data and other photos to create a detailed model of the site —all without anyone having to set foot on it. The model includes a significant amount of stockpiled clean fill, which is a sweetener for any redevelopment deal."[33]

Potential Impact on Construction, Project Management, and Claims Mitigation – The Navigant Construction Forum™ believes that the expanded use of reality capture will help provide much more accurate information on project sites and their surroundings for use by all project participants. From the construction claims perspective, such a development will likely help reduce site condition and constructive change claims.

ROBOTICS

Robotics in construction, until recently, has been a matter of speculation despite the common use of robotics in manufacturing and other areas of life. The term "robotics" is defined as:

"Robotics is a branch of engineering that involves the conception, design, manufacture, and operation of robots. This field overlaps with electronics, computer science, artificial intelligence, mechatronics, nanotechnology and bioengineering." [34]

32. Margaret Rouse, "Reality Capture," *Software Development Glossary*, http://whatis.techtarget.com/definition/reality-capture, Oct. 2016.
33. Tom Sawyer, "Scheming and Dreaming with Reality-Capture Technology," *Engineering News-Record*, July 25/Aug. 1, 2016.
34. Margaret Rouse, "Robotics," http://whatis.techtarget.com/definition/robotics, Oct. 2015.

The Massachusetts Port Authority ("Massport") sponsored a research report concerning robotics in construction. In the introduction to the final report, the authors included the following statement.

"This study explores how robotics is being used, and could be used in the future, in the field of construction. Robotics as a whole is a synchronous combination of mechanical, electrical, and software engineering. It is a field that aims to better the lives of humans in tasks that are dangerous, dirty, or demanding. Construction is the process of creating or renovating a building or an infrastructure facility. Due to the evolving field of robotics, the goal of this project is to find out how robotics can be implemented into construction tasks and to identify as many robotics technologies as possible that can have some application in construction, while also determining if any of these potential technologies can be integrated in the near future. This could potentially facilitate many construction processes to make them safer for workers, take up less time, or even to perform simple tedious tasks."[35]

The report noted the following.

"The rate at which construction progresses is subject to variability. Productivity depends on many variables including the weather and worker productivity which depends on factors such as overtime, morale and attitude, fatigue, stacking of trades, mobilizing and demobilizing, general errors, reassignment of manpower, crew size inefficiency, hazardous work areas, and the list goes on … a common underlying factor to this variability is natural human imperfection."[36]

This research report went on to identify a number of ways robotics can be used in construction – some already in use, limited though they may be, and some still in a developmental phase. The report discussed the following:

- **Demolition Robots** – Robots used to tear down walls, buildings, etc. There are three types of demolition robots: multitooled, hydropowered and ecofriendly. All three types perform the same function but in different ways.
- **Printing and Contour Crafting Robots** – These are robots that are used in conjunction with 3D printing.
- **Drones** – Although previously discussed in this research perspective, it is worth noting that drones ***may*** be truly unmanned, flying robots. This category includes contour crafting robots, swarms of drones, transportation drones, surveying drones, and monitoring drones.
- **Bricklaying Robots** – As the name states, these are robots that assemble the masonry structure of a building.
- **Welding Robots** – Again, the name is self-explanatory. These are robots designed and programmed to perform welding functions on a site.
- **Exoskeletons**[37] – This refers to "robotic exoskeleton suits working with humans to enhance a task or ability the human body lacks. Intelligent suits are meant to increase the strength of the average user, endurance, speed, agility, etc." Such suits allow for injured or disabled workers to work in construction or allow workers to lift and transport heavier objects than normal.
- **Forklift Robots** – Such robots are used to transport heavy or large objects on project sites.
- **Roadwork Robots** – These are robots used to repave and/or restripe roadways.
- **Humanoid Robots** – These robots are still in the conceptual and developmental stage and may be years away from practical day to day use on construction sites. When (if) perfected, humanoid robots conceivably will be able to perform ***any*** task that a human can perform on the site.

Another article added an additional function ***not*** named above – ***robotic security guards***. These robots are also in the developmental stage. As conceived, these robots will use sensors, predictive analytics, and thermal imaging to hear, feel, smell, and send reports back to a control center.

An ongoing, practical example of the use of robotics in construction was featured in a 2014 article concerning the construction of the Tappan Zee Bridge project in New York. The article discussed the issue in the following manner.

"With qualified welders in short supply on the $3.9 billion Tappan Zee Bridge north of New York City, contractors have brought in robots from Louisiana … The robotic welders … are needed to speed installation of the bridge's giant piles, which measure up to 8 ft. in diameter … About 25 machines have been supplied to the bridge project … with each requiring a four person crew to operate. … While robots can work up to twice as fast as workers with fewer defects, the machines required human intervention to prevent problems in the welding process, with a mixed success rate."[38]

35. Alexander Ruggiero, Sebastian Salvo and Chase St. Laurent, *Robotics in Construction*, Worcester Polytechnic Institute, March 24, 2016.
36. Ruggiero, Salvo and St. Laurent, *Robotics in Construction*.
37. "Exoskeletons" are defined as rigid external coverings for the body in some invertebrate animals, especially arthropods, providing both support and protection.
38. Nicholas Zeman, "'Robot' Welders As Labor Boost on Tappan Zee Bridge Piles Spur Controversy," *Engineering News-Record*, June 17, 2014.

Potential Impact on Construction, Project Management, and Claims Mitigation – Assuming that robotics continue to advance and are adopted more widely in the construction industry, it appears likely that robotics will improve site productivity and site safety – as robots ***may*** be able to perform work that is more likely to cause accidents. As productivity ***increases***, claims concerning productivity loss and resulting delay should ***decrease***.

SITE SAFETY

Construction site safety and accident prevention are of concern to contractors, subcontractors, owners, designers, and construction managers. Contractors are especially sensitive to these issues, as they are, as a group, potentially liable under the Occupational Safety and Health Act ("OSHA"), and the resulting increase to the cost of their workers' compensation and, perhaps, other insurance policies, etc. A recent article highlighted the top 10 causes and the cost of workplace injuries. The annual net total cost of these top 10 causes is $51.06 billion or $1.0 billion per week. A summary of these top 10 causes and their costs are set forth below.

Top 10 Causes and Costs of Workplace Injuries[39]

CAUSES	COST (IN US BILLIONS)
Overexertion	$15.08
Falls on Same Level	$10.17
Falls to Lower Level(s)	$5.40
Struck by Object or Equipment	$5.31
Other Exertions or Bodily Reactions	$4.15
Roadway Incidents Involving Motorized Land Vehicle	$2.96
Slip or Trip Without Fall	$2.35
Caught in/Compressed by Equipment or Objects	$1.97
Struck Against Object or Equipment	$1.85
Repetitive Motions Involving Micro Tasks	$1.82

Workplace injuries are painful, and sometimes devastating, for employees, their families, and their employers. Contractors work hard to reduce accident rates, including forming safety committees; holding routine toolbox safety meetings onsite; investing in safety equipment; providing ongoing safety training; conducting site safety assessments; and employing safety engineers/inspectors onsite.

Technology has advanced to the point where ***predictive analytics*** can be used that takes into account a variety of work related factors to anticipate future behavior. One example of this technology is Vantage Predictive Analytics, which is advertised as a Software as a Service ("SaaS") solution. "Each employee's score provided the insight management needs to take action before an incident occurs … This results in a reduction in injuries and associated costs including insurance premiums. … Case study after case study has shown that those companies who utilized Vantage Predictive Analytics reduced injuries."[40]

Another example of technology advances that support a reduction in safety incidents was recently highlighted in another article.[41] This article discusses Cyber-Physical Systems ("CPS"). CPS is defined as:

"Engineered systems that are built from, and depend on, the seamless integration of computational algorithms and physical components. The agency [National Science Foundation] believes CPS will enable advancements in capability, adaptability, scalability, resiliency, safety, security and usability in embedded systems by being a driving force behind continued innovation and competition in industries such as agriculture, energy, transportation, building design, healthcare and manufacturing."

39. Julie Copeland, "Top 10 Causes and Costs of Workplace Injuries," http://www.arbill.com/arbill-safety-blog/author/julie-copeland, 2016.

40. Julie Copeland, "Take a Proactive Approach to Preventing Workplace Injuries," http://www.arbill.com.

41. Penn State College of Engineering, "Cyber Monitored Buildings Will Enhance Construction Site Safety," http://www.claimsjournal.com/news/national/2016/08/01/272479.htm, Aug. 1, 2016.

Penn State College of Engineering prepared a study investigating how linking sensors on structures and virtual models can better ensure the safety of construction workers on or around temporary structures. Monitoring of these temporary structures remains one of the largest safety concerns on job sites. The investigation concluded that CPS monitoring can promote safer construction and prevent failure of temporary structures through "virtual prototyping, data acquisition systems and communication networks."

Two other examples of how new technology can enhance project site safety include the following.

- **Spot-R** – This is a small, belt mounted sensor that automates safety reporting on project sites. The sensor unit, combined with a wireless system, tracks worker movements and logs their activity data. The sensor utilizes an accelerometer, a gyroscope, and an altimeter to instantly recognize when and where a worker has fallen or stumbled. The sensor provides real time notification of hazards and injuries. This allows safety managers and superintendents to know where and when a safety incident occurred and logs all relevant data concerning each incident.[42]
- **Intrusion Detection Systems** – The current intrusion detection system, Railroad Intrusion Detection System ("RIDS"), has been employed on a major transportation network on the West Coast.[43] The system employs tilt sensors on barrier fences and infrared cameras for intrusion detection. Such systems should help enhance worker safety on rail transportation and potentially on other surface transportation construction projects.

Potential Impact on Construction, Project Management, and Claims Mitigation – It appears to the Navigant Construction Forum™ that developing technology can improve site safety and prevent onsite accidents. If such systems are widely employed on construction sites, accidents should ***decrease*** and delay claims related to such events should likewise ***decrease***.

SOFTWARE ADVANCES

Various software applications have been invented and are currently available to assist with project management, including the following:

- **Project Management Software** – There are numerous software packages on the market that allow project and program management teams to establish formal metrics for each project and utilize "project dashboards" to track such metrics and provide early warning signs of project troubles.[44]
- **Deficiency Management** – There are mobile applications that help construction teams manage deficient work items. "Everyone can access the [deficiency] list in real time, see what needs fixing, and submit photos when the work is done … [This software] helps construction projects get finished sooner and subcontractors get paid faster."[45]
- **Equipment Operations and Management** – There is software available that provides project management staff with real time information on the status of equipment moves, scheduled equipment maintenance and repair, and job schedules. The software can also can receive needs from foremen that appear in real time in the schedule process and can receive up-to-date information on planned or emergency equipment repairs that can impact the project schedule.[46]
- **Online Conflict Resolution Service** – Of particular interest to the Navigant Construction Forum™ is a new, online conflict resolution system called Settle-Now. According to the article released in October 2016:

  "The Settle-Now approach blends facilitation, negotiation, mediation, and arbitration to yield a superior system that can often resolve cases within hours, rather than weeks, months, or even years. The simple User Experience often requires no actual help from professionals. However, Settle-Now also offers instant access to a vetted pool of incredibly talented professionals who keep the process moving toward resolutions where both parties are not just relieved that their conflict is over, they're authentically happy with the outcome."[47]

Potential Impact on Construction, Project Management, and Claims Mitigation – The Navigant Construction Forum™ is cognizant that there are a large number of other project and program management software packages available to the construction industry. The Forum chose to highlight these applications because the latter three are unusual while the first software discussed is more common. The Forum is of the opinion that all of these applications will improve project communications that will, in turn, improve project management practices. And, as project communications and management practices improve, the likelihood of claims and disputes should ***decrease***.

42. Jeff Rubenstone, "Belt Clip Tracks Workers, Logs Safety Incidents to the Cloud," *Engineering News-Record*, http://www.enr.com/articles/40821-belt-clip-tracks-workers-logs-safety-incidents-to-the-cloud, Nov. 2, 2016.
43. Luke Abaffy, "Intrusion Detection System Protects Workers and Trains," *Engineering News-Record*, http://www.enr.com/articles/40203-intrusion-detection-system-protects-workers-and-trains, Sept. 14, 2016.
44. Innotas, "The Project and Portfolio Management Landscape, 2016," www.innotas.com.
45. Rick Spence, "How these two women are bridging a gap between the construction industry and new technology," http://business.financialpost.com/entrepreneur/growth-strategies/how-these-women-are-bridging-a-gap-between-the-construction-industry-and-new-technology, Aug. 4, 2016.
46. Pam Kleineke, "Learn How Software Streamlines Operations for Busy Construction Companies," http://compactequip.com/business/learn-how-software-streamlines-operations-for-busy-construction-companies/, June 15, 2016.
47. David Puckett, "Settle-Now Proudly Welcomes the World to Something Truly New in Conflict Resolution," http://www.prweb.com/releases/2016/10/prweb13761150.htm, Oct. 18, 2016.

WEARABLE TECHNOLOGY

Wearable technology is now common in everyday life with the advent of fitness trackers, wearable cameras, smartwatches, heart rate monitors, GPS tracking devices, in ear sleep headphones, smart virtual assistants, etc. Wearable technology is now coming into the construction industry.

"Further fueled by the Internet of Things, wearable technology has become a very big deal. … The wearable space has expanded dramatically to include smart hats, shoes, glasses, jewelry, watches, helmets, and more. These accessories carry embedded actuators, biosensors, and gyroscopes to follow movement heart rates, stress level, and countless other metrics. … Smart gadgets are increasing workplace safety and improving operation efficiency in construction sites across the country."[48]

Research indicates that there is a good deal of wearable technology currently available on the market and in use on construction sites. Following are some examples of wearable technology available for use in construction.[49]

- **Augmented Wearable Glasses** – Although ***not*** yet perfected for construction, the available versions of such glasses are intended to allow contractors and craft labor to walk through a job site and see the finished structure and environment data through digital safety goggles while transforming data and media at the same time to a cloud solution.
- **Virtual Reality Headsets** – Virtual reality headsets interact with project plans through fully immersive and interactive software combined with sensors .
- **Microsoft HoloLens** – These glasses not only display data for the wearer to feel completely immersed in the visualization but a 3D scanner collects data and interacts with the visualization.
- **Daqri Smart Helmet** – This helmet includes an augmented reality display that provides real time data.
- **Smartwatches and Health Trackers** – Health bands track construction worker heart rate, perspiration, temperature, and activity. Armband monitors can manipulate the environment around the wearers and/or interact with smart glasses. ***iBeacons*** around the job site can provide environmental conditions and worker locations, and can provide feedback on both based on GPS data.
- **Safety Vests** – The safety vests currently in development are intended to alert highway workers of moving objects (like cars or trucks) that are approaching. The alert function is able to adjust the volume of the alert based on ambient noise on the site. Other safety vests in development include touch sensors, and will be able to monitor worker conditions like a health sensor.
- **Pulse Oximeter** – Fitted to a hard hat, these devises detect the onset of carbon monoxide poisoning and alerts labor in the area.
- **Wearable Safety Badges** – Such badges track crew locations in real time with 8 inch accuracy. When labor enters a hazardous area these wearable badges or a flashing light-emitting diode ("LED") vest alerts workers to the danger.

48. Thomas Appel, "Can wearables transform the construction industry?" http://readwrite.com/2016/08/02/wearable-technology-transforming-the-construction-industry-dt4/, Aug. 2, 2016.

49. James Benham, "The Evolution of Wearable Tech in Construction Industry, Part 2," http://jamesbenham.com/the-evolution-of-wearable-tech-in-construction-industry-part-2, Sept. 24, 2015. Andrew Ferguson, "Wearable Technology by Industry Series: Vol. 5 – Construction," https://brainxchange.events/wearable-technology-industry-series-construction/ April 15, 2015. Marla McIntyre, "Wearables Wanted Onsite," http://www.constructionexec.com/Articles/tabid/3837/entryid/6438/wearables-wanted-onsite.aspx, July 7, 2016.

Potential Impact on Construction, Project Management, and Claims Mitigation – The Navigant Construction Forum™ understands that there are likely a large number of other wearable technologies available ***not*** included in the list above. But the Forum believes this list is sufficient to make the point that these technological advances are improving project communication, sharing accurate real time information with project participants, and improving site safety. All of these improvements are likely to ***decrease*** claims concerning delays, productivity loss, differing site conditions and constructive changes.[50]

WHERE DO WE STAND TODAY?

As the Navigant Construction Forum™ has illustrated in this research perspective, technology in the construction industry has been under development for some time and is poised to impact both project management and construction claims and disputes in a positive fashion. The question remains, how many construction industry stakeholders are already adopting these technological advances? A recent report providing some answers to this question indicates the following.[51]

Technology Adoption by Company Size[52]

COMPANY SIZE	CUTTING EDGE, VISIONARY	INDUSTRY LEADER	INDUSTRY FOLLOWING	BEHIND THE CURVE
<US$1 Billion	3%	22%	32%	43%
US$1-5 Billion	14%	23%	39%	25%
US$5-20 Billion	11%	18%	50%	20%
US$20 Billion +	7%	46%	20%	27%

Technology Adoption by Region

REGION	CUTTING EDGE, VISIONARY	INDUSTRY LEADER	INDUSTRY FOLLOWING	BEHIND THE CURVE
Americas	10%	25%	41%	24%
ASPAC	7%	17%	37%	39%
EME	7%	30%	23%	41%
Africa	0%	13%	33%	53%

Technology Adoption by Entity

ENTITY	CUTTING EDGE, VISIONARY	INDUSTRY LEADER	INDUSTRY FOLLOWING	BEHIND THE CURVE
Owners	5%	22%	36%	37%
Contractors	11%	25%	36%	28%

50. The Navigant Construction Forum™ notes that there is a ***potential*** downside legal risk involved with the use of some of wearable technologies. Some attorneys are already warning about potential invasion of privacy issues, potential discrimination lawsuits, and/or illegal recordings without "consent of everyone being recorded." See Karen Turner, "Are performance monitoring wearables an affront to workers' rights," *The Washington Post*, https://www.washingtonpost.com/news/the-switch/wp/2016/08/05/are-performance-monitoring-wearables-an-affront-to-workers-rights/, Aug. 5, 2016. See also, Debra Cassens Weiss, "Wearable technology that monitors workers could lead to legal problems for employers, lawyers say," *ABA Journal*, http://www.abajournal.com/news/article/wearable_technology_that_monitors_workers_could_lead_to_legal_problems_for/, Aug. 9, 2016.

51. KPMG International, "Building a Technology Advantage: Harnessing the Potential of Technology to Improve the Performance of Major Projects – Global Construction Survey 2016," www.kpmg.com/gcs.

52. Numbers in the following tables may not add up exactly to 100% due to rounding.

Based upon this survey, the Navigant Construction Forum™ concludes that these technology improvements are starting to gain traction in the construction industry, but there is a long way to go before these advances become ubiquitous in the industry. The survey noted that for this group of large owners and contractors:

- 42% of respondents use drones to monitor construction status
- 30% use robotics or automated technology
- 65% use remote monitoring onsite
- 30% use RFID to track equipment and materials onsite
- 17% use smart sensors to track personal onsite
- 61% use BIM on a majority of their projects

The above percentages may very well be explained by the demographics of the survey respondents. The survey respondents were 218 senior executives – 199 from major project owners and 99 from a range of engineering and construction companies. Participating organizations included both private companies and government agencies. The respondent's companies ranged in annual volume from US$1 billion to +US$20 billion. And, owner entities came from many industries, including energy and natural resources, technology, and healthcare.

The survey concluded that the primary drivers for adoption of these technological advances are the following:

- Efficiency, planning, and cost reduction
- Competition and market forces
- New markets, growth, and profitability
- Client needs and meeting demand
- Technology and talent
- Increasing regulation

What this survey of major players in the construction industry concluded was:

- The construction industry has ***not*** yet fully embraced new technology.
- Data volume resulting from these new technologies is rising exponentially, but many are struggling to make sense of the information gathered.
- Integrated, real time project reporting is still a dream, ***not*** a reality.
- There is more to come from mobile technology.
- There is still much room for improvement in project management basics.

This particular survey may lead one to believe that the construction industry is making great strides in adopting advanced construction technology. However, the Navigant Construction Forum™ believes that this survey is ***not*** truly representative of the average U.S. construction company.

The Navigant Construction Forum™ located what the Forum believes is a much more robust survey of the use of construction technology in the industry, released in late 2015.[53] This survey was conducted by JBKnowledge, Inc. in conjunction with the Construction Financial Management Association ("CFMA"), the Texas A&M University Department of Construction Science and HCSS Construction Software. The survey was distributed to some 30,000 construction industry professionals. A total of 2,044 responses were received – a 6.8% response rate. For various good reasons, 424 of the responses were removed, bringing the final survey responses used in the analysis to 1,620 or a 5.4% response rate. More information concerning this survey follows.

53. JBKnowledge, Inc., "The 4th Annual Construction Technology Report (2015)," http://www.JBKnowledge.com

Industry Type

INDUSTRY TYPE	PERCENTAGE
Commercial	66.2%
Transportation	22.6%
Residential	14.0%
Industrial	13.7%
Water/Wastewater/Solid Waste	12.5%
Power	9.0%
Oil & Gas	7.5%
Manufacturing	6.1%
Telecommunications	2.5%
Hazardous Waste	1.4%

Company Type

COMPANY TYPE	PERCENTAGE
Contractor/Construction Manager	72.5%
Subcontractor/Material Supplier	19.0%
Architectural/Engineering/Design Firm	2.4%
Owner/Developer	2.2%
Government Agency	0.4%
Other	3.6%

Size of Companies

COMPANY SIZE	PERCENTAGE
1-5 Employees	3.5%
6-20 Employees	7.5%
21-50 Employees	14.2%
51-100 Employees	15.0%
101-200 Employees	16.0%
201-500 Employees	19.8%
501-1,000 Employees	8.8%
Over 1,000 Employees	15.2%

Annual Sales Volume

ANNUAL SALES VOLUME	PERCENTAGE
Less than US$1 Million	3.5%
US$1-$5 Million	5.6%
US$6-$20 Million	14.5%
US$21-$50 Million	18.6%
US$50-$100 Million	15.6%
US$201-$500 Million	13.6%
Over US$500 Million	16.7%

The Navigant Construction Forum™ believes that this survey provides a more representative picture of how the U.S. construction industry, at least, is progressing with respect to the adoption of new technology. Some of the more relevant findings of this survey are set forth below.

- **Mobile Technology** – When asked how important mobile technology was to the respondents, the answers indicated the following.
  - ***Not*** important = 22.6%
  - Important = 45.9%
  - Very important = 31.5%
- **Daily Device Usage** – When asked about daily device usage, by type and who provides such devices, the responses showed the following results.

Daily Device Usage

DAILY DEVICE USAGE	LAPTOP	TABLET	SMARTPHONE	WEARABLE
Total	85.6%	69.4%	97.6%	9.2%
Personal	23.3%	38.9%	35.9%	71.4%
Company Provided	91.0%	74.5%	81.1%	33.3%

- **Software in Use** – When asked about what type of software was in use on their projects the respondents replied in the following manner.
  - **Project Scheduling Software** – 95.6% of the respondents use network logic driven computerized software, while 4.4% rely on other software or manual systems for scheduling their projects.
  - **Project Management Software** – 30.5% of the respondent replied that they use either manual processes or spreadsheets, while 69.5% indicated that they use various off the shelf software.
  - **BIM Software** – 47.9% of the respondents stated that they do ***not*** use BIM while 52.1% replied that they use BIM, employing a large variety of BIM software products.
  - **Collecting Data on the Jobsite** – 82.9% of the survey respondents reported that they collect project data either manually or by use of spreadsheets; 41.8% reported that they use software, mobile products or custom solutions; 9.4% replied that they do ***not*** collect site data. 4.0% indicated they used other methods (***not*** specified).

The Navigant Construction Forum™ believes that this survey provides a more representative picture of how the U.S. construction industry, at least, is progressing with respect to the adoption of new technology. Some of the more relevant findings of this survey are set forth below.

Technologies Experimented With

TECHNOLOGIES	PERCENTAGE
Drones	20.7%
3D Scanners	10.2%
3D Printers	5.1%
Virtual Reality	4.9%
Augmented Reality	4.2%
Wearable Devices	3.6%
Other	2.9%
None	**70.3%**

This survey paints the following picture concerning the adoption of technology in the U.S. construction industry.

- Field data collection and project management solutions are the ***most*** likely to have full mobile capabilities, while project scheduling is the ***least*** likely.
- With nearly 50% of constructors ***not*** using BIM, it is hard to see where the next generation of 4D, 5D and 6D solutions will fall into place in the industry.
- Only 26.8% of construction professionals are using a field data collection solution, even less than those using BIM.
- Most constructors are still sorting through all of the software they use today that does ***not*** integrate, and are ***not*** yet thinking of robotics and other advances.

This survey concludes with the following remarks concerning the industry's slow adoption of new technologies.

"The construction industry continues to underspend on technology compared to other industries. … The lack of research and development among the construction companies surveyed highlights the industry's reactive approach to technology. With minimal budget and allocated staff, companies don't have much bandwidth for tinkering with potential technology solutions. As a result, the construction industry is notoriously behind on implementing innovative solutions."

CONCLUSION

The Forum and other industry observers have long noted the low level of productivity in the construction industry; the declining number of qualified craft workers available; the lack of open communications between project participants; and the increasing number of claims centering on productivity loss and project delays.

The leading factors in the slow uptake of technology advances seem to be twofold. First is the general resistance to change common within the industry at large. However, as technology develops and rolls out; as contractors and construction managers continue to hire younger staff who are more familiar with technology; as the younger staff begins to rise in their organizations to project managers and above; and, as competitors begin to make use of technology, it is likely that this resistance will fall away. The second factor appears to be the cost of the new technology. Anyone familiar with the construction industry knows full well that this industry has extremely low margins despite working in a very risky business. But as technology advances become more common in the industry, the cost of these technological advances should come down. To quote Bill Gates on the cost factor – "If GM had kept up with the technology like the computer industry has, we would all be driving $25.00 cars that got 1,000 miles to the gallon." While the Navigant Construction Forum™ is confident that the cost of new technology will never drop to this level, it is likely that as more companies use new technology, the less it will cost for each company.

The Navigant Construction Forum™ is encouraged by the advances in construction industry technology today as well as those under active development. These technological developments seem to be oriented toward and, once employed on project sites, are likely to result in the following improvements:

- Increased open communication between owners, designers, construction managers, and contractors at all levels of project organizations
- Making accurate information available and easily accessible to all project participants on a real time basis
- Improved productivity on project sites
- Reduced project delays and related claims

NAVIGANT CONSTRUCTION FORUM™

Navigant (NYSE: NCI) established the Navigant Construction Forum™ in September 2010. The mission of the Navigant Construction Forum™ is to be the industry's resource for thought leadership and best practices on avoidance and resolution of construction project disputes globally. Building on lessons learned in global construction dispute avoidance and resolution, the Navigant Construction Forum™ issues papers and research perspectives; publishes a quarterly e-journal (*Insight from Hindsight*); makes presentations globally; and offers in house seminars on the most critical issues related to avoidance, mitigation, and resolution of construction disputes.

Navigant is a specialized, global expert services firm dedicated to assisting clients in creating and protecting value in the face of critical business risks and opportunities. Through senior level engagement with clients, Navigant professionals combine technical expertise in Disputes and Investigations, Economics, Financial Advisory, and Management Consulting, with business pragmatism in the highly regulated Construction, Energy, Financial Services and Healthcare industries to support clients in addressing their most critical business needs.

Navigant's Global Construction Practice is the leading provider of expert services in the construction and engineering industries. Navigant's senior professionals have testified in U.S. federal and state courts, more than a dozen international arbitration forums, including the AAA, DIAC, ICC, SIAC, ICISD, CENAPI, LCIA, and PCA, as well as ad hoc tribunals operating under UNCITRAL rules. Through lessons learned from Navigant's forensic cost/quantum and programme/schedule analysis on more than 5,000 projects located in 95 countries around the world, Navigant's construction experts work with owners, contractors, design professionals, providers of capital, and legal counsel to proactively manage large capital investments through advisory services, and manage the risks associated with the resolution of claims or disputes on those projects, with an emphasis on the infrastructure, healthcare, and energy industries.

FUTURE EFFORTS OF THE NAVIGANT CONSTRUCTION FORUM™

Author's Note: This report is my last research perspective. Since December 2010, the Navigant Construction Forum™ has published 22 research perspectives. However, I am retiring from Navigant Consulting in early January 2017. Although I will continue to act as a consultant to Navigant on a very limited basis, I will no longer be the executive director of the Navigant Construction Forum™. I have thoroughly enjoyed my role as executive director of the Forum. I sincerely hope that the efforts of the Forum over the past six years have provided value to the construction industry, an industry that has been and remains so vital to humanity globally.

In the first quarter of 2017, the Navigant Construction Forum™ will issue another research perspective analyzing construction industry issues. Further research will continue to be performed and published by the Navigant Construction Forum™ as we move forward. If any readers of this research perspective have ideas on further construction dispute-related research that would be helpful to the industry, you are invited to e-mail suggestions to Steve Pitaniello at spitaniello@navigant.com.

APPENDIX A

APPENDIX A – LIST OF ACRONYMS

ADM: Arrow Diagraming Method

AMF: Additive Manufacturing File

AMG: Automatic Machine Guidance

AR: Augmented Reality

ASME: American Society of Mechanical Engineers

BIM: Building Information Modeling

CAD : Computer-Aided Drawings

CCD: Charge-Coupled Device

CFMA: Construction Financial Management Association

CPM: Critical Path Method

CPS : Cyber-Physical System

FCC: Federal Aviation Administration

GIS: Geographic Information System

GNSS: Global Navigation Satellite System

GPR: Ground Penetrating Radar

GPS: Global Positioning System

IOT: Internet of Things

ISO: International Organization for Standardization

LED: Light-Emitting Diode

LIDAR: Light Detection and Ranging

NFC: Near Field Communication

OGC: Open Geospatial Consortium

OSHA: Occupational Safety and Health Administration

APPENDIX A – LIST OF ACRONYMS

RFC: Request for Clarification

RFI: Request for Information

RFID: Radio Frequency Identification

RIDS: Railroad Intrusion Detection System

RS: Remote Sensing

RTLS: Real Time Location System

RTK: Real Time Kinematic Technology

SaaS: Software as a Service

UAS: Unmanned Aircraft Systems

UAV: Unmanned Aerial Vehicle

VDC : Virtual Design and Construction

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About Navigant

Navigant Consulting, Inc. (NYSE: NCI) is a specialized, global professional services firm that helps clients take control of their future. Navigant's professionals apply deep industry knowledge, substantive technical expertise, and an enterprising approach to help clients build, manage and/or protect their business interests. With a focus on markets and clients facing transformational change and significant regulatory or legal pressures, the Firm primarily serves clients in the healthcare, energy and financial services industries. Across a range of advisory, consulting, outsourcing, and technology/analytics services, Navigant's practitioners bring sharp insight that pinpoints opportunities and delivers powerful results. More information about Navigant can be found at navigant.com.

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