Game Changing Innovations

4.0 PDH/ 4 CE Hours/ 4 AIA LU/HSW

AIAPDH154
FINAL EXAM

1. According to the U.S. Census Bureau monthly report, Construction Work-in-Place for September 2017 had a seasonally adjusted annual rate of over ___ annual:
   a. $1 billion
   b. $500 million
   c. $1.2 Trillion
   d. $50 million

2. Some industry pundits and experts have suggested that the construction industry has inefficiency and waste of more than______:
   a. none
   b. 30%
   c. 10%
   d. 5%

3. Modern engineering design and drafting can be traced back to _______ in the 16th and 17th centuries:
   a. Algebra
   b. Calculus
   c. Descriptive Geometry
   d. Printing

4. All of the following categories of software tools focus on facility management and operations EXCEPT:
   a. CAFM
   b. CMMS
   c. Dotcom
   d. IWMS
5. Which of the following “reality” technologies does not have promise for construction
   a. Virtual Reality (VR)
   b. Augmented Reality (AR)
   c. Reality TV
   d. Mixed Reality (MR)

6. According to James Benham writing in ConstructionExec, all of the following are best practices for cybersecurity and construction EXCEPT
   a. Sharing passwords
   b. Implement cloud liability insurance
   c. Train Employees
   d. Continuously update software

7. A 2006 Caterpillar study and a 2008 Reykjavik study revealed the following with respect to geo-spatial and construction:
   a. Time Savings or more than 50%
   b. Fuel consumption Reduction of 43%
   c. 20% savings in machine time
   d. All of the above

8. Smart Sensors in Construction include:
   a. “Sensor web” using OGC’s Sensor Web Enablement Framework
   b. Ability for real-time alerts
   c. Enable long-term analysis
   d. All of the above

9. The National Institute of Standards and Technology (NIST) published in 2004 a report entitled A Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry that stated significant inefficiency and lost opportunity costs associated with interoperability problems was estimated to be in amount annually of:
   a. Not significant
   b. About a $100 million
   c. $15.8 billion
   d. $4 Trillion
10. **Artificial Intelligence in Construction** has potential to revolutionize the following

a. Operating machinery  
b. Modeling and Estimate  
c. Improving Safety  
d. All of the above.
Game Changing Innovation
Opportunities and Challenges
For Architects, Constructors and the Built Environment

Course Description

This course provides detailed content and analysis that was presented at a highly acclaimed full day workshop presented at the American Institute of Architects annual A’17 Conference on Architecture in Orlando in April 2017. Eight world renowned experts on the profession, construction industry and forward-looking technologies engaged with over eighty business leaders from around the world, focused on Game Changing Innovative Technologies and Processes that are poised to disrupt the $1 trillion (Annual USD) construction industry.

In this course, you will:

1. Explore current trends in Game Changing innovations and their impact on the profession of architecture and construction.
2. See how specific firms and thought leaders are addressing change, with specific case studies and lessons learned
3. Engage with experts and understand how architectural and consulting firms and organizations are making game changing strides.
4. The industry is already feeling the impact of big data, artificial intelligence, and computational design. This course will help you stay ahead of the sea change.
Learning Objectives:

1. Upon completion, participants will be able to establish and prioritize the top 3 or 4 emerging technologies that interest them and their firms and pose great opportunities for the future of their practice. These innovative technologies enable the architect and architectural practice to increase the value of the built environment in terms of **safety, occupant comfort and well-being**, often using data and technology feedback for human-centric and experiential design processes.

2. Upon completion, participants will be able to understand what path-breaking and leading firms are doing to dramatically improve outcomes and provide innovative services to their clients and customers. These firms have transformed their practices through the immersive use of these innovative technologies and processes, thereby increasing productivity and profitability, in addition to improving **building systems, materials and methods**, as well as quality and integrative of design and construction documents and follow-on construction contract administration.

3. Upon completion, participants will be able to understand how the built environment, form and function of architecture, and everything from small components to entire buildings to regions and **urban scale** can be dramatically improved by new emerging technologies—whether it is wearable computing, cloud computing, or big data.

4. Upon completion, participants will be able to take key ideas back to the office on Monday and create their own **Innovative Technology Execution Plans** for their in-house projects and firm-wide business planning. Included in the workshop is a workbook with exercises throughout the day and a process and strategy to create a personal **Game-Changing Innovation Technology Execution Plan**. The plan can encompass **Pre-Design, Design (including urban ecology, master planning, interiors, safety and security), Materials and Methods such as finishes and products, and Construction Documentation and Post-Occupancy assessment of Occupant Comport such as air quality, ventilation, lighting, sound and egress.**
COURSE OUTLINE

I. Introduction and Overview
   a. What is “Game Changing Innovation”, why does it apply to the construction industry, and why should I care?
   b. What is scale and size of construction industry, in the U.S. and worldwide?
   c. Profile of Industry Today
   d. Who are Stakeholders?
   e. What are challenges of technology and innovation in the construction industry?

II. Historical Perspective of Construction Innovation and Technology
   a. Three Million Years of Construction Technology
   b. A More Academically Accurate Categorization Of the Historical Periods of Construction

III. Tsunami of Game Changing Innovations: Technology and Processes
   a. Technologies and case studies

IV. Industry Innovation Landscape and Drivers Today
   a. Recent Papers on Construction Productivity and Innovation
   b. New Technology Players and Paradigms

V. Making Your Own Game Changing Innovation | Technology Execution Plan
   a. BIM Execution Planning as a role model
   b. YOUR Game Changing Innovation Execution Plan

VI. Conclusion and Path Forward

VII. Table of Figures

VIII. Bibliography
I. INTRODUCTION AND OVERVIEW

This course provides a broad overview, detailed analysis, and global perspective on the tsunami of new technologies and processes in the 21\textsuperscript{st} century that have the potential or are currently upending and disrupting the design, construction and built environment professions and industries.

Game Changing Innovation is defined as new technologies processes or business models that are a significant change from the main stream tools, methods of practice and processes that have pretty much predominated the industry for decades, if not centuries.

It is fair to say that the answer to the question “Why should I care” is that every aspect of life on the planet earth is being transformed by these Game Changing Innovations. But for architects, other design professionals, and those involved in the construction industry, the “why should I care” answer is even more compelling when new opportunities for business and increased profitability are considered.

These new Game Changing Innovations were presented at the American Institute of Architects (AIA) Conventions and other conferences:

- *Architects and Innovation* at 2015 AIA Convention in Atlanta
- *Path Breaking Innovation* at 2016 AIA Convention in Philadelphia
- *Game Changing Innovation: A full day workshop* at A’17 AIA Conference on Architecture and Expo in Orlando FL.
- *Using Technology to Move the Industry Forward* at the NIBS Building Innovation Conference in 2018, and
- *Harnessing the Technology Innovation Revolution* at the upcoming A’18 AIA Conference on Architecture in NYC in June, 2018

The Game Changing Innovations are illustrated in the following image that was the introductory center piece of the full day workshop. There are a myriad of new technologies, well beyond BIM (building information modeling), that are being
developed and deployed to improve outcomes in the architecture profession and construction industry.

As summarized below and discussed in more detail in this course, the design and construction industry is desperately in need of innovation.

The US construction industry is one of the largest components in the US economy. According to the Associated General Contractors of America (AGC) (Reference 1):

Construction is a major contributor to the U.S. economy. The industry has more than 650,000 employers with over 6 million employees and creates nearly $1 trillion worth of structures each year. Construction is one of the largest customers for manufacturing, mining and a variety of services. A study performed for AGC by Professor Stephen Fuller of George Mason University found that an extra $1 billion in nonresidential construction spending adds about $3.4 billion to Gross Domestic Product (GDP), about $1.1 billion to personal earnings, and creates or sustains 28,500 jobs:

- 9,700 jobs direct construction jobs located in the state of investment;
- 4,600 jobs indirect jobs from supplying construction materials and services, mainly within the state where the investment occurs, but some from other states;
- 14,300 jobs induced when workers and owners in construction and supplier – Place businesses spend their additional wages and profits, locally and nationwide.
This course will address the architecture profession, the construction industry, the emerging concept of smart cities, the current trends in infrastructure, and, more broadly, the entire built environment. That broader reach enables us to more comprehensively assess the impact of emerging technologies and gives the course learner a unique “birds eye” view of the built environment through the lens of emerging innovative technologies and processes.

The U.S. Census Bureau has a monthly report that addresses “Construction Work-in-Place” (Reference 2) and provides a more granular statistical picture of the industry we are addressing. In the September 2017 report, the seasonally Adjusted Annual Rate (in millions of US dollars) breaks down to the following categories:

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<tr>
<th>Category</th>
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<tr>
<td>Total</td>
<td>1,219,544</td>
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<tr>
<td>Private</td>
<td>942,729</td>
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<td>Residential</td>
<td>515,422</td>
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<td>Nonresidential</td>
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<td>Public</td>
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<td>State and Local</td>
<td>255,410</td>
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<td>Federal</td>
<td>21,405</td>
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The total for the United States is over $1.2 trillion dollars.

But the global picture is even more impressive. A group called the Construction Intelligence Center Global 50 pegs the size of the construction industry world-wide at $10.3 trillion by 2030 (Reference 3). This grouping of the 50 largest and most influential markets in the world forecasts an average annual increase of 3.9% over 2016-2020. The complete report is available at http://marketreportsstore.com/global-construction-outlook-2020/.

While new technologies such as building information modeling (BIM), laser scanning, model checking, and clash detection have gained some traction in helping stakeholders increase productivity, much inefficiency and waste remains.

Some industry pundits and experts have suggested the value of the inefficiency and waste at over 30%, or more than $300 million annually! Indeed a widely circulated graphic by Stanford Professor Paul Teicholz illustrates how much construction lags
other industries, including manufacturing, in terms of making inroads in this productivity shortfall (see Figure 1).

When you include the size of the global construction market place in your perspective and then factor in the waste and inefficiency mentioned above, the opportunity for improvement and disruptive technologies and business models is immense.

In August 2004, the National Institute of Standards and Technology (NIST) released a report that addressed another issue related to the construction and capital facilities industry inefficiency: lack of software interoperability. The report, prepared for NIST by RTI International and the Logistic Management Institute, estimates the cost of inadequate interoperability in the U.S. capital facilities industry to be $15.8 billion per year (Reference 4).

What if any efforts are underway that might address these concerns about industry waste and inefficiency? It turns out that many investors are waking up to the opportunities. According to CB Insights, there has been Global equity funding worth $778 million across 165 deals in the construction tech space. The following illustrates the most active construction tech investors, as reported by CB Insights:
Some of the key takeaways from an analysis by CB Insights (Reference 5)

- Software incumbents such as Trimble and Autodesk are more active in creating new deals
- Construction Product Companies are Market-share focused
- Across the project lifecycle (Design, Procurement, Construction, Operations) are specific areas where investors and start-ups are deploying solutions
- There is also three different approaches: replace, enable or create
- Some areas of interest include: design tools, project management software, equipment marketplaces, robotics and drones, and Next Generation Commerce for Building Materials
- Most relevant to the subject of this course are the emerging technologies that are being developed and deployed augmented reality, prefab, 3D printing, automated construction, robotics, onsite technology breakthroughs.

One of the key areas that the investors and these myriad of start-up companies are focused on is illustrated by this diagram from the 2016 McKinsey Global Institute (Reference 6) industry digitization index that showed that construction was near the bottom of all industries in terms of becoming digital:
This course will also include the concept of Smart Cities and the global movement to harness IoT (internet of things). It is interesting to note that although the concept of a “smart city” might seem to be very recent, it actually goes back more than 40 years. An article in Planetizen (Reference 7) discusses the timeline and suggests the concept began in Los Angeles as early as 1974. The author, Mark Vallianatos, mentions that in the late 1960s and through the 1970s, much of the focus of smart cities was meant to include databases, analyses of neighborhoods and clusters, and the use of infrared aerial photography to gather data and produce reports. Much of this focus was on warding off urban blight and tackling poverty.

Big data, geo-information systems, cloud computing and models at an urban scale all have an important part to play in the discussion of Game Changing Innovation.

The scale and categorization of the Smart City initiatives is best illustrated by an annual ranking of the world’s smartest cities (Reference 8).

Infrastructure and more broadly the built environment (which can include transportation and regional planning concepts) will also be included in this course to illustrate how Game Changing Innovation works at any scale from components to urban and regional systems.

The structure of this course will include
• a broad view of the Game Changing Technology and Innovation Landscape today,
• An historical perspective of Construction Innovation and Technology,
• The core part of this course, a description of the tsunami of Innovations: Technology and Processes including Case Studies
• Global Organizations Driving Innovation and Disruptive Change,
• An outline of a process for making your own Game Changing Innovation | Technology Execution Plan, and
• Concluding remarks and a vision of a path forward.

As a concluding remark to this introductory section, it is worthwhile looking back at a statement made by Thom Mayne of Morphosis in 2005. Speaking on a panel in front of the entire AIA Convention in Las Vegas, Mayne spoke about BIM technology and said, “If you want to survive, you’re going to have to change…if you don’t, you’re going to perish. It’s as simple as that.”

“If you don’t change...you’re going to perish”

“‘If you want to survive, you’re going to change; if you don’t, you’re going to perish. It’s as simple as that.’ —Thom Mayne, FAIA, 2005 Pritzker Prize Winner

Figure 5 Thom Mayne FAIA and Panelists at 2005 AIA Convention Las Vegas

In summary, the purpose of this course is to give the learner a broad perspective and the tools to not only NOT perish, but survive and flourish in this new age of digital transformation.
II. **Historical Perspective of Construction Innovation and Technology**

There is literally a tsunami wave of new technologies and processes that are blasting through every sector of human life on the planet. And this is also true for the world of architecture, construction, and the built environment. In order to make the list of innovations a bit more manageable for discussion and analysis purposes we will categorize them into groupings in order to make this list more accessible and understandable:

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Before we take a deep dive into the technologies, it is useful to take a look at where technologies and innovation have been historically and how we got to where we are today.

Three Million Years of Construction Technology

Heather Dueitt, Director of Marketing and Communications for NoteVault (Reference 9), wrote a brief but innovative overview of the history of construction through the lens of technology (more specifically, the hammer!). She outlines her characterization of the history in the following broad and somewhat idiosyncratic categories:

- Hammer 1.0 – The Stone Age
- Hammer 2.0 – Getting a Handle on Things
- Hammer 3.0 – The Bronze Age
- Hammer 4.0 – Forging and Iron Working
- Hammer 5.0 – Pulling Nails
- Hammer 5.1-5.9 – Powered Hammers
- Hammer 6.0 – The Industrial Revolution
- Hammer 6.5 – A Simple Revolutionary Feature
- The Twentieth Century – Rapid Disruptions
- The House Boom and the California Framing Hammer
- Space Age – New Materials, New Sciences
- Disruption 1950 – The End of the Hammer?
- Turn of the Century – Reimagining the Hammer?
- The Future of the Tool – The Future of Construction Technology

Ms. Dueitt’s narrative actually provides us with a good framework for looking at Game Changing Innovation. We can view all of these changes broadly or actually look at individual tools and techniques as they have evolved over time and where we are today.

A More Academically Accurate Categorization Of the Historical Periods of Construction

A more academically accurate outline of the History of Construction is outlined in Wikipedia at (Reference 10), with the following major eras examined and briefly summarized below. It is important to consider where the construction industry has come from with respect to tools and technologies in considering the technologies now emerging.
• Neolithic (New Stone Age). This period was roughly from 9000 BC to 5000 BC

• Copper and Bronze Age--Copper and bronze were used for the same types of tools as stone such as axes and chisels, but the new, less brittle, more durable material cut better. Bronze was cast into desired shapes and if damaged could be recast. A new tool developed in the copper age is the saw.

• Iron Age--The Iron Age, from roughly 1200 BC to 50 BC, is characterized with the widespread use of iron for tools and weapons. Iron is not much harder than bronze but by adding carbon iron becomes steel which was being produced after about 300 BC. Steel can be hardened and tempered producing a sharp, durable cutting edge.

• Middle Ages--The Middle Ages of Europe span from the 5th to 15th centuries AD from the fall of the Western Roman Empire to the Renaissance and is divided into Pre-Romanesque and Romanesque periods. Fortifications, castles and cathedrals were the greatest construction projects. The Middle Ages began with the end of the Roman era and many Roman building techniques were lost. A revival of stone buildings in the 9th century and the Romanesque style of architecture began in the late 11th century.

• Renaissance---The Renaissance in Italy, the invention of moveable type and the Reformation changed the character of building. The rediscovery of Vitruvius had a strong influence. A distinguishing aspect of the Middle Ages is that buildings were designed by the people that built them. The master mason and master carpenters learnt their trades by word of mouth and relied on experience, models and rules of thumb to determine the sizes of building elements. Vitruvius however describes in detail the education of the perfect architect who, he said, must be skilled in all the arts and sciences.

• 17th Century--The major breakthroughs were towards the end of the 17th century when architect-engineers began to use experimental science to inform the form of their buildings. However it was not until the eighteenth century that engineering theory developed sufficiently to allow sizes of members to be calculated. Seventeenth-century structures relied strongly on experience, rules of thumb and the use of scale models.

• 18th Century--The eighteenth century saw that the architects and engineers became increasingly professionalized. Experimental science and mathematical methods became increasingly sophisticated and employed in buildings. At the
same time the birth of the industrial revolution saw an increase in the size of cities and increase in the pace and quantity of construction.

- The 19th Century Industrial Revolution--The industrial revolution was manifested in new kinds of transportation installations, such as railways, canals and macadam roads. These required large amounts of investment. New construction devices included steam engines, machine tools, explosives and optical surveying. The steam engine combined with two other technologies which blossomed in the nineteenth century, the circular saw and machine cut nails, lead to the use of balloon framing and the decline of traditional timber framing.

- The Twentieth Century--With the Second Industrial Revolution in the early 20th century, elevators and cranes made high rise buildings and skyscrapers possible, while heavy equipment and power tools decreased the workforce needed. Other new technologies were prefabrication and computer-aided design. In the end of the 20th century, ecology, energy conservation and sustainable development have become more important issues of construction.

As we begin the 21st century as the next chapter details, a veritable tsunami of next-generation and path-breaking technologies is changing the landscape of construction in numerous and profound ways.
III. A Tsunami of Game Changing Innovation Technologies and Processes

The historical overview above puts technology in context and helps set the stage for an analysis of each of these trends in innovation, as categorized at the beginning of the last chapter and shown in the table below:

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<th>Model Authoring / Checking Tools</th>
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Model Authoring / Checking Tools

Model authoring tools such as those meant to delineate lines and arcs and circles to depict architectural floor plans, sections, renderings and perspectives is a good place to begin the exploration of Game Changing Innovations.

Computer Aided Design (CAD)

Computer Aided Design (CAD) has a history dating back to its roots in the 16th and 17th Century (Reference 11). Engineering and drafting can be traced to the development of mathematical disciplines including descriptive geometry. Still, these methods of creating drawings changed little over those centuries and up until after World War II
But the war brought considerable investment in innovations, including real-time computing. Massachusetts Institute of Technology (MIT) was a center of research and development, including the numerical control of machine tools and automating engineering design.

Setting the stage for what we know of as CAD was the work of two people: Patrick Hanratty and Ivan Sutherland. Hanratty, often considered as “the Father of CADD/CAM.,” developed an early programming system for control of machines while he was working at GE in 1957. In 1962, Sutherland had developed his Ph.D. thesis at MIT titled “Sketchpad, A Man-Machine Graphical Communication System.” Among its features, the first graphical user interface, using a light pen to manipulate objects displayed on a CRT. The 1960s to 1980s brought significant innovations:

The 1960s brought other developments, including the first digitizer (from Auto-trol) and DAC-1, the first production interactive graphics manufacturing system. By the end of the decade, a number of companies were founded to commercialize their fledgling CAD programs, including SDRC, Evans & Sutherland, Applicon, Computervision, and M&S Computing.

By the 1970s, research had moved from 2D to 3D. Major milestones included the work of Ken Versprille, whose invention of NURBS for his Ph.D. thesis formed the basis of modern 3D curve and surface modeling, and the development by Alan Grayer, Charles Lang, and Ian Braid of the PADL (Part and Assembly Description Language) solid modeler.

With the emergence of UNIX workstations in the early ’80s, commercial CAD systems like CATIA and others began showing up in aerospace, automotive, and other industries. But it was the introduction of the first IBM PC in 1981 that set the stage for the large-scale adoption of CAD. The following year, a group of programmers formed Autodesk, and in 1983 released AutoCAD, the first significant CAD program for the IBM PC.

CAD and its further evolutions into PLM (product life cycle management) are still two dimensional applications. Nevertheless, CAD and PLM continue to be a significant and prominent, if not predominant, technology mode for many industry participants.

**BIM (Building Information Modeling)**

BIM truly has been a game changing innovation over CAD and it is worth exploring the topic in depth to reflect on the change that has occurred in the industry do to BIM and how it prepared industry stakeholders for the tsunami of other technologies that is cascading now over the world. We will touch on the following subtopics to flesh out some of the more interesting aspects of BIM:
BIM Technological and Historical Roots

Building Information Modeling (BIM) from its inception was conceived as a three dimensional model. The BIM author begins to model in three dimensions and both a structure and its components are all configured in multi-dimensional space. What this technology permits is the ability to rotate and see all sides of the object being modeled, and users escape the confines of a very limiting two dimensional view.

The best reference to describe this technology in detail is the BIM Handbook by Chuck Eastman (Reference 12), who is often and affectionately called the “father of BIM.” From the abstract roots of academia and Eastman’s research at Georgia Tech, the technology took shape and market adoption when significant technology firms began marketing BIM tools.

During the “dotcom” bubble of 1998-2000, an adolescent start-up named Revit began shaking the roots of the leading CAD technology firm, Autodesk, threatening to gain market share and change the landscape of computer for design and construction. Autodesk quickly recognized the existential threat as well as an opportunity and purchased Revit in 2002 for a large sum of money. Revit for Autodesk then became its flagship platform for BIM. Indeed, to the consternation of competitors, Revit became known synonymously as BIM. However, the competitors including Graphisoft,
Nemetshek, Bentley and another start-up At-Last Sketchup, all made their own inroads and niches in the design and construction marketplace. Karen Kensek’s Building Information Modelling ([Reference 13](#)) is a comprehensive companion to Eastman’s and brings forward more practical and pragmatic updates to the foundational work of Chuck Eastman.

**McGraw-Hill Smart Market Reports**

During this period McGraw Hill Construction began authoring Smart Market Reports that documented the extent of influence BIM was having on the design profession and construction industry. The following is a list of Smart Market Reports published:

One of the informative research results revealed in the Smart Market Reports was the extent of adoption, albeit uneven, among architects, engineers, constructors, subcontractors, and owners. The Smart Market Reports can be all accessed for free from the Dodge Research and Analytics site ([Reference 14](#)). Reports that are relevant to this course include:

- SmartMarket Brief: BIM Advancements No. 1
- The Business Value of BIM in the Middle East SmartMarket Report
- The Business Value of BIM for Infrastructure 2017 SmartMarket Report

**Dodge Data & Analytics Research**

All reports are free: [analyticsstore.construction.com](http://analyticsstore.construction.com)

![Smart Market Reports Images](Reference 14)

**Figure 7** Images of Smart Market Reports (Reference 14)

Along with an industry reporting perspective provided by McGraw-Hill is the emergence of BIM Guides published and BIM Programs developed by industry stakeholders. The
following is a list that we will explore in a bit more depth to discuss their impact and, again, how they prepared the stakeholders for the game changing innovation to come.

- **AGC BIM Guide.** The Associated General Contractors of America were one of the first to publish and promulgate a guide to BIM. It established AGC and its sister organization the BIM Forum (www.bimforum.org) as pioneers.

- **U.S. General Services Administration (GSA) 3D / 4D BIM Program and Guides.** An article in Federal Computer Week in November 2006 (Reference 15) explained the initial “GSA mandate”:

  The General Services Administration has mandated that new buildings designed through its Public Buildings Service use building information modeling in the design stage.

  BIM is an emerging technology that involves creating a structure as a 3-D virtual model and linking it with data. GSA’s mandate covers the design phase, but advocates of the technology say it has far-ranging potential for use in ongoing facility management.

  “We are making this fiscal ’07 requirement as a minimum requirement,” said Calvin Kam, GSA’s BIM project manager. “We are encouraging [people], project by project, to go over and above the minimum.”

  The 3-D design is the most visible and striking aspect of BIM, but it is only one manifestation, Kam said. By connecting the spatial representation to data, agency officials can quickly calculate a building’s heating costs or see where design elements don’t correctly fit together. “Where we add the most value is working with customers to leverage the data they already have,” said Juliana Slye, director of government solutions in the infrastructure solutions division at Autodesk, a BIM vendor.

  GSA is just dipping its toe into the water, said Deke Smith, chairman of the National BIM Standard Project Committee.

  “Where they’re now requiring BIM is on space planning,” Smith said. “It’s only a piece of what BIM could be, even for a new building. It’s a very small first step. The long-range benefits are just huge.”

  GSA’s Office of the Chief Architect began working with BIM in 2003 and has completed 10 pilot projects, with 25 more under way, said Charles Matta, director of the Center for Federal Buildings and Modernizations.

  Technology has become increasingly important as GSA’s workforce has shrunk from more than 40,000 to about 12,500, Matta said. “When an [architect or engineering firm] brings in a design and says ‘Yes, it does have the efficiencies we require,’ we don’t have the means to go into their documents and confirm,” he said. “We don’t have the resources and staffing to do so. When they present a
model to us, it's easy."

Several software vendors offer BIM products, and GSA usually encounters them via the architectural firms involved in designing federal buildings, Matta said. During the past three years, GSA asked the companies to show that their technologies could work together.

"We wanted to make sure they all work toward an interoperable way of delivering" the data, he said. If, for example, a new architecture and engineering team joined an existing project, and the new team had a different BIM vendor than the original team did, they should be able to use the work product and not need to redo it.

GSA has an inventory of more than 342 million square feet of office space that houses 1.1 million federal employees, according to the agency. The agency owns about half of that space, in 1,500 buildings, and leases the rest.

GSA since 2003 has developed an extensive series of guides for its 3D/4D BIM program that encompasses the entire range of the facility life cycle. (Reference 16) Those guides include the following

- **BIM Guide 01 – 3D-4D-BIM Overview**
- **BIM Guide 02 – Spatial Program Validation**
- **BIM Guide 03 - 3D Laser Scanning**
- **BIM Guide 04 - 4D Phasing**
- **BIM Guide 05 - Energy Performance**
- **BIM Guide 06 - Circulation and Security Validation**
- **BIM Guide 07 - Building Elements**
- **BIM Guide 08 - Facility Management**
- **BIM Guide Terminology**

- **U.S. Department of Veterans Affairs BIM Guide.** (see [https://www.cfm.va.gov/til/bim/bimguide/lifecycle.htm](https://www.cfm.va.gov/til/bim/bimguide/lifecycle.htm)). As stated in the preface of the VA BIM Guide:

  - VA’s **Office of Construction and Facilities Management (CFM) has determined that Building Information Modeling (BIM) represents both an enhanced technology and a process change for the architecture-engineering-construction-facilities management industry. VA is committed to moving both the organization and its service providers to BIM as effectively and efficiently as possible, and to integrating BIM process requirements and Integrated**
Project Delivery (IPD) methodologies into its delivery requirements.

- The goal of CFM’s conversion to BIM is to deliver higher value and maximize lifecycle building performance to support VA’s mission to deliver excellent medical services. Just as the VA’s digitization of patient records has greatly improved the business and management process of care delivery for patients, so the digitization of building data will improve the design and management of VA buildings across their lifecycles—from concept to design to construction to operations to reuse and eventual demolition. And, just as standardized data in electronic medical records helps VA find ways to improve patient care, so standardized building data available electronically across VA will help the agency find better ways to design and manage its facilities in the future.

- **U.S. Army Corps of Engineers (USACE).** As stated,
  - As the U.S. Army Corps of Engineers (USACE) continues on its path towards fully utilizing BIM, ensuring that the private sector understands what is required to deliver a BIM-based project is paramount to success. This class will discuss the collaborative development of the USACE BIM contract language, discuss requirements, list deliverables, and explain the USACE BIM project execution plan (PxP) template and the new Minimum Modeling Matrix (M3).

- **Massachusetts Port Authority (Massport) BIM Guidelines for Vertical and Horizontal Construction** (see http://www.massport.com/media/1143/bim-guide-071715-disc.pdf)

- **State of Wisconsin Building Information Modeling Guidelines for Architects and Engineers** (see https://doa.wi.gov/Pages/DoingBusiness/BIM.aspx)

**UK Initiative**

The UK has promulgated a robust and comprehensive approach to BIM. (see Reference 17) David Philp, Head of BIM Implementation Cabinet Office of the UK Government explained that a key driver for the UK was the conclusion that “Government as a client can derive significant improvements in cost, value and carbon performance through the use of open sharable asset information”. The UK Initiative has
been focused on key drivers from the outset: cost, carbon and the entire building lifecycle, from planning through construction and occupancy.

Part of the overall strategy was to have both a “pull” (Government-Be good at buying data—as well as assets and services—and do it consistently); and “push” (Supply Chain—Early Warning to Mobilize, Training and Methods & Documentation)

This governmental-level initiative was similar in nature to the “stake in the ground” by the U.S. General Services Administration (GSA) in 2003, when a certain level of BIM compliance was mandated for GSA’s capital construction projects (see narrative and reference above).

In the case of the UK, in their published “Government Construction Strategy,” they succinctly stated that the Government will require fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016. A staged plan was scheduled to be published with mandated milestones showing measurable progress at the end of each year.

Where does the UK initiative stand today? The NBS National BIM Report 2017 (Reference 18) is an annual comprehensive assessment of BIM in the UK. What are the key findings in the 2017 report? Among the headline statistics in this year's study are the fact that:

- A majority of respondents (51%) think that the Government is on the right track with BIM and awareness is near-universal and adoption is up (62% of practices use BIM on some projects - up 8% year on year). Indeed, the year just gone has seen the most rapid BIM growth since 2014. 78% see BIM as the future of project information. There is, however, work to do - 65% said BIM can bring real benefit beyond the design stages but 72% believed clients don't understand these benefits.

- Government hopes that BIM will help in delivering projects for lower cost, more rapidly, with fewer greenhouse emissions and a better trade balance for construction projects. Our survey showed that 60% of respondents think that BIM will help bring time efficiencies, reducing time from inception to completion, 70% believe cost reduction in the design/build/maintain lifecycle will be realised. Those who responded were, however, less convinced on BIM's ability to reduce greenhouse gas emissions (44% agreed) or improve the trade gap (32% agreed).

- A majority thought the Government was failing to enforce the mandate. A third of respondents stated they were not clear on what they had to do to comply with the BIM mandate. Many cited a lack of client education
limiting the effect of the BIM mandate to fully reap the fullest rewards. Across the board nearly 18% of respondents said they used BIM on every project - 29% said they used BIM on more than 75% of projects. Our survey shows that once BIM is adopted it usually becomes the design methodology of choice.

- For the first time a majority describe themselves as confident in BIM (55% - compared to 35% back in 2012) but 90% said BIM adoption requires changes in workflow, practices and procedures. Learning from colleagues (75%) and fellow professionals (62%) were cited as key ways people keep skills sharp. Professional bodies and expert organisations, such as NBS, the BIM Task Group, BSI and RIBA, were also deemed significant.

- Thinking about BIM maturity most respondents said that Level 2 was the highest level reached on a project (70%). 7% said they were at BIM Level 3, 22% at Level 1. Our survey shows more than three quarters of organizations who have adopted BIM are at or beyond the level required by the BIM mandate.

- Respondents were clear in their demand for manufacturers to provide BIM objects and well-structured generic objects. 45% said they use a BIM object library - 66% create objects as needed and a similar number create objects in-house and re-use them across multiple projects. Placing standards and specifications squarely in the BIM environment via BIM software tools was also seen as key.

- 41% of respondents use Autodesk Revit, just 14% AutoCAD. Indeed, Autodesk dominates the UK market with 66% using an Autodesk product; that said Graphisoft, Nemetschek and Bentley have a significant user base. 35% manage specification references digitally using a free plug-in from NBS.

As a profound insight, the strategy also included a very well-crafted approach to the culture and organization of the industry. (see Figure 8)
Richard Waterhouse, Chief Executive at the UK’s NBS and RIBA Enterprises (a partnership with the Royal Institute of British Architects) expanded on the vision and strategy for the UK and BIM and his session at the 2017 AIA Workshop in Orlando.

Richard focused on both the technological challenges as well as cultural barriers to achieving the UK’s goals. He first quoted David Philp, mentioned above, and his comment that “The biggest danger is that we get bogged down in a technical discussion, when BIM is a behavioral change programme more than anything else.”

Richard also quoted Francis Maude, a Minister in the Cabinet Office, about the overall UK Vision for BIM: “This Government’s four year strategy for BIM implementation will change the dynamics and behaviors of the construction supply chain, unlocking new, more efficient and collaborative ways of working. This whole sector adoption of BIM will put us at the vanguard of a new digital construction era and position the UK to become the world leaders in BIM.”
One of the key steps Waterhouse outlined for success was the development of a clearly defined Master Information Delivery Plan (MIDP). Another way that Waterhouse describes in a series of graphic images is to align the process of design and construction and clearly plan the work.

One of the key accolades that Waterhouse and the rest of the UK initiatives players has received is a compliment from Patrick MacLeamy, CEO of HOK, who stated “The UK programme based on the BIS BIM Strategy is currently the most ambitious and advanced centrally driven programme in the world. The UK has a window of opportunity to capitalize on the success of its domestic programme and to take on a global leadership role in BIM exploitation, BIM service provision and BIM standards development.”

The significant metrics that are embodied in the UK’s initiatives are included in their “Construction 2025” publication and the Digital Built Britain branding to include:

- Lower costs by 30%
- Faster delivery by 50%
- Lower emissions by 50%
- Improvement in exports by 50%

How does the Digital Built Britain expect to achieve these goals?

- Level 2 legacy activity, to continue to drive Level 2 uptake
- Addressing those development needs which are grounded in current knowledge and understanding (eg developing new construction contracts, IPR protocols, some aspects of data interoperability);
- Areas going beyond our current knowledge and requiring the interaction of differing technologies (eg sensor and systems).
What has been one of the most powerful aspects of the UK, NBS and Digital Built Britain efforts is their totally open, free and excellently designed websites. One example is shown in the image below and can be accessed at [http://bim-level2.org/en/](http://bim-level2.org/en/).

![UK BIM Level 2 Website](image1)

**Figure 10 UK BIM Level 2 Website**

**Technology in Architectural Practice (TAP)**

The AIA TAP is one of over twenty knowledge communities that form a very robust community of practitioners at the Institute. AIA TAP has been in the forefront of the industry, and two of the key activities that TAP has sponsored, Building Connections Congress and BIM Innovation Awards, are discussed below.

**Building Connections Congress (2004-2018)**

In 2004 AIA TAP began an annual event focused on Innovation in Technology and Emerging trends that would drive innovation. ([Reference 19](#)) The event has been consistently held for 14 years, culminating in 2018 with an all-day session entitled “The Future of Design.” With the major modules of the conference including “Module I—Teach Machines to Think Like Us” and “Module II—How Machines Do Things for Us”. The breakdown of content from this latest session is one worthy of further research, with topics including:

- Exploring Ideas and Building Expertise through Machine Learning
- Big/Data/machine learning as media for (re) training client expectations, capabilities and outcomes
Data Before Automation. Collecting Data today to Drive Automation and Artificial Intelligence in the Future

Automatic for the People: Learning from machine learning, embracing and capitalizing on AI

Functional Modeling: Enabling Computational Design

Machine Learning and Project Delivery (Smartvid.io)

AI and Machine Learning for Construction

Machine-Readable Deliverables

Bio-Inspired Robotic Swarm Construction

Figure 11 AIA TAP Building Connections Congress in 2004 and 2015

BIM Innovation Awards (2005-2018)

In 2005, at the same time that various owners were developing initial Guides and Programs for BIM, the American Institute of Architects (AIA) Technology in Architectural Practice (TAP) BIM | Innovation Awards began a program to highlight the best of BIM illustrated by case studies. In particular, the category most aligned with the Institute itself was Stellar Architecture. This was defined by excellent architectural expression that could not have been achieved without BIM technology. From 2005 to 2017, 13 years of awards programs were promulgated (Reference 20)
The first several years of the AIA TAP BIM awards showed the true value of BIM as an innovation tool, even in the early days of 2005. The first year that the Stellar Architecture award was given in 2005, the jury decided that Arup, an engineering firm, was the winner for the Beijing Swim Center for the 2006 Olympics. The exterior of the building, not to mention the schedule and logistics, could not have been achieved without BIM and without addition technologies Arup deployed.

In 2006, the second year of the BIM awards, the juror awarded the Stellar Architecture Award to Mortenson Construction, a contractor (!), for the Denver Art Museum. Again, as the Mortenson team attested in numerous presentations after the award was given, the project could not have been achieved without BIM. And, in fact, over 250 separate models were developed to complete the project.

In 2007, another interesting result was promulgated by the AIA TAP BIM Award jury. The Stellar Architecture award was presented to Kieran Timberlake, a small-medium sized architectural firm from Philadelphia, for the Loblolly House. The Loblolly house was an example of how a modest firm could achieve design and technical greatness, even on a residential scale.

From 2008 to 2018, a continuing parade of significant projects have been awarded both Stellar Architecture and many other categories in the now Innovation Awards by AIA TAP, all demonstrating Game Changing Innovation.
Clash Detection

One of the first uses of BIM was in 3D visualization and then spatially comparing various systems and disciplines in a building during design and construction.
As BIM authoring tools have become mainstream, one of the key issues that remained in the design process was conflicts in three-dimensional space between various disciplines, such as structural elements in the same space as mechanical piping, electrical conduit, and major pieces of equipment. And a nuanced example of these conflicts is the access space required beyond equipment for periodic maintenance (such as lubrication or filter replacement), as well as overall equipment repair and/or replacement.

Navisworks is a software tool introduced in 2001 that dramatically improved the quality of BIM/VDC modeling by pulling in various discreet models, registering them accurately in 3D space, overlaying them to illustrate clashes and then documenting the correction and resolution of the model defect. The automation and visualization provided by tools such as Navisworks and Solibri Model Checker was an incredible step forward in productivity and design quality.

**Model Checking**

Model checking as epitomized by Solibri Model Checker took the identification and resolution of design issues to a whole new dimension, far beyond just 3-dimensional clash detection. Questions such as 'does my project meet the life safety code or are security zones required by a project fully addressed in the design' were easily and quickly resolved by Solibri. Of course, this presumes first that a useful model has been created, second that a set of rules or constraints has been properly created, and third that a tool such as Solibri is used not just once but iteratively to correct deficiencies and continually improve the design throughout the project lifecycle.

One of the most illustrative examples of the power of BIM, digitalization and model checking is in the work performed by GSA’s 3D 4D BIM team lead by Calvin Kam, PhD in collaboration with Chuck Eastman’s team at Georgia Tech. The collaboration team utilized BIM, visualization and Solibri Model checker on a new courthouse. As illustrated in the composite image below, the critical issue was building circulation and the separation of security zones within a complex architectural design. The most significant security issue in courthouses is the separation of occupant circulation into three fundamental zones for the judges, the criminal defendant, and the public.

When the design of the courthouse becomes a complex three-dimensional puzzle vertically and horizontally, the opportunities for conflicts violating the security issue abound. In this case, a BIM was created of the courthouse. This BIM included all of the floor levels, spaces, and connecting corridors. Then constraints or “rules” were created about what could be adjacent to each other and what circumstances would violate the rules. Then Solibri Model Checker was used to run the constraints through the model and assess whether the design was in compliance. The amazing metric about this case study was the **27,000 routes were tested through the design checking against 302**
circulation rules, all within 20 seconds!! What would have happened if this technology had not been deployed? As the team looked at the scheme being checked, they realized that the judges, in order to reach their library in another wing of the building, would have had to go down to the sub-basement parking level and then back up in order to avoid the public and the criminals along the way. So an embarrassing and costly design error was caught in design before it was implemented in construction!

Figure 14 Illustration of Automated Circulation Validation Using BIM in the GSA 3D/4D BIM Program
Figure 15 Illustration from GSA 3D/4D BIM Program of power of automation and BIM in Analyzing Complex Rules in BIM
Simulation

While the power of BIM as a three-dimensional modeler and the advantages to an entire collaborative design team has been discussed above, simulation of the activities that occur within and to a facility is also an important innovation. While some of the 4D BIM tools will be discussed in the Immersive Technologies section later, simulation of other aspects of a building also include energy performance and even occupancy factors. Michael Kilkelly, in an article entitled “Five Digital Tools for Architects to Test Building Performance” (Reference 21), discusses tools for energy modeling, including DOE 2.2, EnergyPlus, VABI Apps, Sefaira Architecture, Autodesk’s Green Building Studio, OpenStudio by the National Renewable Energy Laboratory (NREL), IES Virtual Environment for Architects, as well as several outsourcing options including BIM IQ Energy.

Simulating occupancy of a building is another important subject and Autodesk has done some significant research on this subject (Reference 22). Topics include how to build your own simulation tool, and modeling the occupants of a building in various scenarios.

The importance of this topic is that occupants can dramatically affect building performance by their actions, and that is an important issue in modeling a building’s performance. Several research efforts have documented this idea of simulation and its potential on both building design as well as energy performance. The first is by Autodesk Research (Reference 23) and in particular a case study of 210 King Street which established a dataset for integrated performance assessment.

Also researchers at Carleton University (Reference 24) have written a research paper which describes the following in their paper abstract:

*Building Information Modeling (BIM) and its open standard Industry Foundation Classes (IFC) are becoming popular in the design phase in the Architecture and Construction industry. Here, we focus on integrating BIM and DEVS (Discrete Event Systems Specification) simulation of occupancy analysis. We present a case study for Copenhagen’s New Elephant House, where people can move with different direction probabilities and wait randomly when visiting in the two floors of this building. The idea is to automate to extraction of building information that can be subsequently used in a simulation. We also show how to obtain advanced 3D visualization within BIM authoring tools. This work brings designers to understand better among different building properties occupancy management and future improvement.*

And Lawrence Berkeley National Laboratories (LBNL) actually has an online app (see http://occupancysimulator.lbl.gov/) which “… takes high level input on occupants,
spaces and events, then simulates occupant movement and generates occupant schedules for each space. The generated schedules capture diversity and stochastic nature of occupant activities. These schedules can be downloaded and used for building simulation.

Figure 16 LBNL Online APP to compare Occupancy Impacts on Building Spaces
Another example of simulation is United Rentals, presented by Jim Bedrick FAIA in our 2017 Workshop in Orlando, when he explained how the company is utilizing simulation and virtual training to enhance training on their own equipment.

Computer Aided Facility Management (CAFM)

Computer Aided Facility Management (CAFM) is a category of software tools that focuses on the facility management and operations end of the project life cycle. A concise definition and comparison of CAFM, CMMS and IWMS (Integrated Workplace Management System) or also known as IWOMS is provided on the Whole Building Design Guide (WBDG) at [Reference 25]:

Not to confuse a Computerized Maintenance Management System (CMMS) with a CAFM system, consider a patient room in a hospital. Ensuring that the Nurse Call System in the room is "properly inspected, maintained, and repaired" is a CMMS activity. "Knowledge" about the medical department staff, and the specific patient(s) in the room, the room's contents (phones, TVs, beds—including their movement from room-to-room), and equipment connections (electrical, oxygen, communications, etc.) relate to CAFM activities. CMMS and CAFM systems have begun to continue to merge into Integrated Work Order Management Systems (IWOMS).

The WBDG further defines the purpose of CAFM as:
Computer-Aided Facilities Management (CAFM) includes the creation and utilization of Information Technology (IT)-based systems in the built environment. A typical CAFM system is defined as a combination of Computer-Aided Design (CAD) and/or relational database software with specific abilities for Facilities Management (FM).

The purpose of a CAFM system includes:

- Helping the facility manager ensure the organization's assets are fully utilized at the lowest possible cost, while providing benefit to every phase of a building's lifecycle, and

- Supporting operational and strategic facility management, i.e. all of the activities associated with administrative, technical, and infrastructural FM tasks when the facility or building is operational, as well as the strategic processes for facilities planning and management.

Why is CAFM game changing? Again WBDG provides a summary of all of the various functions that can make this a game-changing innovation:

Benefits of CAFM usage in FM tasks can be organized into quality of life, cost reduction, cost avoidance, and information improvement. Typical benefits include the following:

- More efficient space utilization to achieve cost savings and potential reduction in asset inventories.
- Reduced moving and relocation activities resulting in greatly reduced relocation costs.
- Continuous improvement in FM efficiencies.
- Improved project planning leading to reductions in architectural and engineering, construction, and building maintenance costs.
- Fast and accurate reporting on critical facilities information.
- Existing processes will become more efficient and streamlined, using standardized data that is shared across the enterprise.
- CAFM will give facilities managers the tools necessary to become more proactive instead of reactive to facilities’ requirements and enable better decision making.
- Improve safety and environmental planning capabilities, reducing risk from accident and regulatory compliance violations.
• Disaster planning capabilities are significantly improved to reduce the potential for human injury or death in a disaster as well as to improve those planning capabilities required for operational recovery.
• Data standardization across the organization and the elimination of redundant information held by multiple organizations in various degrees of quality and accuracy.

**Computerized Maintenance Management Systems (CMMS)**

The comparison of CMMS with CAFM and IWMS was mentioned above in the article on WBDG. Again, WBDG provides a concise summary description of CMMS (Reference 26).

CMMS are used by facilities maintenance organizations to record, manage, and communicate their day-to-day operations. The system can provide reports used in managing the organization's resources, preparing facilities key performance indicators (KPIs)/metrics to use in evaluating the effectiveness of the current operations, and for making organizational and personnel decisions. In today's maintenance world, the CMMS is an essential tool for recording work requirements, tracking the status of the work, and analyzing the recorded data in order to manage the work, produce reports, and help control costs. Facility professionals use tools to manage the planning and day-to-day operations and maintenance activities required for a single facility or a large complex. These tools also provide all of the information required to manage the work, the work force, and the costs necessary to generate management reports and historical data.

Perhaps most important are the key capabilities of a CMMS:

- Operating Locations
- Equipment
- Resources
- Safety Plans
- Inventory Control
- Work Request
- Work Order Tracking
- Work Management
- Quick Reporting
- Preventative Maintenance
- Utilities
- Facility/Equipment History
- Purchasing
- Facilities Maintenance Contracts
- Key Performance Indicators (KPI) Metrics
Specialized Capabilities and Features

What makes automated systems such as a CAFM, CMMS and IWMS so game changing? Consider the analysis performed for the Department of Defense Health Administration by Onuma Inc. In looking at just one aspect of facility management for their world-wide health care facilities, work orders, in their FM current application the Onuma team analyzed the status quo process for initiating, processing, and completing a work order.

The first diagram below details the final calculation of 70 minutes to complete a work order. But on a global basis, defense FM processes 783,917 work orders annually for all of the health facilities worldwide.

The second diagram then calculates the cost of this current analog work order process, given current labor rates: $113,407,424 annually. Surmising that making this process entirely digital and automated could save at least 30% of this annual expenditure, the savings would be over $33 million annually.
Figure 19 Illustration of power of Automation when a Field Order can become Digital in Workflow
In addition to many organizational and project/facility benefits, automation of just one specific function could save tens of millions of dollars. Transforming other existing laborious and analog processes into digital workflows offer the same potential for speed, accuracy and cost efficiency and would make for game changing improvement in the management of facilities.

**Immersive Technologies**

The applications described above have demonstrated both cost efficiencies and overall project improvement. Immersive technologies that take the 3D improvements of BIM and move beyond that to additional dimensions such as 4D, 5D, 6D, 7D and beyond present the possibility of quantum improvements for designers, constructors and users of the built environment. The ability to place one-self directly into the design and seeing the impact beyond geometry to include time, cost, sustainability and the entire project life cycle is a game changing innovation.

One commentator and consultant on this subject has concisely diagrammed *(Reference 27)* the concept of immersive technologies:

![Figure 20 3D 4D 5D 6D and 7D BIM from BIMpanzee.com](image)

The concept of immersive technologies also includes “Reality”, with descriptions and case studies of virtual and augmented reality. The purpose of this section is also to explore beyond the typical 3D characterization of BIM and beyond just modeling to also
making, i.e. not just authoring objects in a computer but also physically generating them in 3D printing machines.

3D Printing

Autodesk has an excellent article on the background and history of 3D Printing, entitled: “A History of 3D Printing in Construction & What You Need to Know”, written by Heather Head (Reference 28).

Heather outlines the history in the following historical moments:

- Full-Scale Practical Applications: Where We Are Now (2000-2016)
- Near Future Applications: Where We’re Going Soon (2017-2020)
- Speculative Future Applications: The Wild, Wild Not-So-Distant Future (2050 Maybe)

3D / Laser Scanning

One of the earliest adopters and implementers of 3D / Laser Scanning for design and construction was developed by Calvin Kam and the 3D/4D BIM team at the U.S. General Services Administration (GSA), as early as 2003-2005. Taking what was typically at the time considered a specialty survey tool and methodology, Kam created an array of very effective case studies with GSA projects and existing facilities. From early stage project feasibility, all the way through construction commissioning, handover and facility management and operations, the 3D/Laser Scanning technology provided immense benefits. One example was the Philadelphia Custom House, an historic building built in 1937 that needed its envelope repaired, including ornate and complex gargoyle ornaments. The project included 8 roofs, 1050 windows, documentation of defects, and a building information model that could be provided to the design term for further project documentation.

Figure 21 Philadelphia Custom House Envelope Repair

Enabled by 3D Laser Scanning
Fast Company Magazine in October 2015 (Reference 29) entitled “These 3-D Scans Are Digitally Saving Ancient Monuments before ISIS Blows Them Up”. For both historic structures mentioned above in Philadelphia and ancient monuments in war torn Palmyra, 3D/Laser Scanning provides optimistic promise. The article mentioned a nonprofit firm called CyArk who is taking the lead on combining BIM, Drones and 3-scanning of ancient architecture to digitally preserve it for the future. They will achieve their goals by either recreating the ancient monument in a virtual reality environment for a global audience of viewers, or using the scanning as a roadmap for creating an actual physical rebuilt structure. They have embarked on this initiative in collaboration with the International Council of Monuments and Sites and are in the process of digitally documenting dozens of at risk sites.

After the automated work in the field is completed and the data is collected, the team goes back to their offices in Pennsylvania for processing and later deep archiving. The data can be turned into 3-D models, images, interactive virtual tours, and blueprints for reconstruction. “It’s like you’ve virtualized the site,” says one of the CyArk principals. “You can continue to work on that information and study it, plan future restoration efforts, without actually being in the field.” CyArk’s larger mission to document all of the world’s historic sites and over a five-year period they’re planning to digitally save 500 heritage sites.

The 3D / Laser Scanning technology is actually combined with aerial drones and photogrammetry to achieve their mission. As described at (Reference 30) a French start-up company Iconem is taking the steps needed for integration of these technologies. Utilizing over 20,000 images of a particular site the firm stitches these 20,000 images together using photogrammetry techniques. With an algorithm that analyzes spatial properties obtain from imagery as well as the drones, they are able to triangulate spaces for accurate location and even detect and render texture and colors accurately.

![Figure 22 Illustration of a Room Inside Historical Palmyra Palace with Imagery from 3D Laser Scanning, Aerial Drones and Photogrammetry](image)
There have been several recent articles discussing the role of 3D/Laser Scanning and the construction industry. Erin Fallon (Reference 31) wrote about “scanning the third dimension” and outlined the following key points:

- What is 3D Laser Scanning
- Primary Uses
- Reported Benefits

Jeff Yoders in May, 2014 wrote an insightful article (Reference 32), entitled, “How Laser Scanning Helps a Building Company Save Time and Money in the Field”. This was a great case study illustrating how Gilbane Co and the technology provider Faro Focus 3D worked at the National Institutes of Health (NIH) to generate value to that campus environment.

Matterport (Reference 33) highlights its features and suggests on its opening webpage: “Streamline documentation, 3D scan as-builts, and collaborate with ease. With Matterport, creating 3D models takes almost no time at all”

There are several published sources that include best practices and advice for planning and implementing 3D/Laser Scanning.

A Building Design and Construction Magazine article in February 2015 (Reference 34) described “9 best practices for effective laser scanning” which included:

1. Identify the intended use of the laser scan data.
2. Educate your customer on laser scanning technology.
3. Understand the physical space where laser scanning is being applied.
4. Know the project scope.
5. Determine the required deliverable.
6. Establish project survey control before you start scanning.
7. Collect more data than you need, because “more is more.”
8. Assess time available to deliver the finished product.
Another technology already making progress in construction is 4D Scheduling. This can be defined as: “4D Building Information Modeling” 4D BIM is a process that involves the intelligent linking of a 3D digital model with time or schedule related information. It provides precise and useful construction project information for teams.”

A company such as Srinsoft (Reference 35) explains how the expertise and advantages of technologies such as Naviswork Manage and Synchro 4D can make tremendous strides in the areas of:

- Risk mitigation due to improved team coordination and communication
- Conflict detection
- Improved delivery time and cost savings
- Improved quality

It is interesting to look at the historical roots of this technology, as documented in a paper published by Bonsang Koo and Martin Fischer of Stanford University’s Center for Integrated Facility Engineering (CIFE) in August 1998 (Reference 36). Although the article outlined the benefits and limits of 4D CAD, it laid the theoretical framework for progress 20 years later.
The firm Synchro goes on to brand its form of 4D scheduling a “Digital Construction Platform” (see https://www.synchroltd.com/). Synchro highlighted one significant case study, explaining how the integration of the model and schedule affords the design/construction team greater detail and also enables in many cases the exact timing of key project elements. Whether it is egress pathways, foundation phasing, notifications to the owner, scaffolding crane placement or many contractor needed information, 4D BIM fleshes out critical activities and sequences of construction.

5D and Beyond

If 4D BIM discussed above has major benefits, going beyond 4D to 5D and additional dimensions has the potential for dramatic quality, cost and schedule improvements. Haskell (Reference 37) describes what we mean by 5D:

“Use 3D models linked to schedule with time and cost. Clearly visualize the construction sequence and cash flow of the project. Adding the element of Time to the 3D BIM model as the 4th Dimension produces a visual simulation of the sequencing for the project. This helps convey the project schedule to our clients in a clear manner, bringing the schedule to life, beyond a lengthy paper schedule Gantt chart that can be difficult to process.
Moreover, the 4D sequencing video can alert our project managers to potential conflicts in work areas before they occur. Linking the project estimate to the BIM model produces a 5th Dimension, Cost, that highlights the cost of work associated with the different sequences of the project through the progression of time."

Perhaps the most comprehensive description of 3D, 4D, 5D, 6D BIM is available at the knowledge base of UK’s NBS (Reference 38), with the following key categories:

- **3D** (the shared information model). This is what everyone is most familiar with, creating a mixture of graphical and non-graphical information capable of being shared in a Common Data Environment (CDE).

- **4D** (construction sequencing). This 4D BIM adds the next additional dimension of scheduling data to the project information model. So now the BIM becomes time-related, which can include project aspects such as lead time, how long components take to fabricate, install/construct, and other details such as operational testing, curing, hardening, etc. This also includes sequencing which is critical to scheduling.

- **5D** (cost) 5D BIM adds the ability to extract cost data throughout the use of the BIM.

- **6D** (project lifecycle information). 6D BIM goes to the end of the project life cycle and provides information supporting facility management and operations. Optimizing a facility for energy, organizational and other factors is a positive by-product of 6D BIM

- **Beyond 6D**. To fully realize the potential of the work already done to develop and populate the model, 7D-nD models enable continual updating of the model. This is particularly relevant when we talk about sensors or the Internet of Things (iOT)

**Augmented Reality | Virtual Reality | Mixed Reality**

Virtual Reality (VR) and Augmented Reality (AR) have seen an explosive amount of interest in the past year or two. Now the term “mixed reality” (MR) is coming into use. What do these terms mean? An article on Foundry.com (Reference 39) provides some insight and the highlights are paraphrased below:

- **Virtual Reality (VR)**. Virtual reality is the process of creating a truly immersive experience for the user. With technologies such as computer-simulated reality, the physical environment of the real world is replicated in a virtual or imaginary world. Interaction of the building in this manner has powerful implications. VR can be considered an over-arching umbrella term for many different immersive experiences, whether it uses real world content, user-generated synthetic content, or a hybrid mixture of both.
• There has been a tremendous amount of activity by many technology firms in developing content-viewing hardware such as head-mounted display and the range has been from simple and very cheap Google Cardboard to relatively expensive HTC Vive. Cameras that help to create these immersive experiences are also an amazing innovation, including products such as the Nokia OZO launched in December; GoPro has its Odyssey—a collaboration with Google Jump; Ricoh has Theta; and there’s also Bublcam and Giroptic.

• 360 Degree Video is an immersive experience which utilizes only real world content obtained from filming with a 360 degree camera. It differs from VR, which includes non-real-world content noted in the next definitions.

• Computer Generated VR (CG VR) means that the immersive experience is entirely computer or machine-generated. The rendering the 3D world can be from realistic to fantastical. It is possible to blend both the 360 Degree video and computer-generated, and this is often the most prevalent today in applications from cinema to actual renderings of buildings, interior spaces and even urban environments.

• The AR/MR Debate. Augmented Reality adds additional synthetic information for the user to an immersive view of the real world. Technologists have coined the term Mixed Reality to essentially convey the same things. For the consumer world, AR seems to be the more prevalent term in use, propelled by firms like Apple, Microsoft, Amazon and Google in their emerging product offerings. Regardless, we will explore both definitions below:

• Augmented Reality (AR) can be described as a technical overlay of content on the real world, but that content is not anchored to or part of the real world. In other words, there is not interaction between the two. Ikea has an app that shows their products in a consumers own kitchen or living room, so one can view many alternatives from the Ikea catalog with a technological boost to their own visualization and imagination. Google Glass had similar aspirations and promised the AR experience could be infinitely portable.

• Mixed Reality (MR) is an interesting counterpoint to AR in that the synthetic or computer generated content is overlaid on the real world, but actually is anchored in space and interacts with the real world in 3 and even 4 dimensions. Surgeons, for example, might overlay analytic imagery such as CT scans or ultrasounds in a MR view as they operate in real time on a patient. Microsoft has created its HoloLens and is actually calling it another term: “holographic computing.” The Foundry article provides a perspective on this reality discussion for the future and moving forward:

As Autodesk’s Redshift (Reference 40) notes in the article “What Is Augmented Reality, and How Can It Help Architects and Contractors?” from Architecture Magazine written by Jeff Yoders in March 2014, augmented reality is a “live, copied view of a physical, real-world
environment whose elements are augmented (or supplemented) by computer-generated sensory input. Virtual reality replaces the real world with a simulated one, whereas augmented reality takes the real world and adds to it with—in the case of architecture—a 3D model of your design.”

The technology allows for advanced augmented reality technology that also might include image recognition so the user is much more engaged in the 3D content the built environment moves from “imagery” to a digital manifestation. What is necessary, of course, is real world coordinates from the synthetic content to mesh with the real world. Yoders explains and gives a current example: “AR Its utilization matured in the AEC industries in the past five years when contractors such as Seattle’s BNBuilders began using it to show clients proposed designs in the context of existing conditions using iPads and other mobile devices on a construction site.”

![Figure 25 Illustrating of Augmented Reality on a Mobile Device: Courtesy DAQRI](image)

The UK has become quite forward thinking about augmented reality in construction. UK Construction Online ([Reference 41](#)) describes in an article “Augmented reality and what it could mean for the construction industry” in April 2017 a new firm called DAQRI. The article explains two ideas:

- How do they describe augmented reality to the uninitiated?
- Their vision for the role augmented reality can play in the construction industry
AR is a technology that “overlays 3D digital content seamlessly onto the real world, using specialized hardware and software.” For example, AR can be used to overlay digital building information modeling (BIM) data directly on a construction site to help spatially orient architects, construction workers, and clients. AR BIM data can provide both a preview of what the completed project will look like as well as operational guidance along the way.

DAQRI’s has developed several rugged wearable AR products – DAQRI Smart Helmet and Smart Glasses – that are intended to do exactly what is described above for the construction industry. DAQRI’s products have applicability beyond just the construction phase, including the full lifecycle of a facility. Their AR products increase productivity, enhance training, and improve safety for enterprise businesses. Their vision includes worker training and even remote applications. Their “AR Work” application can reduce errors and improve learning curves. Their “Remote Expert” application also has the ability to share one’s point of view, thereby allowing the user to receive live assistance or collaboration from anyone, anywhere in the world. The “Thermographer” application can build a 3D model of an environment, and then add heat sensing information directly into the spatial information.

What possible roles can augmented reality play in the construction industry? One emphasis is on more tightly coupling design, build and operate phases of a facility, reducing excess back-and-forth and improving communication, quality and efficiency across all the stakeholders involved in making a new building a reality.

Skanska in particular has taken the DAQRI toolset and made real world use of it on their construction projects, tying the virtual and augmented tools together on the site (see image below).
And in August 2017, the University of Strathclyde in Glasgow (Reference 42) announced the creation of a consortium to build a new reality for construction. They have secured £1 million of funding from Innovate UK to develop the use of virtual and augmented reality in the construction industry. Among the ideas the consortium has included an “Augmented Worker System (AWE System)”, with the purpose of bridging companies with new AR technologies and design, construction, maintenance and the entire project life cycle. The consortiums ambitions are actually focused on ROI: “targeting a 25% cost reduction, 25% decrease in waste, and 30% increase in productivity on projects.” It is significant that this consortium is relying not just on technology but also high powered leadership supported by a steering group of industry organizations, including AECOM, Doosan Babcock, Laing O’Rourke, Autodesk and Microsoft.

**Reality Capture**

As Autodesk states (Reference 43) “Reality Capture is a photogrammetry software solution that helps you create 3D models from photographs or laser scans. Reality Capture vastly improves productivity, accuracy, quality, and safety throughout the project.”

![Figure 26 Examples of Hardhat and Augmented Reality Imagery Output. Courtesy Skanska and DAQRI](image-url)
This is perhaps another name for 3D laser scanning, but it describes another means of creating a “digital twin” for many purposes in design, construction, facility management and operations. The steps are

- Capture
- Compute
- Create

FieldLens is a company that specializes in reality capture. Their commentary (Reference 44) emphasizes eliminating errors at both the design and construction stage of a project. FieldLens relies on a 3D model that is created by a scan, then differences are noted between what is actually installed on the site and what is on the drawings and in the design. A further elaboration and more sophisticated application is the embedding of sensors around the site and feeding data back to a reality capture overlay of actual and designed.

Skanska is in the forefront of innovative technology for construction and utilizes reality capture effectively (Reference 45). Skanska sees the benefit as:

- Reveal inconsistencies between as-planned and as-built
- Increase predictability in the field and reduce risk
- Reduce change orders and improve schedule performance
Skanska combines several technologies (laser scanning, photogrammetry, and high definition 360-degree photography) and integrates them into a single view to assess how construction is progressing as well as conformance to the design.

![Image of several technologies (laser scanning, photogrammetry, and high definition 360-degree photography) and integrates them into a single view. Courtesy Skanska](image)

**Figure 27** Example of several technologies (laser scanning, photogrammetry, and high definition 360-degree photography) and integrates them into a single view. Courtesy Skanska

Procore, in an online presentation document ([Reference 46](#)), explains reality capture by explaining that although there is a lot of buzz about VR and AR, for many projects the most important and more basic and pressing need is to simply capture "actual reality. And in many cases, laser scanning can be logistically difficult or prohibitively expensive and photogrammetry can provide a low-cost alternative to laser-scanning. In examples such as very confined spaces, where just an approximation is needed, or broad contextual areas such as site and master planning, digital photography and photogrammetry can be a cost-effective and viable solution. So this is called "photography-based scanning" and utilizes surveying practices that go back to the mid-19th century. As Procore notes in its paper, “Today’s sophisticated photogrammetry uses multiple, overlapping digital images to not only capture and measure distances, but to build an increasingly accurate 3D visualization of the subject matter, with computer software using camera’s specifications, its lens, and its relative position, and then comparing common visual elements shared across multiple photographs”
What makes *immersive technologies* game changing? Above we have discussed the following:

- 3D Printing
- 3D Laser Scanning
- 4D Scheduling (4D BIM)
- 5D and Beyond
- Augmented Reality | Virtual Reality | Mixed Reality
- Reality Capture
- And even photography-based scanning

For all of these technologies, the ability to get closer and closer to reality and to be able to construct a “digital twin” is becoming more realistic. These all are immense advantages in engaging all stakeholders in a project earlier in the life cycle, reducing or eliminate design errors and construction deficiencies, and ultimately make the built environment higher quality and more responsive to all its creators and inhabitants.

Immersive technologies are game changing because roles and responsibilities, time to design and construction, cost and what actually can be created all are impacted by these technologies.
Internet Technologies

There are a range of technologies directly related to the internet, World Wide Web, and the cloud that are becoming powerful tools for design and construction.

Cloud Computing

What is cloud computing and why is it critical to the design and construction industry? As one CPA firm’s presentation document (online website) (Reference 47) describes cloud computing. "Cloud computing is a general term for anything that involves delivering hosted services over the Internet. These services are broadly divided into three categories: Infrastructure-as-a-Service, Platform-as-a-Service and Software-as-a-Service." Cloud computing is on the rise for the construction industry and the benefits include enhanced collaboration, productivity, ability, redundancy and cost-savings.

Cybersecurity

Along with the opportunity of cloud computing and the internet comes challenges and one of the most critical of challenges if cybersecurity. In an article Construction Executive Tech Trends (Reference 48) entitled "Cloud Computing Risks for Construction Companies" in January 2017. James Benham writes that many construction companies do not have cloud security policies and procedures in place. This includes cybersecurity defenses to protect sensitive project and client data.

Benham’s article describes best practices for cybersecurity and construction:

1. **Implement cloud liability insurance.** Cyber and privacy policies cover a business’ liability for a data breach in which a company’s personal information is exposed or stolen by a hacker or other criminal who has gained access to the firm’s electronic network.

2. **Hire a third party for audits and security.** Get an expert to assess the company’s system’s security and install the appropriate network security software.

3. **Train employees.** Companies should lead by example by setting up and communicating best practices and policies, enforcing safeguards and identifying suitable applications.

4. **Continuously update software.** Make sure all software and operating systems are current. Check with vendors as well to make sure they’re enabling updates and aren’t using any unsupported systems.

Another article in the Legal Intelligencer (Reference 49) describes how vulnerable the construction industry could become. Part of the challenge for the construction industry derives from its historical lack of innovation and, in particular, digitalization. If the industry is primarily analog and paper-based, there is little data to protect. Data is usually in hard copy form, printed and handed to partners throughout the project life.
cycle until handover to the client. Today, many large firms are fully adopting new technology tools, from BIM authoring and checking to cloud computing to collaboration, and from their back office operations to the construction field, commissioning, and ultimately facility handover. Those new digital tools are now becoming part of every aspect of a professional practice, construction company, construction job site and even facility management and operations. Other industries, such as finance or health care, have for years had strict regulations and protocols for cybersecurity, but the lack of such protocols for the construction industry are leaving them significantly susceptible to cybercrimes.

**Geo-Spatial | GIS | Location**

An article published in November 2016 (Reference 50) suggests that “Geospatial and BIM will be the key to transforming construction.” The article also references the McKinsey Global Institute’s report on “Imagining Construction’s Digital Future”: The report suggests that there are five technologies that will be transformative and two technologies, BIM and geo-spatial, will play a key role in digital disruption and transformation.

**Figure 28 McKinsey Diagram of Five Trends Shaping Construction**
Geospatial

About 4 million excavations are carried out on the UK road network each year to install or repair buried utility pipes and cables. Not knowing the location of buried assets causes practical problems that increase costs and delay projects, but more importantly, it increases the risk of injury for utility owners, contractors and road users. The problems associated with inaccurate location of buried pipes and cables are serious and are rapidly worsening due to the increasing density of underground infrastructure in major urban areas. In the U.S. it is estimated that an underground utility is hit every minute. Underground utility conflicts and relocations are the number one cause of project delays during road construction.

BIM

The construction industry has yet to adopt an integrated platform that spans project planning, design, construction, operations, and maintenance. The industry still relies on bespoke point solutions. Designers, contractors, and operators use different software that do not sync with one another. There is no single source that provides an integrated, real-time, full-lifecycle view of project design, cost, and schedule.

Trimble is a leader in geo-spatial equipment and technologies. In a February 2011 article in Geospatial World (Reference 51) Bryn Fosburgh notes the productivity gains possible integrating geo-spatial into construction projects. One of the major companies in this area is Caterpillar, who is naturally interested in geospatial for their line of products and their customers. In a 2006 study, they estimated that automated construction systems can provide time savings of more than 50 percent and a 43 percent reduction in fuel consumptions. Another study by the School of Science and Engineering at Reykjavik University in 2008 regarding pipeline trench excavation showed that automated systems produce savings of 20 percent in machine time and fuel consumption, and virtually eliminated over-excavation.
In November 2017, ESRI and Autodesk announced a partnership (Reference 52) to integrate the two technologies and improve their respective software offerings for customers. ESRI and Autodesk plan to build a bridge between their two technologies (GIS and BIM / CAD). Their plan is to enable a broad range of industries to “gain better context by visualizing data of the man-made world, the environment, citizens and the networks that weave it all together.”

“It is important to consider the needs of future generations during the design and building of projects today,” said Jack Dangermond, President, ESRI. “The benefits of partnering with Autodesk will include securing sustainable resources for the growing population, a responsible human footprint on our natural environment, better use of our planet’s resources and more resilient cities.”

Enabling BIM and GIS mapping software to more seamlessly work together will optimize infrastructure companies’ ability to plan, design, build and operate infrastructure assets saving precious time and money. Improving the integration of Esri and Autodesk software has the potential to dramatically decrease workflow times.

One of the goals are to provide industry and city planners the ability to design in the context of the real world. This will allow communities to build more connected, resilient cities, and infrastructure with a focused eye on sustainability. Benefits are expected to include unprecedented reductions in permitting through improved stakeholder engagement, more sustainable and resilient design through enhanced project insight,
and reduced risk via improved end-to-end flow of materials, resource availability and scheduling during construction.

**Sensors /Sensor Web**

Geospatial and BIM as technologies can be greatly enhanced with integration with sensors in the built environment. What are sensors and what is the sensor web? As noted in Wikipedia (Reference 53)

> The concept of the "sensor web" is a type of sensor network that is especially well suited for environmental monitoring. The phrase the "sensor web" is also associated with a sensing system which heavily utilizes the World Wide Web. OGC's Sensor Web Enablement (SWE) framework defines a suite of web service interfaces

Why could this be an advantage for many aspects of the building lifecycle, from planning, design through construction and facility management / operations?

One example of a start-up company making use of sensor technologies to improve construction site safety is Pillar Technologies (Reference 54). Pillar has developed smart sensors to deploy on construction sites, along with backend systems to turn the data collected from the sensors into a system for real-time alerts and long-term big data analytics of the risk level of construction sites and accidents.

The sensors can detect temperature, humidity, dust particulates, pressure, noise vibration and volatile organic compounds (which arise from an overload of varnish or paint). The sensors can be as small as a shoebox and, when spread around a construction site about every 2,000 sq. ft of a construction site or building space. The key to the success of the sensors is that data points gathered from hundreds of sensors can give a picture of the changing environmental conditions across an entire site. The most important thing this system does is give real-time alerts to site managers – for example rising temperatures or humidity in one part of the site.

Alex Schwarzkopf, co-founder of Pillar Technologies, explained that by getting this information quickly to contractors they can mitigate or prevent damages before it occurs. For example, a construction company could be alerted by the humidity sensor and catch water damage before it spreads to the rest of the building.

**Mobile | Wearable**

The mobile revolution in computing has made all of these technologies more accessible and useful for construction sites. A December 2017 publication (Reference 55) has outlined both challenges and opportunities. The next evolution of cloud computing is mobile cloud computing (MCC), and this idea of providing remote, mobile and ubiquitous access to data is particularly relevant to construction. While the main risks are information security, privileged user access, regulatory compliance, data location, availability, and disaster recovery. In terms of execution, cloud-based mobile
applications present mostly benefits since they enable users to execute ubiquitously high-performance operations in mobile devices.

**Conclusion to Immersive Technologies**

What makes automated systems such as Immersive Technologies so game changing? Perhaps the most compelling reason is that the built environment in time and space is now becoming more accessible and affordable for everyone, and that has profound implications for all the stakeholders in the design and construction industries.
Machine / Computational Technologies

As computational power continues to improve at an exponential rate, many of the technologies that utilize this power now have an opportunity to disrupt and transform the design and construction industries.

Artificial Intelligence | Machine Learning

What is Artificial Intelligence (AI) and Machine Learning all about and how could it be relevant to the construction industry? An Inc. Magazine article in December 2017 (Reference 56) by Christina Des Marais emphasizes the hype around AI.

An article in AI (Reference 57) also outlines 10 use cases for AI in construction, including:

1. Analogy-Based Solution to Markup Estimation
2. Neuromodex – Neural Network System for Modular Construction Decision Making
3. Neuroform – Neural Network System for Vertical Formwork Selection
4. Belief Networks for Construction Performance Diagnostics
5. Modeling Initial Design Process using Artificial Neural Networks

Engineering News Record (ENR) in September 2017 in an article by Andrew Rink (Reference 58) emphasized how AI can improve construction site safety. An AEC start-up called Smartvid.io has created software to inspect project photos and videos from construction sites to detect safety risks automatically. Think of it as a jobsite inspector who never sleeps.

One of the key data points about the construction industry is that although it is a huge industry in size, it is also currently causing 20% of U.S. worker deaths, according to the U.S. Dept. of Labor. Construction companies and insurers send trained safety experts to inspect jobsites every day, but they're expensive and there aren't enough to go around, making it impossible for every site to get the attention it needs. Millions of pictures and videos are taken on construction projects world-wide every week for documentation purposes and safety.

Smartvid.io is an example of a start-up company that is making use of these pictures and videos that usually sit idle in project management software and other storage medium. What Smartvid.io has done is take advantage of a dramatically new and emerging application of deep learning referred to as computer vision, or the mechanism that makes possible for computers to “see” what is in a picture or video. As Andrew Rink describes it:

> It's both tireless and all-seeing, often surpassing human vision. Just as your phone can identify faces in a picture, computer-vision engines can be trained to spot things that are missing, from a worker not wearing a hardhat or safety vest to scaffolding or stairs that lack railings.

> How does it do that?
It's not with algorithms written by programmers. Instead, Smartvid.io showed its AI engines hundreds of thousands of photos of construction sites that human inspectors determined as either safe or dangerous. The system then figured out for itself what it should look for to determine what constitutes "dangerous." This is the magic: A deep-learning system can debug itself as it analyzes the data for the problem at hand.

Autodesk has many resources, webinars and presentation documents on the topic of AI and design and construction. A webinar entitled “The Future of Making Things: AI in Design and Manufacturing” (Reference 59) describes recent advances in AI that are revolutionizing the creative process. One key point is that as industries such as manufacturing and construction become more digitized, AI can do wonders to simplify, amplify and increase efficiency in the making of things.

A JBKnowledge article on Artificial Intelligence in Construction (Reference 60) in February 2017 talks about AI in construction, autonomous equipment, and computational BIM. The article highlights AI as one of the most significant “game changing innovations” to revolutionize the industry. One example is autonomous equipment, or equipment that is aware of its surroundings and, therefore, capable of moving about a construction site and the built environment without human interaction. The technologies that it makes use of includes GPS, LiDAR, and radar. SmartConstruction is one such revolutionary application:

Komatsu provides a solution, SmartConstruction, which connects job site information concerning equipment and people. SmartConstruction allows users to survey their job site via drone or 3D scanner to produce a 3D model of the job site’s existing conditions, bring the data into KomConnect to automatically simulate creation of construction plans, and then transmit the data into automated driver less earth-moving vehicles to automate excavation.

Komatsu’s intelligent machine control can eliminate human error and prevent safety hazards that can occur when humans are exposed to heavy machinery. Traditional processes like staking and earth moving can be eliminated or significantly expedited with autonomous equipment.

Computational BIM is another example of automating the creation of elements inside a building information model, making use of parameters, data sources, geometry tools and interacting with other digital applications without human interaction.

BuildingSP is disrupting the BIM market with their product GenMEP. GenMEP is an add-on to Autodesk Revit that uses computer algorithms to automatically route MEP systems through Revit models and even point clouds captured from laser scanners without clashes. Users simply tag the start and end points of the MEP systems and GenMEP will...
automatically route those systems, with the goal of minimizing complexity and maximizing efficiency. GenMEP creates real Revit family content when generating these systems.

Another product from BuildingSP is ClashMEP, which uses data created from GenMEP to detect any clashes that occur when modeling new MEP elements in Revit in real-time. BIM modelers can use ClashMEP to check for clashes in real-time without having to leave Revit.

Computational BIM software like the tools mentioned above prevent human error and save time by removing the human labor necessary to produce all components of complex BIM models manually in Revit, to save materials by building systems more efficiently, and to prevent future coordination issues like clashes.

**Big Data / Analytics**

What is Big Data?

An article posted on TheBalance.com ([Reference 61](Reference 61)) by Rachel Burger in November 2017 discusses the implications and opportunities of Big Data in the construction industry. Big data is defined as a huge amount of data stored in the past and, in most cases, continuing to be acquired on a real time basis. In the case of construction, this can come from people, computers, machines, sensors, and any other data-generating device or agent. This includes both data acquired during design and construction, but also the entire project life cycle to a completed building, occupancy and operations. Sources of the data can be as diverse as on-site workers, cranes, earth movers, material supply chains, and even buildings themselves.

Big data can be understood in the context of current traditional information systems, including diverse project schedules, CAD files, cost estimates, invoices, labor time sheets. Big data often involves unstructured data such as free text, printed information or analog sensor readings. The value of big data isn’t on its own, but it’s what you do with it using big data analytics programs that count. It is useful to look at various stages in the building lifecycle to understand.

In the design phase, data inputs such as environmental data, stakeholder input, and social media data streams can improve programming efforts by helping to decide what to build, but also where. In the case of Brown University, big data analytics were used to decide the location and other factors of a new engineering facility. In the construction phase and even the procurement phase, big data from weather, traffic, and community and business activity can be analyzed to determine optimal phasing of construction activities.

Forbes has an excellent article highlighting the role of big data and analytics in transforming construction. Bernard Marr in April 2016 ([Reference 62](Reference 62)) noted that he is seeing construction firms with R&D resources and a focused mission are moving into areas such as real-time, cloud-powered analytics of large unstructured data relevant to
their business operations. JE DUNN, responsible for some of the largest construction projects in the US, has achieved break-through innovations by building partnerships with tech firms in order to develop industry specific tools. John Jacobs, CIO for JE DUNN, explained their use of Big Data:

“Here’s the primary issue – we have a complex process that we go through to build a building. We need access to 2D and 3D data, financial data, corporate data, documents, schedule elements, weather – all this has to be linked and it’s a complex web.

“The world has Dropbox and Go to Meeting to collaborate – we don’t have anything like that specifically for construction. So we had to set out to build our own. And that means we’ve created a tech foundation that we’re really finding to be transformational.”

JE DUNN partnered with Autodesk to build systems allowing real-time, data driven predictive modelling. They tied Autodesk’s large model viewing functionality with their own estimating system to develop custom visualization technology known as LENS.

“Now you have a picture,” says Jacobs. “The owner can see that concept model from our design partner and see the dollars tied to it. You can say ‘Show me what it would be like if we added another floor’ or ‘what if we made this part bigger?’ Every element in the design is tied to our cost estimate. It is completely integrated so the solution changes visually, on the fly.

“This changes everything – the owner can see that we understand what they want, and see that our numbers are right. That level of reliability is really changing the industry and effectiveness of our early pricing”

This massively speeds up the design process and already, even at this early stage, contributes to waste saving. Whereas before, minor changes to the design could mean several weeks or months of backwards and forward communications between architects, engineers and owners, insights into the effects of changes are now visible almost instantaneously.

But big data also applies not just to design and construction but to the broader concept of Smart Cities and regional urban planning. An article by Kaushik Pal in October 2015 (Reference 63) illustrates a real life example of big data helping build a smart city. Songdo is a city in South Korean, about 40 miles south of Seoul and near the Incheon International Airport.

Songdo, since 2000, had a vision of becoming a completely connected “smart” city. In collaboration with Cisco, Songdo has been working on wiring every inch of the city with fiber optic broadband. Some of the ways the city will function with this massive amount of broadband includes many aspects of everyday life. Traffic will be measured and regulated with the help of RFID tags on the cars. The RFID tags will send the geo
location data to a central monitoring unit that will identify the congested areas. Citizens will always know via their smartphones and mobile devices the exact status of public transportation and its availability. Even garbage collection will generate data. Residents who dispose of garbage will need to use a chip card in the containers. The city planners and architects along with Cisco are working on the concept of totally eliminating garbage trucks. Garbage trucks will not collect and dispose garbage anymore. Each house will have garbage disposal units and garbage will be sucked from them to the garbage treatment centers which will dispose it in an environment friendly way. The garbage will used to generate power for the city. Data will make life more secured for the citizens. For example, children playing in the parks will wear bracelets with sensors which will allow the children to get tracked in case they go missing. The smart energy grid can measure the presence of people in a particular area in a particular moment and can accordingly adjust the street lights. For example, the smart grids will ensure that areas that are scantly populated will automatically have some of the street lights turned off. This will result in a lot of energy savings.

Blockchain

Anyone who is aware of the current craze around crypto-currency and its underlying technology called “Blockchain” will wonder what the implications are of blockchain beyond the financial services and banking industries. Arup on the “Thoughts” portion of their website in April 2017 (Reference 64) has a good overall definition of Blockchain and the potential to enhance, transform and even disrupt the construction industry.

First, what is blockchain? A blockchain is a decentralized, tamper-proof digital ledger of transactions. Blockchain Technology was developed and deployed in 2009 as the technological foundation to Bitcoin, a digital cash system that has a peer-to-peer configuration. Computer scientists have long tried to solve the problem of having digital assets that cannot be copied and counterfeited. Blockchain enables “two or more parties to transfer monetary or any other representation of value, share information and run automated ‘smart’ contracts in a way that does not rely on a trusted third party like a bank, a notary or any private company as a trusted middleman.”

As Arup describes the benefits to come industries, it challenges the construction industry to step up to the plate, “Many global financial and legal institutions are exploring and discussing the potential impacts and opportunities of Blockchain Technology in their businesses. The security gains and cost savings for the financial, legal and technology sectors are obvious. Design, engineering and construction need to now examine the benefits of this technology.”

What is unique about blockchain for these industries? It is the “ability to create, validate, authenticate and audit contracts and agreements in real-time, across borders, without third-party intervention, makes Blockchain Technology appealing to many professional services organizations.”
Supply chains, especially ones that cross jurisdictions, political boundaries and borders, are ripe for this kind of game changing innovation. As Arup states, “The decentralized, permission-less and censorship resistant approach of Blockchain Technology opens up completely new ways to track the flow of materials, contracts and payments in supply chains. Knowing in real-time which materials have arrived at a construction site, who handled them and where they originate from, makes a blockchain potentially valuable to the operation of a circular economy.”

In addition to supply chains, just the concept of the “I” in Building Information Modeling (BIM) could make use of blockchain. “This could include smart self-executing contracts between the owner, operator and component or system suppliers involved. A blockchain could also be used to verify who added which components to the digital model.” And as the building is completed, the concept of the Internet of Things could make invaluable use of blockchain. “For as more and more things become interconnected, be it in transportation, infrastructure, energy, waste or water, we will need a trusted system for transactions between these autonomously provided services and information sources. A decentralized, industry wide blockchain could play a central role here.”

Design Automation

Design automation can be defined as utilizing computer power to run scripts on CAD BIM or other files, leveraging the scale of the machine to automate otherwise repetitive tasks. Architect Magazine, in June 2015 in “Why Architects Can't Be Automated” (Reference 65) explained design automation with respect to automation and labor:

In many service-based industries, workers have found themselves supplanted by algorithms. Accountants have given way to personal finance software, travel agents have been displaced by websites, and taxi drivers are poised to face off with self-driving cars. In a recent interview with NPR, Andrew McAfee, co-director of the Initiative on the Digital Economy at MIT, predicted, “Twenty or 40 years from now, we will not need the labor of a lot of the people alive in order to have a very, very productive economy.”
So if a computer can do our taxes, drive our cars, and book our holidays, could it also design our buildings?

The article goes on to look at the history, going back to the 1960s, of applying computer technology and automation to building design. There was even a book published in 1977, authored by Nigel Cross, entitled “The Automated Architect.” Much of the research at the time focused on automated redundant and tedious tasks for building design, ultimately failed. Why? The complexity of design goes way beyond the automating of tedious tasks. But, also, the 1970s and 1980s are not the 21st century, with AI, Big Data and powerful computing and cloud computing becoming cheap and ubiquitous.

The article continues to detail how both Autodesk and Google have pursued design automation
Autodesk and Google are two of several technology companies pursuing the potential of automated design. During the keynote presentation at Autodesk University last year, Autodesk chief technology officer Jeff Kowalski said his company is “developing a CAD system that learns the same way we do, by referencing mechanical engineering textbooks, and building codes, and part catalogs, and even by observing real-world examples.” In his nine years as CTO, he said, “This is the biggest, most fundamental change that I’ve ever seen coming our way.”

Fully aware that he was speaking to a room full of architects, Kowalski added that his company’s system would only be designing “starting points”—a companion to designers, rather than a competitor … for now, at least. (Autodesk hasn’t publicly released any tools that Kowalski discussed, but Project Dreamcatcher appears to be one hint.)

Autodesk’s Forge Platform (Reference 66) is one of the tools that allows for automate tasks, in particular on Autodesk’s own AutoCAD files, performing tasks such as:

1. creating new DWG files
2. querying for information in existing DWG files
3. purging drawings and saving them to other DWF file formats
4. plotting DWG files to DWF and PDF
5. translating text from one language to another

Digital Fabrication

Wikipedia (Reference 67) has a good overall definition of digital fabrication. Digital fabrication combines 3D modeling, BIM and CAD with either additive or subtractive processes in manufacturing. 3D printing is the additive process, and machining is the subtractive process.

An article in Wired UK by Neil Gershenfeld (Reference 68) provides a good explanation of the difference between Digital Fabrication and 3D printing, which was discussed earlier in our course. Gershenfeld, who leads MIT’s Center for Bits and Atoms, describes the hype around 3D printing as too much publicity, "The future is turning data into things, but it's not additive or subtractive." In 1952 the first milling machine was connected to a computer. As Gershenfeld continues, "What has grown forward is a digital revolution in making things. It's cutting, grinding, lasers, plasmas, jets of water, wires, knives, bending pins, weaving, molding, extruding, fusing and bonding." And Gershenfeld explains is the real revolution if “bringing programmability to the physical world”. He compares 3D printing to Lego construction sets. Whereas Legos enforce constraints in assembling thereby ensuring accuracy, 3D printing can often accumulate errors as it layers on top of bottom layers that might be imperfect. He sees 3D printing to the analog, and Legos closer to the digitalization that occurred when analog communication became digital.
Drones

Harvard Business Review in May 2017 published an article by Chris Anderson, editor in chief of Wired Magazine (Reference 69) entitled “Drones Go to Work.” Anderson describes a construction site with drones that are constantly scanning, creating archive photos and looking for errors and deficiencies. So drones are the new 21st century technology compared to cranes in the 20th century and, therein, lies the real revolution and game changing innovation. And these drones are assisting in “reality capture” (as described previously). And these technologies are truly transforming business.

“Reality capture” — the process of digitizing the physical world by scanning it inside and out, from the ground and the air — has finally matured into a technology that’s transforming business. You can see it in small ways in Google Maps, where data is captured by satellites, airplanes, and cars, and presented in both 2-D and 3-D. Now that kind of mapping, initially designed for humans, is done at much higher resolution in preparation for the self-driving car, which needs highly detailed 3-D maps of cities in order to efficiently navigate. The methods of creating such models of the real world are related to the technology of “motion capture,” which drives movies and video games today. Normally that requires bringing the production to the scanners — putting people in a large room outfitted for scanning and then creating the scene. But drones flip that, allowing us to bring the scanner to the scene. They’re just regular cameras (and some smart software) precisely revolving around objects to create photo-realistic digital models.

In some ways it’s astonishing that we’re using drones on construction sites and in movies. Ten years ago the technology was still in labs. Five years ago it was merely very expensive. Today you can buy a drone at Walmart that can do real enterprise work, using software in the cloud. Now that it’s so cheap and easy to put cameras in the sky, it’s becoming commercially useful. Beyond construction, drone data is used in agriculture (crop mapping), energy (solar and wind turbine monitoring), insurance (roof scanning), infrastructure (inspection), communications, and countless other industries that touch the physical world. We know that “you can manage only what you can measure,” but usually measuring the real world is hard. Drones make it much easier.

Industries have long sought data from above, generally through satellites or planes, but drones are better “sensors in the sky” than both. They gather higher-resolution and more-frequent data than satellites (whose view is obscured by clouds over two-thirds of the planet at any time), and they’re cheaper, easier, and safer than planes. Drones can provide “anytime, anywhere” access to overhead views with an accuracy that rivals laser scanning — and they’re just getting started. In this century’s project to extend the internet to the physical world, drones are the path to the third dimension — up. They are, in short, the “internet of flying things.”
So that is a perfect segue into the topic of Internet of Things. Whether it is buildings or smart cities or infrastructure, the concept of the Internet of Things is something profoundly important in this new age of Digitalization. What is the definition of IoT (Reference 70)?

“The Internet of things (IoT) is the network of physical devices, vehicles, home appliances and other items embedded with electronics, software, sensors, actuators, and network connectivity which enables these objects to connect and exchange data. Each thing is uniquely identifiable through its embedded computing system but is able to inter-operate within the existing Internet infrastructure. “

“Experts estimate that the IoT will consist of about 30 billion objects by 2020. It is also estimated that the global market value of IoT will reach $7.1 trillion by 2020.”

The graphic below highlights how big data and the Internet of Things can turn a normal city into a Smart City, with big data and streams of information flowing for internet of things throughout a city in areas of 1) city planning and operations, 2) transportation analytics, 3) water management, and 4) and an open cloud connectivity for the citizenry.

Figure 30 Infographic Smarter Cities: Turning Big Data into Insight
Robotics

An article from the Conexpo/Conagg event website (Reference 71) focuses on AI and Robotics and suggests where technologies are headed. The key factor is that robotics systems can sense and then act in the real, physical world. Their use of AI techniques such as machine learning and sensor technology makes them “thinking” and responding in a much more significant way than, say, on a manufacturing assembly line.

One of the construction trades that appear to be a surprise adopter of robotics is brick. As noted by David Silver in August 2017 (Reference 72) robotics is actually a necessity because of a growing skilled labor shortage. The Hadrian X is a bricklaying robot courtesy Australia’s Fastbrick Robotics, which uses its 30-metre metal arm to lay bricks at a rate of 1,000 bricks per hour, compared to a human worker's average of 1,000 a day. Due for release in late 2017, Hadrian X can read a 3D CAD model of the house and then it follows those instructions precisely, working day and night.

Summary of Why Machine / Computational Technologies Are Game Changing

What makes machine / computational technologies so game changing? Certainly the ability of the machine to enhance human activity, do things that currently aren’t possible, and look at an infinite number of choices to optimize is where the power of these technologies will both transform and disrupt the design and construction industry.
Social Technologies

Social technologies now being deployed in the construction industry include:

1. Social Networking and Media
2. Gamification
3. Crowd Sourcing

All have a role in the digital transformation of the design and construction industry. Fieldlens, for example, (Reference 73) highlights the social aspects of the industry. And there are several references (Reference 74) with “101 Social Media Ideas for Contractors.” These range from the personal and “party occasions” to other solutions for business itself. Construction World (Reference 75) discusses “How Construction Companies Can Integrate Social Media as a Marketing Strategy”.

And Skanska has partnered with OSHA to combine VR with Gaming to reduce occupational hazards on construction sites (see image below).

**Figure 31** Virtual Reality and Gaming Deployed by OSHA to reduce Construction Site Safety Violations

What makes automated systems such as Social Technologies so game changing? It is truly about the people, and how well-connected and networked the people are.
IV. Industry Innovation Landscape and Drivers Today

The landscape of the industry today includes those with a stake in the status quo such as technology providers, architecture, construction, real estate firms and owners, and industry professional organizations with a stake in the ongoing success of the industry.

But the Tsunami of Game Changing Innovations is changing the landscape in significant ways. This course section will look at the broader industry perspective provided by

- A report by McKinsey's Global Institute (MGI), entitled “Imagining Construction’s Digital Future”. (Reference 76) was published in August 2016. The infographic below summarized the findings of that report, with the following key highlights
  - Cost and schedule overruns are the norm in the construction sector
  - Construction labor productivity has not kept pace with overall economic productivity
  - The construction industry is among the least digitized

Five trends will shape construction and capital projects:
  - Higher-definition surveying and geo-location
  - Next-generation 5-D building information modeling
  - Digital collaboration and mobility
  - The Internet of Things and advanced analytics
  - Future Proof design and construction

- World Economic Forum’s (WEF) report “Shaping the Future of Construction: A Breakthrough in Mindset and Technology”, May 2016) (Reference 77) along with companion publication: “….Inspiring Innovators Redefine the Industry” (Reference 78). The document was prepared in collaboration with The Boston Consulting Group and examines a wide range of dimensions of the industry. The document is worth reading from cover to cover, but the key take-aways are the following.
  - The Industry is ripe for transformation. It is crucial to society, the economy and the environment. Megatrends already underway will shape the construction industry’s future. In addition, internal challenges must be confronted if progress is to be made. In addition to being ripe for transformation, the industry also is capable of transformation.
  - Private companies can and should spearhead this transformation. This involves materials, tools, technologies, processes and operations. It isn’t just about technology, but also people, organizational issues and culture.
Industry as a whole needs to come together in a cohesive manner, both collaborating as well as marketing.

Government definitely has a role in encouraging and supporting this transformation.

The WEF has some significant recommendations in “What’s the Future of the Construction Industry?” (Reference 79) WEF concludes that the key is digitalization.

*The key is digitalization. More and more construction projects are incorporating systems of digital sensors, intelligent machines, mobile devices, and new software applications – increasingly integrated with a central platform of Building Information Modelling (BIM).*

*The challenge now is to achieve widespread adoption and proper traction. Wherever the new technologies have properly permeated this fragmented industry, the outlook is an almost 20% reduction in total life-cycle costs of a project, as well as substantial improvements in completion time, quality, and safety.*

Much more is written in that reference, but the conclusion is telling:

*The gap between digital leaders and laggards is widening – for construction companies themselves, for technology providers, and also for governments in their role as project owners and regulators. All these stakeholders need to master the dynamics, upgrade their competencies and investments, and adapt their processes and attitudes, or risk losing out competitively.*

There are firms that in the forefront of this digital transformation and are truly AEC Game Changers today. Just a few that have been mentioned in this course are worth looking at their websites for more detailed information

- WeWork (https://www.wework.com/)
- HOK (www.hok.com/)
- NBBJ (www.nbbj.com/)
- Hansel Phelps (https://www.henselphelps.com/)
- Thorton Thomasetti CoreStudio (http://core.thorntontomasetti.com/)
- Skanska (https://www.skanska.com/)
- Arup Foresight (www.driversofchange.com/)
- Kieran Timberlake (www.kierantimberlake.com/)
- Woods Bagot (https://www.woodsbagot.com/)
- Morphosis Architects (https://www.morphosis.com/)
- Gehry Technologies (http://www.gehrytechnologies.com/en/)
- Trimble - Transforming the Way the World Works (www.trimble.com/)
- Onuma Inc (http://www.onuma-bim.com/)
- Aditazz (www.aditazz.com/)
- dRofus (http://www.drofus.no/en/)
- Autodesk (https://www.autodesk.com/)
- Redshift | Exploring the Future of Making Things – Autodesk (https://www.autodesk.com/redshift/)
V. Making Your Own Game Changing Innovation | Technology Execution Plan

Penn State University Computer Integrated Construction Program, in conjunction with the Pankow Foundation, in 2007 began work on BIM Execution Planning as a key factor in success of BIM on projects.

As described on the CIC website (Reference 80)

Figure 32 BIM Project Execution Guide and Planning Guide for Facility Owners
“In 2011, the Charles Pankow Foundation, along with others, awarded the CIC research program a grant to begin the development of an Owner’s Guide to Building Information Modeling. During the research and creation of the very successful BIM Project Execution Planning Guide, the group determined there was a need to develop a guide for facility owners and operators that includes a procedure to develop a strategy for integrating BIM throughout their organization. This guide, developed primarily for facility owners, will focus on the decisions required to define their organization’s standard BIM processes and practices; design information integration strategies; and identify appropriate BIM contracting strategies.

The goal of the website is to be a hub for the Project BIM Execution, Owner BIM Execution Planning Guides and BIM use definitions. Please take some time to review our research and we welcome your feedback. “

What is a BIM Execution Planning Guide and how might it apply to our Game Changing Innovation Technologies: As the CIC continues to describe it:

This Guide provides a structured procedure for creating a BIM Project Execution Plan. The four steps within the procedure include:

1. Defining high value BIM uses during project planning, design, construction and operational phases
2. Using process maps to design BIM execution
3. Defining the BIM deliverables in the form of information exchanges
4. Developing a detailed plan to support the execution process

Those documents provide a thorough and tested approach to incorporating new technologies (in this case BIM) on both projects as well as within a firm.

The Game Changing Innovation Execution Plan would involve similar steps to the BIM Guide above:

1. Team Building: Either with a project team or within a firm, gather stakeholders and discuss the goals of the plan
2. Educate: Present a range of technologies such as the ones listed in this course. Discuss both concepts and case studies
3. Discuss how 3 or 4 of these technologies can be the initial focus for a project or for a firm’s digital and innovative transformation
4. Make a specific action plan, including goals, objectives, and tasks and a timetable to complete them
5. Iterate and get constant feedback
6. Award all participants a certificate as an AEC Game Changer!
Are You an AEC Game Changer?

One way to come up to speed and stay informed with all of the information provided in this course is look at these other resources as well that provide an incredible font of knowledge and information:

- Designing Buildings Wiki (see https://www.designingbuildings.co.uk/wiki/Home)
- Future of Construction (see https://futureofconstruction.org/)
- BIM HUB see (https://thebimhub.com/)

In addition, Flipboard is a powerful visual interface to a news feed and collaboration tool that has significant information on innovation and the topics relevant to this course. The Flipboard Magazine entitled “Game Changing Innovation”, (Reference 81) has over 6,250 viewers, 86 followers, and 2,900 stories included as a resource.

Joining this resource and contributing to it is as easy as going to the following link: https://flipboard.com/@shagan2012/game-changing-innovation-jk7kt717y and you will arrive at the FlipBoard Magazine illustrated below, where you can view or actually join and contribute:

Figure 33 Screen Shot from FlipBoard and Game-Changing Innovation Online Magazine
VI. Conclusion and Path Forward

We began this course with a discussion about the size of the construction industry ($1.2 trillion annually in the U.S., $10.3 trillion globally). But equally as significant as the size of the industry is how fragmented and inefficient it is. By some calculations, the numbers above have a 30% waste built in. A key premise of this course is that Game Changing Innovation can reduce that waste or, more importantly, transform that waste into value added for all the industry stakeholders.

We also noted at the outset of the course that many new venture capitalists and technology start-ups are now focused on that waste. By one accounting by CB Insights, over $778 million in 165 venture deals are now funded to transform the industry. And that is just the start. And the McKinsey Global Institute’s 2016 study said that a key to that transformation is digitalization.

We looked at Game Changing Innovation in the broad categories of 1) Model Authoring/Checking Tools, 2) Immersive Technologies, 3) Internet Technologies, 4) Machine / Computational Technologies and 5) Social Media / Technologies. We also briefly noted the historical perspective of how technology has transformed design and construction from the Stone Age to modern times and, in turn, those technologies directly changed the built environment itself.

We also highlighted many of the initiatives that have been a foundation of innovation, both in U.S. and abroad. Certainly all of the BIM Guides developed by the federal agencies such as Army Corps of Engineers, GSA, VA, State of Wisconsin and State of Massachusetts have added significantly to the body of knowledge. We also discussed in a fair amount of depth the contribution of the Technology in Architectural Practice Knowledge Community at the American Institute of Architects, including its annual Building Connections Congress and BIM/Innovation Awards.

Certainly the work in the UK has been and will continue to be a strong force for innovation. With its emphasis on extensive (and free!) online tools and resources, and the breadth of its approach, the Digital Built Britain brand will continue to be a highlight and innovation engine for the future.

We highlighted at the beginning of the course the statement made by Thom Mayne FAIA on a panel at the 2005 AIA Convention in Las Vegas. At the conclusion of this course it seems that the statement 13 years ago is just as relevant as today (see diagram below courtesy of Kimon Onuma, Onuma, Inc), and applies equally to Game Changing Innovation we’ve discussed here as well as BIM back then in 2005.
Either you “change or perish”. Hopefully this course will give you a broad foundation to change and flourish.

Figure 34 "Change or Perish" for @AECGameChangers A’17 Workshop in Orlando in April 2017. Courtesy: Kimon Onuma and Onuma, Inc.
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