BUILDING INFORMATION MODELING
(BIM)

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1.0 Introduction

The purpose of this report is to provide insight into a digital translation technology used by the building construction industry known as Building Information Modeling (hereafter abbreviated as BIM). The Department of Energy's Building Technologies Office (BTO) examines issues of construction productivity. BTO plans to include one or more topics related to BIM in the second Phase I SBIR Topic release in FY2021. Of particular interest is understanding the gaps in interoperability among the various roles that participate in the U.S. building construction industry, as well as identifying opportunities for significant improvement.

According to the 2017 McKinsey[1] report:

"**The construction industry** employs about 7 percent of the world's working-age population and is one of the world economy's largest sectors, with $10 trillion spent on construction-related goods and services every year. But the industry has an intractable productivity problem and, according to *Reinventing construction: A route to higher productivity*[2], [the industry has] an opportunity to boost value by $1.6 trillion."

The U.S. construction industry is among the world's largest ($1,231 billion)[3]. However, growth is stagnant, as the industry faces a number of challenges including: (1) increasing materials costs, (2) skilled labor shortages, (3) technology development/integration, (4) green construction techniques and (5) compliance with safety practices. BIM falls under the category of technology development/integration along with other advancements such as contract management software, project management software, drones and aerial photography. According to the Bureau of Labor Statistics productivity varied by building type during the period between 2007-2018[4].
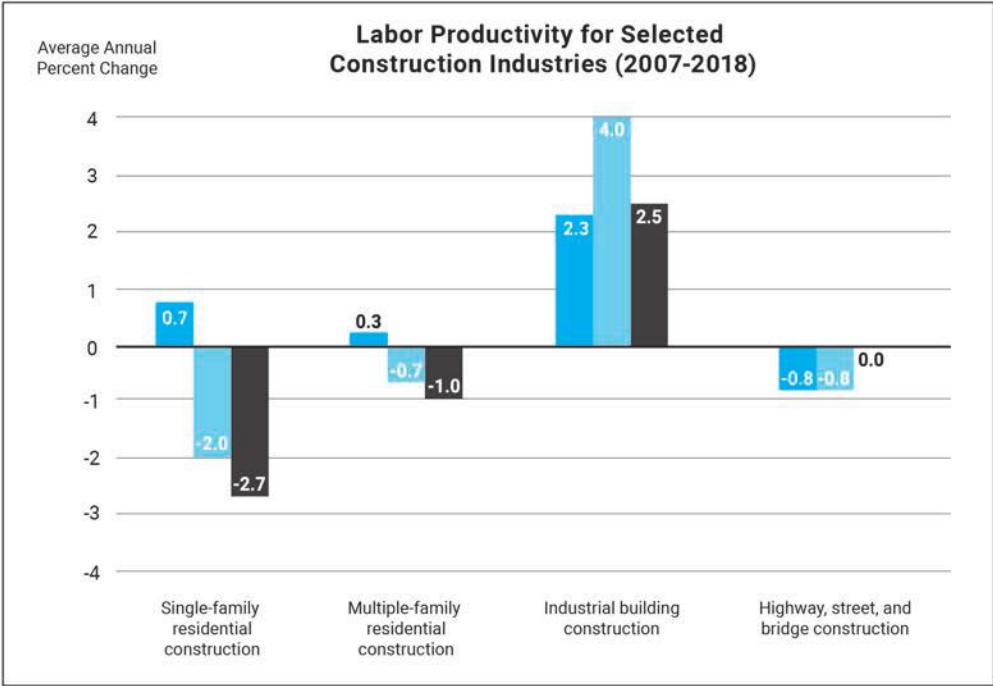
Source: U.S. Bureau of Labor Statistics, Office of Productivity and Technology

FIGURE 1: Productivity in the U.S. Building Industry by Building Type (2007-2018)

With labor shortages increasing as the construction labor force ages, it is anticipated that new technologies such as BIM could fill a gap and expedite growth. However, the US construction industry has been slow to adopt BIM technology. The purpose of this report is to provide insight into a subset of questions of interest to the Building Technologies Office including:

- **Who are the key players in BIM?**
- **What BIM software tools are used?**
- **What are the problems and gaps where interoperability occurs?**
- **What are the opportunities for significant improvement, resulting in productivity and efficiency improvements?**

2.0 Methodology

Both primary and secondary market research were conducted to address the questions of interest. The primary market research was exploratory in nature and included in-depth interviews with 23 individuals who play various roles within the building industry: Architect (N=4), Architect & Engineering (N=7), Building Contractor (N=8), University Professor/Building Technologies (N=3), Start-up/BIM (N=1). The complete interviews are contained in Volume 2. Secondary information came from both public and subscription databases. Throughout this report information from both primary and secondary sources are interspersed. To provide more insight on given topics sections from key interviews are included.
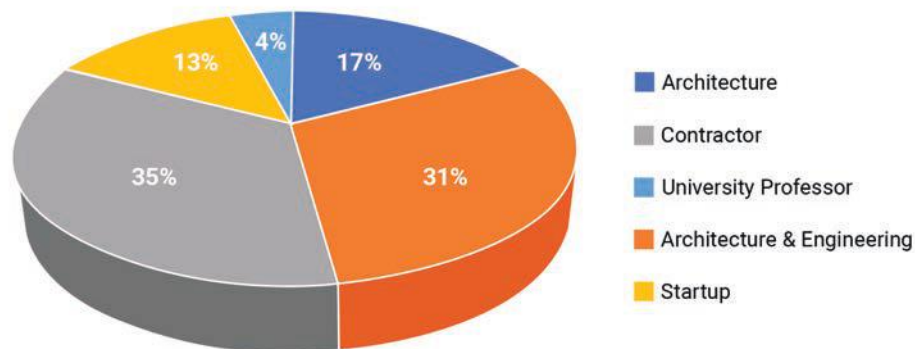
FIGURE 2: Distribution of Primary Interviews by Role

3.0 BIM Software Used in the Construction Industry

In June 2019, information was released through Statista pertaining to preferred building information modeling software used in the US construction industry. Based on a survey conducted in July 2018 (with 2,825 respondents), the following BIM software programs surfaced as preferred programs among those working in the US construction industry (multiple responses were allowed):

- › Revit (Autodesk) − 41.1% of respondents
- › AutoCAD MEP (Autodesk) − 31.2% of respondents
- › Navisworks (Autodesk) − 18.5% of respondents
- › BIM 360 Glue (Autodesk) − 15.8% of respondents
- › Bluebeam − 4.5% of respondents
- › Sketchup (Trimble) − 4.5% of respondents
- › Assemble Systems − 3.2% of respondents
- › Tekla (Trimble) − 2.7% of respondents
- › Trimble Realworks − 2.3% of respondents
- › AutoCAD Civil 3D − 2.3% of respondents
- › CADmep − 2.3% of respondents
- › ReCap (Autodesk) − 2.2% of respondents
- › Bentley − 1.9% of respondents
- › Microstation − 1.9% of respondents
- › A360 (Autodesk) − 1.7% of respondents
- › ArchiCAD − 1.3% of respondents
- › PlanGrid − 1.2% of respondents
- › Synchro − 1.2% of respondents
- › Fabrication Inventor − 1.2% of respondents
- › Solibri − 1.2% of respondents
- › Trimble Sysque − 1% of respondents[5]

3.1 Guidance from the U.S. General Services Administration

The US General Services Administration (GSA) is a key BIM stakeholder in the United States and has prepared Guidelines for BIM Software. In these guidelines they specifically mention Revit, Bentley, and ArchiCAD.[6] According to the GSA's website, in order to ensure that all team members across BIM-enabled projects have access to the model, it is necessary to standardize versions of BIM software. "GSA uses BIM internally and in coordination with other agencies. It is required for all new construction and major renovations by GSA facilities standards for the Public Building Service since 2009." The software currently approved by the US GSA for use on BIM projects includes:

- › Autodesk Revit Architecture
- › Autodesk Revit Structural
- › Autodesk Revit MEP
- › Autodesk Navisworks
- › Industry Foundation Class (IFC)[7]

As Autodesk products are emphasized by GSA and are used more than any other products, an overview is provided of Autodesk. Information on Bentley and ArchiCAD are provided in Appendix A.

3.2 Autodesk

Autodesk is a clear leader in the BIM market and offers a number of BIM software solutions. According to the company over 100 million people use Autodesk software (not limited to BIM software solutions—but certainly including BIM solutions, such as Revit).[8] In the company's most recent Annual Report, the total subscriptions reached 4.3 million in 2019.[9]

3.2.1 Revit

Revit is one of Autodesk's top BIM software products. According to a 2018 Revit manual, "Revit has an installed base of approximately 300,000 users (and this number is increasing)."[10] The cost of Revit is approximately $305 per month for a monthly subscription, $2,425 for a 1 year subscription, and $6,550 for a 3 year subscription.[11] The company also offers bundled pricing for Revit and AutoCAD together ($2,965 for 1 year).[12] In terms of features, Revit is a BIM software solution that addresses architectural design, structural engineering, MEP (mechanical, electrical, and plumbing) engineering, and construction. These features also support building and infrastructure management. Main product features include generative design (produce design alternatives based on defined goals and constraints), parametric components (a graphical system for design and the basis for building components designed in Revit), work sharing (contributors from different disciplines can share and save their work to a centrally shared file for easy collaboration), schedules (a tabled display of model information extracted from the properties of the elements in a project), interoperability and IFC (Revit imports, exports, and links data with commonly used formats such as IFC4), add-ins (users can extend Revit functionality with API access, third-party solutions, add-ins and a content library on the Autodesk App Store), annotation (users can communicate designs using WYSIWYG editing and features to control test appearance), Dynamo for Revit (expand and optimize BIM workflow with an open-source graphical programming interface that installs with Revit), and global parameters (embed design intent with project-wide parameters that work with radial and diameter dimensions and equality constraints).[13]

There are a number of products that appear to interface with Revit. They include Insight, Advance Steel, Dynamo, BIM 360, Navisworks, and AutoCAD. A related product, Revit LT, enables users to produce 3D architectural designs and documentation. Revit LT supports BIM workflows and offers features such as 3D design and visualization, high quality documentation, auto-generated schedules, and photo-realistic rendering. The tool appears to focus more on the architectural design phase. The cost of Revit LT is $55 for 1 month, $450 for 1 year, or $1,215 for 3 years.[14]

3.2.2 BIM 360

BIM 360 is another key product offering from Autodesk. BIM 360 is a unified platform that connects project teams and data in real-time, from design through construction. The platform is used by notable construction management companies such as Balfour Beatty, Mortenson, Van Wijnen, Stantec, DPR Construction, and JE Dunn Construction. In terms of pricing, BIM 360 pricing starts at $480 per year, per user.[15]

BIM 360 is actually 7 separate products—BIM 360 Docs, BIM 360 Design, BIM 360 Ops, BIM 360 Build, BIM 360 Plan, BIM 360 Coordinate, and BIM 360 Layout. BIM 360 Docs allows users to share, view, markup, and manage construction drawings, documents and models anywhere and access all information in one spot. It focuses on the design through construction phase.[16] BIM 360 Design is a design collaboration software tool that supports Revit cloud work sharing and collaboration workflows for Civil 3D and Plant 3D. This solution improves collaboration among different project teams.[17] BIM 360 Ops is a BIM program that is designed for maintenance management. The tool was designed to get asset data to maintenance personnel. Building dashboards provide relevant role-

based information for technicians and building managers. Teams can access and update asset information from mobile devices and they can import a building's assets and data from Revit, BIM 360 Field, or a spreadsheet to start the process.[18] BIM 360 Build is a type of construction project management software that enables users to track quality and safety inspections, manage RFIs and submittals, mange budgets and contracts, change order workflows, and pay applications within one system.[19] BIM 360 Plan is a type of construction production planning software. Users can develop work plans using Lean Construction principles and reduce waste from overproduction, excess inventory, and rework.[20] BIM 360 Coordinate facilitates the construction design review process. Teams can easily identify and resolve issues before construction with "shared coordination spaces and clash resolution workflows."[21] BIM 360 Layout is used for construction site layout.

3.2.3 Architecture, Engineering & Construction Collection

Autodesk also provides an Architecture, Engineering & Construction Collection which is comprised of integrated BIM tools for architecture, engineering, and construction projects. The purpose of offering this package is to eliminate the hassle of managing multiple product licenses. Users can choose between subscriptions that provide single-user access for one person or they can give teams permission to share licenses with multiple-user access. The entire AEC software collection is available for $2,965 per year for a single-user.[22] The AEC software collection includes the following software programs: 3ds Max, Advance Steel, AutoCAD (AutoCAD, AutoCAD Architecture, AutoCAD Electrical, AutoCAD Map 3D, AutoCAD Mechanical, AutoCAD MEP, AutoCAD Plant 3D, AutoCAD Raster Design, AutoCAD Mobile App, and AutoCAD Web App), Autodesk Drive, Autodesk Rendering, Civil 3D, Dynamo Studio, Fabrication CADmep, FormIt, InfraWorks, Insight, Navisworks Manage, ReCap Pro, Revit, Robot Structural Analysis Professional, Structural Bridge Design, and Vehicle Tracking.[23]

The following table provides a comparison of the Architecture, Engineering and Construction Collection, Revit, and BIM 360. Information has been gathered directly form the Autodesk website, using their product comparison tool.

Architecture, Engineering and Construction Collection	Revit	BIM 360
Access integrated BIM and CAD technologies for building and infrastructure design, engineering and construction. Work more efficiently from planning and analysis, through design and construction.	Plan, design, construct, and manage buildings and infrastructure with powerful tools for Building Information Modeling.	Use the project delivery and construction management cloud platform to connect people, data, and workflows on your project. Improve decision-making throughout the project life cycle.
The entire collection is available for $2,965/year	Cost is approximately $2,425/year	Cost starts at $480 per year, per user. Pricing for BIM 360 Design is $945/year
Use for building design, civil infrastructure design, and construction.	Use for architectural design, structural engineering, MEP engineering and detailing, and preconstruction design.	Use for project team collaboration, design sharing and review, and construction management.
What it does: • Integrate building and infrastructure project workflows • Plan and design using real-world data and rich 3D models • Connect conceptual and preliminary design to detailed engineering and fabrication • Maintain a consistent design model throughout the project using integrated tools • Use visual logic to design workflows and automate tasks • Conduct analysis to inform design for better building performance • Perform simulations and analysis to improve infrastructure project outcomes • Conduct advanced BIM structural analysis and code compliance verification • Generate near-realistic images and turn models into immersive experiences • Combine design and construction data and simulate construction sequencing • Speed review and verification workflows • Integrate civil structure design and conduct structural bridge analysis	**What it does:** • Conceptual design • 3D parametric modeling • Detailed design documentation • Multidiscipline coordination • Modeling building components • Analyzing and simulating systems and structures • Iterating and visualizing designs • Generating design documentation for fabrication or construction • Structural steel modeling and documentation • MEP fabrication modeling and detailing • Photorealistic 3D visualization • Building performance analysis • Construction documentation	**What it does:** **BIM 360 Docs** • Control information sharing • View, mark up, and compare 2D and 3D files • Maintain version control • Track all project activity **BIM 360 Design** • Collaborate with multidiscipline design teams • Control Revit worksharing in the cloud • Track and coordinate deliverables exchange • Visualize changes to central model **BIM 360 Glue** • Conduct constructability reviews • Identify issues during preconstruction • Improve multidiscipline coordination • Automate clash detection **BIM 360 Build** • Improve construction quality control • Use checklists to promote safety conformance • Create, assign, and manage issues, RFIs, and submittals • Track field performance with reports and analytics **BIM 360 Layout** • Free iPad app for BIM 360 Glue subscribers • Conduct constructability reviews on the jobsite or in the office **BIM 360 Plan** • Create work sequences • Track and analyze performance • Keep teams on schedule **BIM 360 Ops** • Mobile-first maintenance management

Includes:	Includes:	Includes:
Revit	Dynamo computational design software	N/A
AutoCAD	Insight building performance analysis	
Civil 3D	software	
InfraWorks		
Navisworks Manage		
3ds Max		
Advance Steel		
Autodesk Rendering		
Dynamo Studio		
Fabrication CADmep		
FormIt Pro		
Insight		
ReCap Pro		
Revit Live		
Robot Structural Analysis Professional		
Structural Bridge Design		
Vehicle Tracking		

3.2.4 Autodesk Acquisitions

Assemble Systems also surfaced as a key player in the BIM market. Assemble has been acquired by Autodesk and their platform was integrated into Autodesk's BIM 360 project management platform. PlanGrid is another Autodesk company that provides a BIM software solution. PlanGrid provides Construction Productivity Software that has been used on over 1 million projects around the world.[25] PlanGrid's Construction Productivity Software keeps teams on the same page, enabling markups, photos, and punch lists. The software syncs the team and users can overlay different versions or unrelated blueprints to identify differences and avoid change orders or conflicts at a later time. Plan revisions are automatically inserted in order so the team is working from the latest set, while still having access to project history. PlanGrid's BIM software is a feature of their Construction Productivity Software. Users can access model properties from any location, in 2D and 3D. PlanGrid BIM is available to all PlanGrid users. PlanGrid BIM interfaces with Revit and the solution supports design and pre-construction, construction, and facilities management.[26] With the design and pre-construction phase, users can conduct design reviews and owner walkthroughs. In the construction phase, users can see all data properties in 2D and visualize how more complex work comes together in 3D. For facilities management, users can "hand over high fidelity as-builts with asset details and 3D views."[27] Individual pricing for PlanGrid software ranges from $39-$119/month, depending on the plan selected and assuming annual billing. If billing month to month, the software ranges from $49-$139/month.[28]

In February 2020, Autodesk released a presentation pertaining to *Fourth Quarter and Full Year Fiscal 2020 Earnings*. In total, Autodesk reported 4.9 million total subscriptions. This figure includes 205,000 subscriptions from recent acquisitions, which refers collectively to PlanGrid and BuildingConnected (another recent acquisition for Autodesk).[29]

3.3 Industry Foundation Classes (IFC)

Apart from Autodesk products, the General Services Administration also recommended the use of Industry Foundation Classes (IFC). According to a 2017 report from the Joint Research Centre (JRC), the European Commission's science and knowledge service, and authored by Martin Poljansek:

"BIM, short for Building Information Modelling, is a digital tool disrupting the construction industry as a platform for central integrated design, modelling, asset planning running and cooperation. It provides all stakeholders with a digital representation of a building's characteristics in its whole life-cycle and thereby holds out the promise of large efficiency gains. One particular area where standardization on BIM is needed is the exchange of information between software applications used in the construction industry. The leading organization in this domain is buldingSMART which has developed and maintains Industry Foundation Classes (IFCs) as a neutral and open specification for BIM data model."[30]

The IFC data model describes architectural, building and construction industry data. It is a neutral, open file format with a data model developed by buildingSMART (formerly the International Alliance for Interoperability). IFC was designed to facilitate interoperability in the architecture, engineering, and construction segments, and it is often used to streamline BIM-based projects. IFC supports interoperability between software platforms, making it an important factor in terms of adopting and using BIM. A few European countries have specifically enacted requirements related to IFC. In 2007, Finland mandated that any design software needed to pass IFC certification. Norway has also been using IFC file formats—as well as BIM—in their projects since at least 2010.[31] The Danish government has required the use of IFC format for publicly-aided building projects.[32]

buildingSMART International is the key stakeholder responsible for IFC. BuildingSMART publishes BIM standards, technologies, supporting information, and documentation. Their standards cover a wide range of process and information capabilities that are unique to the building industry, including IFC (an industry-specific data model schema).[33] BuildingSMART International is headquartered in the UK, with chapters in the following countries and regions:

› Australasia (buildingSMART Australasia)
› Austria (buildingSMART Austria)
› Benelux (Netherlands, Belgium, Luxembourg) (buildingSMART Benelux)
› Canada (Canadian chapter, buildingSMART International)
› China (China Construction Technology Group)
› France (buildingSMART France)
› Germany (buildingSMART Germany)
› Hong Kong (Hong Kong Alliance of Built Asset & Environment Information Management Associations)
› Italy (buildingSMART Italy)
› Japan (buildingSMART Japan)
› Korea (buildingSMART Korea)
› Nordic (Denmark, Finland, Sweden) (buildingSMART Denmark, buildingSMART Finland)
› Norway (buildingSMART Norway)
› Poland (buildingSMART Poland)
› Russia (buildingSMART Russia)
› Singapore (buildingSMART Singapore)
› Spain (buildingSMART Spain)
› Switzerland (buildingSMART Switzerland)
› Turkey (buildingSMART Turkiye)
› United Kingdom and Ireland (buildingSMART UK and Ireland)
› USA (BIMForum)[34]

According to buildingSMART:

> "In general, IFC, or "Industry Foundation Classes," is a standardized, digital description of the built environment, including buildings and civil infrastructure. It is an open, international standard (ISO 16739-1:2018), meant to be vendor-neutral, or agnostic, and usable across a wide range of hardware devices, software platforms, and interfaces for many different use cases. The IFC schema specification is the primary technical deliverable of buildingSMART International to fulfill its goal to promote openBIM."[35]

The IFC schema is a standardized data model that is used to logically codify:

> › Identity and semantics (name, machine-readable unique identifier, object type or function)
> › Characteristics or attributes (such as material, color, thermal properties, etc.)
> › Relationships (including locations, connections, and ownership)
> › Objects (columns or slabs)
> › Abstract concepts (performance, costing)
> › Processes (installation, operations)
> › People (owners, designers, contractors, suppliers, etc.)[36]

The IFC schema can describe how a facility or installation is used, constructed, and operated. IFC is useful in defining the physical components of buildings, manufactured products, mechanical or electrical systems, and more abstract structural models, energy analysis models, cost breakdowns, and work schedules. According to buildingSMART:

> "IFC is typically used to exchange information from one party to another for a specific business transaction. For example, an architect may provide an owner with a model of a new facility design, an owner may send that building model to a contractor to request a bid, and a contractor may provide the owner an as-built model with details describing installed equipment and manufacturer information. IFC can also be used as a means of archiving project information, whether incrementally during the design, procurement, and construction phases, or as an "as-built" collection of information for long-term preservation and operations purposes.
>
> The desired IFC data can be encoded in various formats, such as XML, JSON, and STEP, and transmitted over web services, imported/exported in files, or managed in centralized or linked databases. Software vendors of building information modeling tools - including model authoring, design, simulation and analysis, viewing and more - will provide interfaces to end users to export, import, and transmit data in some IFC format. It is up to users to decide what they want to share from their tools via IFC."[37]

Hundreds of software applications can send and receive IFC data. Over the years, IFC has been tested and trialed, and it is used on a worldwide scale. IFC was ISO certified in 2013. The corresponding ISO standard is ISO 16739-1:2018.[38] ISO 16739-1:2018 (*Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries – Part 1: Data schema*) was published in 2018. The abstract for this ISO standard is as follows:

"The Industry Foundation Classes, IFC, are an open international standard for Building Information Model (BIM) data that are exchanged and shared among software applications used by the various participants in the construction or facility management industry sector. The standard includes definitions that cover data required for buildings over their life cycle. This release, and upcoming releases, extend the scope to include data definitions for infrastructure assets over their life cycle as well. (Key ISO standards related to BIM are included in Appendix B.)

The Industry Foundation Classes specify a data schema and an exchange file format structure. The data schema is defined in:

› EXPRESS data specification language, defined in ISO 10303-11,

› XML Schema definition language (XSD), defined in XML Schema W3C Recommendation, whereas the EXPRESS schema definition is the source and the XML schema definition is generated from the EXPRESS schema according to the mapping rules defined in ISO 10303-28. The exchange file formats for exchanging and sharing data according to the conceptual schema are

› Clear text encoding of the exchange structure, defined in ISO 10303-21,

› Extensible Markup Language (XML), defined in XML W3C Recommendation.

Alternative exchange file formats may be used if they conform to the data schemas.

ISO 16739-1:2017 of IFC consists of the data schemas, represented as an EXPRESS schema and an XML schema, and reference data, represented as definitions of property and quantity names, and formal and informative descriptions.

A subset of the data schema and referenced data is referred to as a Model View Definition (MVD). A particular MVD is defined to support one or many recognized workflows in the construction and facility management industry sector. Each workflow identifies data exchange requirements for software applications. Conforming software applications need to identity the model view definition they conform to."[39]

IFC is an important factor influencing BIM adoption and use. IFC is the common exchange schema which makes BIM more effective, as it enables the effective exchange of information among construction parties. Architecture, engineering, and construction companies are using a range of software packages to design buildings and manage their construction. With different software programs and packages in use, this can lead to issues related to data sharing. Each software vendor may have a file format that is not necessarily compatible with other AEC software packages. The IFC schema was designed to facilitate data sharing between AEC parties and others involved in building construction and management. Information can be shared in a common format that enables interoperability.[40] IFC offers significant benefits to the parties that are involved in the design, building, commissioning, and operation phases. According to a 2019 article from Capgemini, "the adoption of IFC has seen a lot of success in Finland, where IFC is being used by 60% of Finnish municipalities for submitting planning applications in 3D."[41] IFC is being embraced by BIM stakeholders and companies around the world, but support for IFC is often traced back to use or mandates surrounding IFC in countries such as Finland, Norway, and Denmark.

Software Tools Used by Sample Interviewed

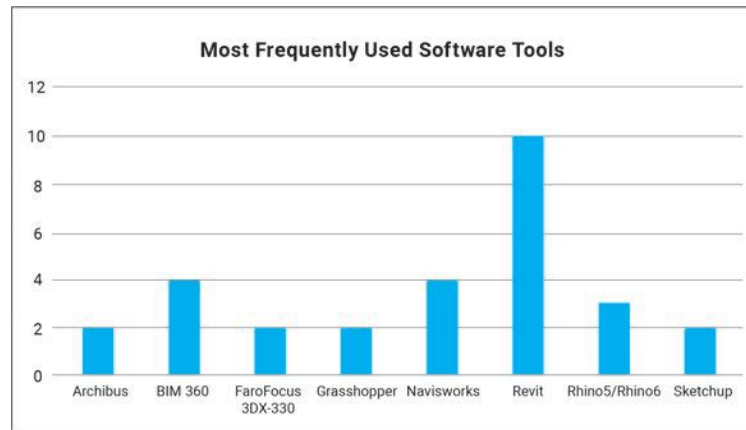Over 31 software tools were mentioned during the interviews, conducted by Dawnbreaker.

FIGURE 3: The most frequently cited software tools

We use Revit to input and extract information. It works well with other programs. There are many tools that are used for and with BIM. Hypar.io for example, is a web-based cloud platform and API which executes users' code. There is always some retooling, rekeying of information when you go from design to other steps in the process. The designers like to use a tool to present their ideas and their vision such as SketchUp. It provides a visual to work from but no real parameters to export to the next phase. Architects will use SketchUp and then take the rendering and rebuild it in Revit. As the design is developing, it changes so quickly the Revit model never catches up.

We are also using **Rhino5 and Grasshopper**. Grasshopper is a computational plugin to Rhino. We are putting the design in Rhino and then using Grasshopper to leverage and change the design on the fly based on new information provided. Using these tools, we can and often do perform analysis on energy consumption on projects. In that way, when we transfer data out of Revit it's already finished – including the location of building (how it sits facing north, east, south, west), the height of building, etc. Anything we

draw in Grasshopper will automatically be developed in the Revit model saving time, and less rekeying of information. If we change the height of the building in Grasshopper it automatically changes it in Revit.

Next, we start the design development from the file already developed in Grasshopper. All of the design is in place, ready to go in the Revit file. The next step is to talk to consultants/subcontractors and bring them into the process. This creates additional Revit models that get added to the original model.

Without having the right contract language, we can't deliver a Revit model as the final deliverable. Most people / organizations in the industry are old school and protective of their own data. Often the contractor will build off of our paper prints instead of the Revit model. At the end, when the design is complete and ready for the build, we provide the hard documents and they build from paper prints. **The contract specifications are one of the biggest hurdles in getting models to be used by everyone. The quality of the models could be a lot better industry wide if more groups actively participated.**

Large Architectural Firm
Corporate BIM Director

The Value of BIM

BIM is used for every job we do. We have six FTE specialists whose sole job is to work in BIM. They use BIM all the way from design stage through finished product. We use it to coordinate what happens 'above the ceiling'. Architects figure out 50-60% of where to run things and then the subcontractors insert the rest. The subcontractors that use software do the bulk of the work and it's all coordinated around trades. Everyone in the pipeline from start to finish will use some form of BIM software. The architect will send basic model then HVAC always goes in first, then fire protection, then electrician, etc. Once you finish the work you hit a button and it will check for conflicts! When you discover a conflict, the group then looks at the model and solves the problem. It's all done at the office and you don't even have to send someone out to the site. Many subcontractors use different software like AutoCAD, REVIT and Navisworks but I haven't run into any compatibility issues.

The software tells us the length of pipes, ductwork etc. The parts will also be cut and shipped and correspond to the drawing. QC control is better in shop, so we'd rather have parts cut there. BIM is especially important for healthcare construction planning. Healthcare construction requires a lot of specialty electrical, plumbing etc and being able to plan ahead is important. There's so much stuff in the ceiling you need to plan well ahead. Once you have things in system, you know it's going to work. You don't need a tape measure, you can just do it on your computer at the office. There's no need coordinate out on the field."

In the past working a job might take three to four months but now it only takes three weeks. The planning stage takes longer but there are fewer changes in the field since they have a plan to follow. Another advantage is that at the end of a project the building owners have an electronic record of everything that is in the walls. One recent innovation was the software's ability to use scanning for automated data entry – it's a cutting edge process and it's becoming more and more common.

3.3 The Value of Plug-Ins

A number of the software tools mentioned on page 13 are actually plugins – most noticeably Grasshopper and Rhino. Blogger Vinesh Kaushik maintains that it is best to create a federated BIM model using Computational BIM workflows rather than sticking with the limitations of any one BIM system.[42] These facilitate interoperability between conceptual modelling tools and BIM software. The following figure shows the relationship between a number of interoperability plug-ins, BIM Systems, IFC and other interoperability plugins. Figure 4 uses the phrase "Tightly coupled workflow" to indicate that the plugin is fully compatible with BIM systems, while "Loosely coupled workflow" means that it is fully interoperable through model exchange.
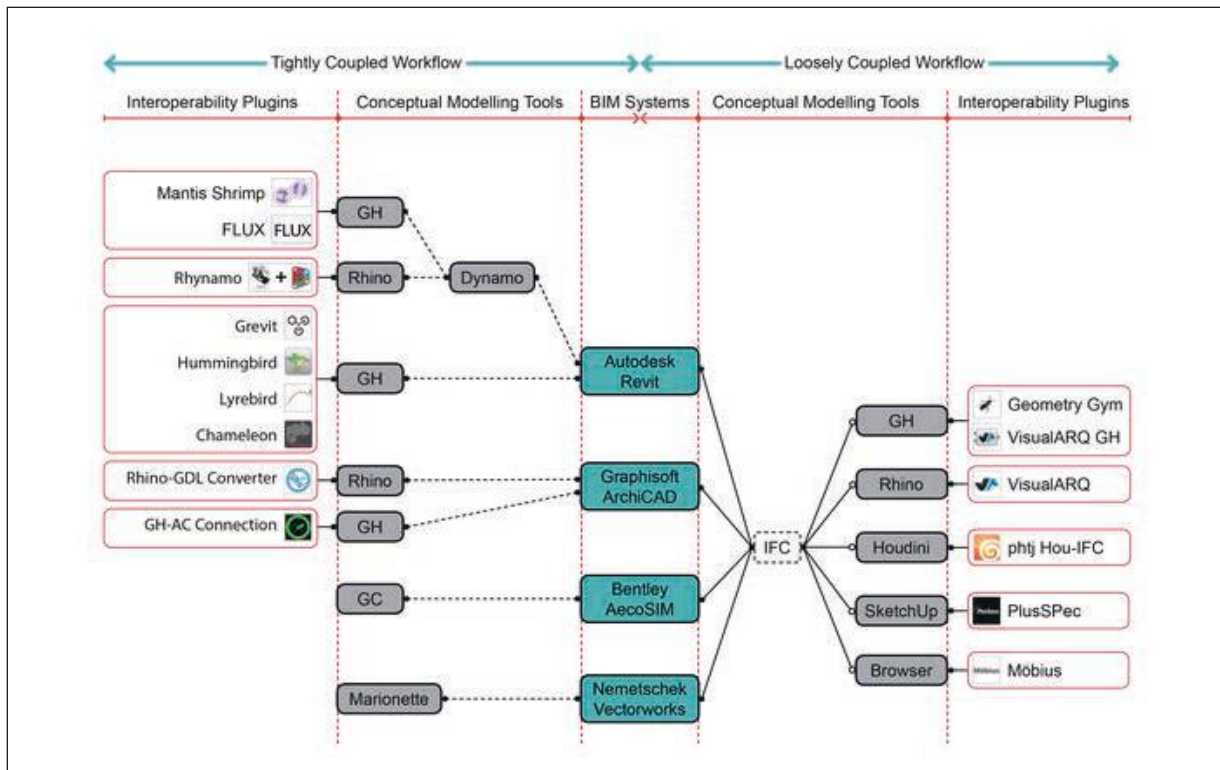
Source: The Seven Best Computational BIM Workflows for Architects. (March 17, 2017)

FIGURE 4: Plugins commonly used with BIM Systems.

Plugins such as Grasshopper 3D, Rhino and SketchUp are commonly used. The following is a brief introduction to each of these tools.

Grasshopper 3D

Grasshopper 3D – This is a visual programming language that runs with the Rhinosceros 3D computer-aided design (CAD) application. It was developed by David Rutten at Robert McNeel & Associates and first released in 2007 under the name Explicit History. According to AEC Magazine it is popular among students and professionals and is used widely by architectural design

Visual Programming Languages "(VPLs), such as Grasshopper have developed to the point that they are forcing a blurring of the boundaries between the traditionally distinct disciplines of design, programming and electrical engineering, and so significantly changing practice and design outcomes. A single designer is now able to model, prototype, test and even manufacture complex electronics or applications using visual tools and workflows potentially within a single piece of software, as in the case of Rhino with the Grasshopper add-on. …. The graphical tools of Grasshopper turn the complex process into logical blocks of code which flow from one to the next, sharing much in common with the mind maps and flow diagrams that designers commonly use throughout the design process. The ability of a designer to learn a tool like Grasshopper is therefore increased, because of the similarities to practices already employed. Rather than needing to learn a completely new skill - or in the case of traditional coding, a completely new language – the designer can draw parallels with previous experience and discipline knowledge to engage with electronics during design development."

Rhino

Rhinosceros 3D was also developed by Robert McNeel & Associates. The company facilitates work initially being done on Rhino being transferred to Revit. It is considered an excellent choice for 3D or 2D models. It uses NURBS (Non-Uniform Rational B-splines) mathematical model and provides a high level of accuracy and detail. It is said to be very reasonably priced, has a free trial and is preferred by small architectural firms. Tools such as VisualARQ facilitate the interface between Rhino and BIM software.

"VisualARQ is a Flexible BIM solution powered by McNeel's Rhinoceros 3D. This combination of tools allows you to model any object with Rhino's freeform modelling tools and turn it into an informed BIM object. VisualARQ enhances Rhino by adding powerful associative object styling and dynamic documentation tools which adapt to fit your workflow. VisualARQ also gives you the power to automate many modelling tasks through the VisualARQ visual programming components built for Grasshopper 3d. Finally, you can use VisualARQ to collaborate with other tools through the IFC import / export capabilities built into the software. This combination of features gives you the power to define your BIM workflow."

SketchUp

SketchUp is a 3D modeling software tool used by 38,000,000 users to create 3D models. The software was originally developed by a start-up called @Last Software and acquired by Google in 2007 and released as a downloadable version with integrated tools using Google Earth and Google 3D Warehouse. In 2010 SketchUp 8 was released with Google Maps and Building Maker integration. In 2012 Trimble Navigation purchased SketchUp from Google and in 2013 a new version of SketchUp was released.

4.0 What are the Problems and Gaps Where Interoperability Occurs?

4.1. Who Uses BIM and for What Purpose?

Recent publications by Autodesk[43], JBKnowledge[44] and FMI[45] provide insight into who is currently using BIM. In the **2019 Construction Technology Report** a variety of interesting statistics were highlighted:

- 55% of the over 2,500 respondents indicated that they already use BIM
- 30.9% indicated that they don't bid on projects involving BIM
- 11.8% outsource BIM entirely
- 28.3% have a BIM department
- 48% indicated that the General Contractor takes the lead on BIM projects
- 24.6% of the total projects executed used BIM/VDC workflow.
- The primary application of BIM was for clash detection (60.5%)

In a report from FMI they cited that 30% of engineering and consulting firms use applications that don't integrate with one another and that 96% of all data goes unused in the E&C industry.[46] Putting these statistics in perspective it is important to consider the size and complexity of the construction industry in the United States. According to Statista there were over 454,367 small and moderate size construction companies in the US and 211,304 large construction firms. It is difficult to secure a large enough sample to provide statistics on use by type and size of player in the construction supply chain.
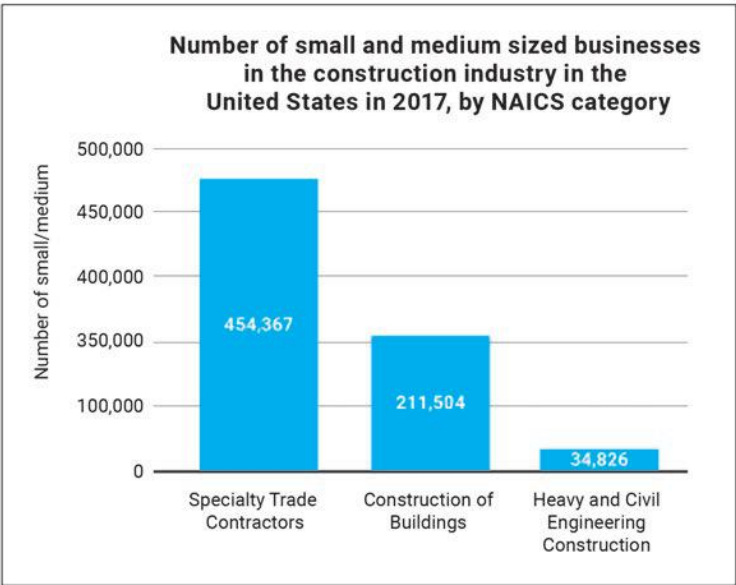
Source: Statista

FIGURE 5: Number of small and medium sized construction firms

Challenges with BIM?

More than half of the respondents indicated that a major deterrent to using BIM was the cost, time and expertise required.

Creating BIM models requires time, money, and/or expertise

43%   57%

■ Yes
■ No Response
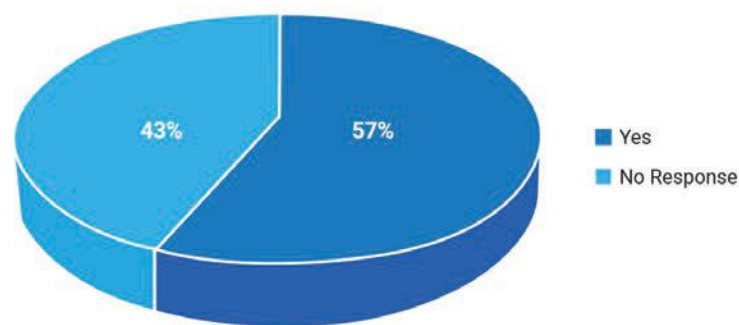
FIGURE 6: Interview responses regarding time, money, expertise

Most organizations are NOT using BIM. They are just developing a 3D model. A true BIM model will include all the characteristics for everything in the job. For example, a type of door, type of fixtures, cost of the door, the type of paint applied to it. BIM includes a ton of data entry. It is not just a simple 3D model of the building.

Large owners might be able to hire an in-house BIM expert or BIM consultant group to advocate for them and understand how the BIM process should be done on a job to meet the best interests of the owner. Any mid-size to large size contractor typically has very good BIM capabilities. **The smaller firms often will rely on consultants if BIM is required on a project. Then when you look at the various construction trades, you have even less adoption of BIM**. Low bid is king. Low price will usually win the bids. **The trades typically cannot use BIM at all**. And if it is required on a job, when they find out what BIM costs, they don't understand the high expense and realize they did not bid the job properly. When you purchase BIM, you aren't just buying a software package, purchasing Revit or other Autodesk products, you need a BIM team that understands and can use the BIM tools.

Some organizations are just starting to integrate asset management data into BIM models. If they don't have an in-house team for this, they won't get there. A small shop can't afford $10K to license Revit for their team and then pay a person's salary to operate and use the software. For a lot of small firms, small trade groups, this is an investment they don't want to make it or can't make. That's where a firm like ours comes in and provides them with a [temporary] BIM team. **The investment for smaller firms to develop an in-house BIM team is too big!**

Small Architectural & Engineering Firm President

Every complex system in a building is designed by the architect and the engineer. **But the contractor on the job is required to provide shop and installation drawings.** There isn't enough detail for the contractor to build from the architect's/engineer's model. It needs to be redrawn. And they are responsible for it, so they want to make sure it is right, and drawn in a way that will allow them to properly fabricate it. For example, if it is a steel frame, the steel OEM might lay it out in BIM and then the fabricator may ask for the BIM model. **The architect's drawings might have the beams, but they don't show the steps for fabrication of a beam, the details necessary for that component to be built.** So this has to be drawn again by the fabricator in order to ensure it is built correctly. You don't get this from the architect's BIM model.

With HVAC systems, the contractor might request the architect's Revit model. But these drawings are only used to produce their own drawings in AutoCAD, to redraw the piping, the ductwork. Again, a lot of time goes into this. By law, by the contracts, they are obligated to do this. It is often something that is legally required to do by the contractors, especially on larger projects often they are required to do this.

We are working on a $4 million to $5 million building renovation. **Everything with hand drawings could have been done in 10 sheets. With Revit and BIM, he has over 150 sheets for this project. They will have just as many problems in construction with 150 sheets and Revit as they would with 10 sheets.** He doesn't understand how using Revit benefits the industry when you create so much additional work and then you have the same or possibly even more issues during the construction. Where are the benefits? One might think the more information you provide to contractors the more help it is. But it takes a lot of time and money to do this. **And how does it help if the contractors still have to redraw the system even after receiving the BIM drawings?** With a very big building, large project clash interference is a simple problem to resolve. You don't need to create 10x drawings to do this, to see there are interferences.

4.2 Interoperability Issues with BIM

Interoperability issues extend beyond data. The supply chain in the construction industry is comprised of an extremely diverse set of professions and trades, each of which attracts individuals with different strengths and weaknesses. How an architect or a code compliance officer looks at their roles relative to building design and construction are very different. The tools that each profession uses are often unique to that trade. Each group has become efficient in the use of those tools so that they can keep the cost of their quotes low, the quality of their work high and win jobs. Not everyone in the construction supply chain spends their day in front of a computer. Different tools are used by craftsmen/craftswomen. Compound this by the fact that each member of the supply chain does not fully understand the level of detail that is required by the next team to do their job – so data is often missing that are important to others in the supply chain. In addition, sometimes it's just quicker to fix some thing, rather than recording the changes in the BIM model. The result is that one can't trust that the data provided are complete or correct. Everyone has contracting terms and conditions that they have to meet – so that they are compliant. The following statements are drawn from the interviews conducted:

Investors

Our largest interoperability issues come in regards to dealing with data sets. Oftentimes, we are trying to integrate in a dataset into our optimization methodology for which there is no Grasshopper plugin. This often requires us to write custom components simply to access something like seismic or census data

Interoperability is an issue only because they feel locked into their software (Revit and AutoDesk). We can't use other tools because the others aren't standardized within the industry. There are multiple platforms that are better, but they're difficult to use. There may be more open architecture with features they'd use, but it's difficult to justify paying more money for a new feature or two.

Architects

We struggle to coordinate among trades.

Submittals have to be made at the beginning of the project to get the materials approved—you have to make a cover sheet for each one and upload it, it's sort of a pain and that seems like something that could be streamlined. Also—when they (GCs, architects, etc.) issue document updates, it's often very tedious to actually find the changes they made—they just change it, but often the changes are not highlighted. This can be very time consuming because, as a subcontractor, you have to read through the documents very carefully to spot the changes. It would be great if there were programs that essentially had a "track changes" like function to highlight where changes were made. It would also be great if something like Procore (or other BIM tools) could interface with PayApps (construction progress payment software). The accounting side doesn't necessarily tie into the rest of it (BIM), but it would be very helpful if it could.

Engineers

Building Information Management for Masonry (BIM-M) is still in development. Ideally we want the same tool to be used and usable by the engineer, designer, architect, and robotic tools to assemble the structure. We want to use this tool in this combination of 3D printing and robotic assembly. Many key players in the design and construction process, including specialized subcontractors. The problem is inefficiency between these different players. With Design-Build, there is a single source that takes it all the way through the process. Updated BIM-M would help make this seamless.

One of the biggest issues we have seen is that everyone is on their own island, their own individual silo. Each group uses different tools. Then, each individual project may have different tools required to be used on that project. One set of software tools doesn't necessarily "talk" to another set of tools. Some may have better interoperability than others. As you go down the value chain, you get into more organizations, smaller contractors, that do not have the money or resources to teach people in their organization multiple systems. So they do not use the BIM tools at all. Not having the systems and tools available linked together is a big hinderance in the industry.

ProCore is a firm that is trying to pull everything together and provide more interoperability between various software tools used in the industry. Designers and engineers typically will use Revit. As you go to the contractor, they have to deal with whatever they are provided. They might use a tool like ProCore as a catch-all, taking in everything thrown at them and using it to synthesize the data into information they can use.

Every owner does things in a slightly different way, every architect, every engineer, every contractor. They use different tools, become proficient in certain tools and like to stick with them. In order to extract additional value you need the contractors to use BIM tools too. You need buy in from every level along the value chain. Another item that comes up is that every project is different in terms of different requirements. Different software tools might be required, and then you have different monetary project sizes that may or may not justify learning to use other tools. Therefore, it's difficult for a contractor to invest in any package directly on their own and get up to speed on it, and provide their employees the training and education needed. The contractors do what is required for the job.

The subcontractors, your electricians, HVAC, and other small groups, are even less likely to use any type of BIM tools. They don't have the money, the people, educational background, to invest in developing and using BIM tools. They want to print off the plan and do the job from that, "old school." They have heard that some of the subcontractors will take a 2D print from the contractor and redraw what they need to for use in their shop to prefab parts and then fabrication on the job site.

Some other hurdles include:
- Each group wants to maintain ownership of the BIM elements. They don't want to share it with others because of the time and effort to develop it.
- If everything was available in the BIM tools and meet all code compliance requirements, design requirements, you then diminish the need for an architect and engineer in the design phase of the job.

Interoperability is a big problem with BIM modeling, moving from a common 3D modeling

program to a BIM software program is a big problem to address. It is getting better. Straight up 3D modeling to BIM needs better interoperability tools. 3D modeling is just that – there is no information associated with that, a piece of jewelry, a house, a college campus – it's just geometry. Rhino3D is a common software tools used. SketchUp is another common one. They are used for straight design activities by architects. In her classes, she will hear from students working on early stages of design that they can't take the model from one system directly into another system. There is a lot of extra work involved to get the model into another software tool. Architects want to design good buildings, addressing key interoperability issues at the early, virtual design stages would be very beneficial to the overall construction process, code compliance issues, and energy efficiency.

You get the 3D geometry into BIM and then the data is added. This is one issue. Next, if we look at energy modeling simulation, you have more interoperability issues. What does the energy modeler need to know? For example, what is the color of paint (architect) vs. reflectiveness of the paint (energy person). Someone knowledgeable has to put the information into the BIM. A material such as concrete has some values ready to go into the model but some information has to be added. The energy modeler uses their favorite software and there are maybe half dozen different choices available out there. If you try to go directly from the BIM to the energy modeling, some stuff goes over ok, some stuff looks like it goes over but it may leave a blank or change the data. There is a huge, gigantic opportunity right there to fix things! Standards would be huge. 3D models are different for an architect than for an energy modeler. Going from BIM to BIM Energy Modeling. GREAT OPPORTUNITY! It takes an enormous amount of time to develop the energy model. Once the energy modeler makes the changes in their software, then it is difficult to get that back into the BIM model. This creates more time re-keying the new information, another issue to address. People are working on this problem, but there is no good solution right now.

4.3. Code Compliance

Building codes are complex because of the variability that exists at the local, state, and/or federal level. There are two types of codes: model and adopted[47]. Model codes are suggested practices. They are not law, but can become law if adopted by local, state or federal government. Adopted codes are those developed by the jurisdiction itself that set the minimum standards that must be adhered to. Multiple types of codes exist for different aspects of building construction including building codes, energy codes, and fire codes. Codes regulate the design and construction of structures where adopted into law and are applied by numerous professions in the construction supply chain including architects, engineers, interior designers, constructors, manufacturers of building products and materials. Failure to meet the codes by the parties involved can have dire consequences including legal action, hefty fines, cancellation of insurance, building permit revoked, and cessation of construction until the appropriate repairs are made to bring the building into compliances.

Standards are applied to establish testing methodology and materials specifications. In the US building construction industry the main standards used are the International Building Code or International Residential Code [IBC/IRC]. In 1994, the International Code Council (ICC) was established which publishes codes that apply to residential, commercial and institutional structures. The ICC integrates 15 model codes, referred to as the I-Codes including: the International Building Code (IBC), the International Residential Code (IRC), the International Existing Building Code (IEBC), the International Green Construction Code (IgCC), the International Energy Conservation Code (IECC),

Lighting

Homeowner

the International Fire Code (IFC), the International Wildland-Urban Interface Code (IWIUC).

Efforts are being made to integrate Code Compliance into BIM. Automated Code Compliance (ACC) refers to digital design tools that allow only the design of elements that meet legal and physical requirements such as International Building Codes. "This is typically achieved via databases of code-compliant elements, the automatic calculation and adjustment of any non-compliant user decisions, or the automatic checking of all design elements for compliance, providing the user with the respective information[48]. According to Nguyen and Kim:

> "Traditionally, building code compliance of a building at a particular design phase is not evaluated until all design works for the building have been completed. Further, the evaluation task is usually conducted in a manual fashion through numerous physical meetings (Goedert and Meadati 2008). This in turn makes the evaluation process time-consuming, potentially expensive, and prone to error, since the meeting participants or evaluators often become overwhelmed with a huge volume of project information and design criteria. In the case that the building design does not comply with the current building codes, the designer need to meet with other project participants, whose designs may have affects on the code violations, to determine how to appropriately modify the design so that the code violations can be avoided.[49]"

Companies working on ways to integrate code compliance with BIM are highlighted in a recent article entitled "Building Code Review Software: Feasible or Far-Fetched?". A company called UpCodes, developed and introduced a tool called UpCodes Web which is an on-line database of codes and are working on a new product called UpCodesAI that will be an add-in for Revit. "UpCodes AI uses natural language processing, a form of artificial intelligence that processes and analyzes natural language, to read from the UpCodes Web code database and check BIM elements against the code requirements." Another company called SMARTreview is working on providing a solution as well for the interface between BIM and building codes also using Revit. (See YouTube demo). An interview was conducted with Dr. Mark Clayton as part of this study. Dr. Clayton is a Professor at Texas A&M and also the founder of SMARTreview.

University Professor
Small Business Owner
– BIM Software

INTERVIEW
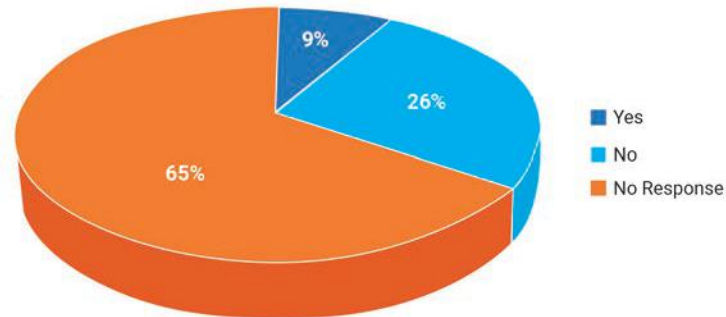
FIGURE 7: BIM could assist with code compliance

Building codes are a bottle neck in the design process. It takes too long to get a building permit – in fact, several months to years to get it. Everything just stops in the process while you wait for the permit. Our software, SMARTreview develops a workflow that is much faster. Right now, architects produce drawings and submit the drawings in order to receive a permit. Building code officials then review them and get back to the architect with questions and issues. Depending on the backlog, the review of drawings and code provisions can take a very long time to complete. There isn't a very standardized process so there is a lot of digging that takes place.

A required code compliance provision may be on the drawing or it may be found in the specs. Building code officials have to look for it. The real issue is to help architects create a compliant design. Computers can be used to help certify the design. The city could then become familiar with the SMARTreview product and say it is going to be ok or they could do some spot checks on documents and drawings. This alone could eliminate major delays in a project. SMARTreview is targeting this level of capability in 5 to 10 years (it's more disruptive and will take longer to fully develop this capability).

SMARTreview is designed to help the architect get code compliance right the first time. The goal is to avoid going back and forth with the city during the permitting process. When the design is checked by the city for compliance, they don't want any issues to come up. If any are found, the city sends it back to the architect for revisions, changes are made, and then it goes back to the city for review again. The SMARTreview software helps to shorten the turnaround cycle. By using the tools, you save the architect time and money, the city saves time and money, but you really save the building owner the most money. Until the building is built and occupied, the owner is losing money. Any delays in the schedule have a negative impact on profits. The building owners will greatly benefit from expediting the plan review process.

What did others say about the challenge of code compliance:

BIM tools are used on the front end and can include **some integration** of code requirements. For example, you can build in code required clearances into the design for doors. Or you might want to look at material usage such as the amount of fly ash used in the construction. Another example is providing minimum clearances around mechanical equipment or valves.

In the design world we often focus on Revit but equally important are the codes required, the job specifications, owner standards, building operation standards, maintenance schedules. All of that information should impact the design from the beginning and development of the BIM model. However, that doesn't happen the way things are done. Basically, they currently design in a silo and transition it to the next group, the owner. In order to solve the disconnect you need to get the other groups talking to each other earlier in the process. When they build a model in Revit, what if there was a code compliance included in the design? A lot of this is still very manual process. There is a large disconnect between design and code compliance. Right now, people might check the design with code compliance digitally, using .pdfs on a screen but it's still a very manual, time consuming process. And number of code compliance issues are binary (yes/no) items. The software system should help find those issues. Their drawings are often sent to a city, a town, or other government group reviews them manually for compliance. This takes time and sometimes items are missed. After that, you get the contractors involved but they are responsible for building to the drawing, not conducting another code compliance check. Including more code specifications built into the software tools used early in the design work would be very helpful. They have started to take a look using and potential integration of BDS Speclink (https://bsdspeclink.com/), a tool to link the Revit drawings to the specs / codes required on the job. Looking at an integration of this.

> **One area that would minimize mistakes with BIM models is more on-site construction experience for the developers.**

A lot of programs will allude to having code checking capabilities built-in, but he hasn't really seen a good one to use yet. Through the design and development process, they have a lot of code experts involved. This is not something you can let the computer do. The software programs are not that good yet. You might build blocks of families to help you check for code compliance manually, but you will still want to have code experts review drawings and design to ensure compliance is met.

The designer has heard from other groups in the industry that there are positives and negatives to using BIM models. One area that could help minimize mistakes with BIM models is more on-site construction experience. Many designers have not actually worked on a construction job site and therefore, don't understand some of the issues that can come up on a job. For example, something as simple as not showing the frame of the door being hinged and meeting handicap accessibility requirements. Her company creates drawings in 2D and does not have a program to check for code items such as this. They do it manually off of the prints and if they make a mistake it costs them to fix it. If a Revit BIM model included checking for code compliance items like this, it would be very helpful for the industry and those that use BIM tools.

"I know most basic codes for electrical or my uncle with 40 plus years knows the answer. In my trade the current code book is how most guys lay out on prints and all big companies are giving blue prints at the job once it's a certain size project. But for someone like me or really small companies most of the time we just walk through with the owner or project manager to figure out what they want. Then use the code book to determine the rest of the lay out."

This is very difficult. There is a lot that goes into design an Americans with Disabilities Act (ADA) compliant restroom. The door handles have to be the right height, toilet heights need to be a certain height, you need specific clearances. It's a big problem trying to add this into a model. If you could do this early in the design process, it would streamline a lot of items and save a lot of money.

A lot still comes back to the way the contracts are written and standards applied. DoD has BIM standards. They are very well written. They have the time and money to hire all the right people to develop them. The problem is no one in industry can achieve those deliverables the way they are currently written. **The Army Corps has a good set of standards (https://www.wbdg.org/ffc/army-coe/cad-bim-technology-center) that could be used for the entire US**. But there is no national delivery process for them. We don't have a national standard on how BIM modeling should be done so you get different, customized solutions from different groups. If we could develop a set of standards a majority of the industry followed, then it will help the industry elevate, help the industry perform better and capture efficiencies.

5.0 Standards and Factors Influencing BIM Adoption in Europe

Standards were mentioned a number of times during the interview process. An observation that surfaced was the encouragement to use BIM in Europe, led by initial efforts in the United Kingdom. This section of the report highlights the evolution of BIM mandates. ISO standards are also available in Appendix B.

In May 2019, *The Architect's Newspaper* published an article titled *How the U.K. Forged a Path to Global BIM Standards*. According to this article, in the early days of using BIM, there were efforts to develop and release government standards—one of the most notable examples of this involved the General Services Administration (GSA) and their attempt to create a standard. In Singapore, they developed BIM-derived digital permitting submissions. Both of these projects received attention, but they did not gain much traction in terms of implemented technologies or operating protocols.[50] With that said, these efforts did have one significant impact:

"In the loosely organized, disparate network of the building industry supply chain, government could provide a galvanizing influence. At least when government spoke, the industry listened."[51]

In 2011, the UK published the *Government Construction Strategy* which had a significant impact on BIM adoption in the UK. Other entities and individuals had developed earlier theories regarding industry productivity and the need for process integration—so the problem had been identified earlier and there was awareness of the issue. Moving forward, the government viewed construction as a "critical economic engine, concluding that improving the cost and carbon impacts of building while bolstering UK capabilities as a global building leader would drive growth." The resulting government policy document included BIM as a key pillar and it included the following requirement:

"Government will require fully collaborative 3-D BIM (with all project and asset information,

documentation, and data being electronic) as a minimum by 2016. A staged plan will be published with mandated milestones showing measurable progress at the end of each year."[52]

Approximately 40% of construction dollars in the UK are spent by the government and the industry paid attention to this guidance. They formed cross-industry collaborations and also established and implemented BIM requirements for all their projects (logistical and financial support for this came from the government). BIM adoption in the UK increased from 10% in 2012 to 70% in 2018. The resulting standards were clear, rigorous, and implementable"— which may have played a role in the industry embracing such standards. The efforts in the UK spread across Europe and government leaders throughout the European Union have developed standards for the entire EU. There have also been efforts in Latin America and Southeast Asia. As BIM has become more familiar to those worldwide, the trend toward global BIM standards is a logical path forward.[53]

While the UK and Europe may have taken the lead in developing BIM standards, other countries—including the US— have also developed standards. NBIMS-US V2 is the national BIM standard for the US. According to information about NBIMS-US from the National Institute of Building Sciences:

> "The transformation in the building industry fostered by the evolution from use of analog drawings and text to the use of digital electronic Building Information Modeling (BIM) is comparable to the transformation that has already occurred in the aircraft, microprocessor, and automotive industries. Early definitions which assert that BIM is simply a 3D model of a facility are far from the truth and do not adequately communicate the potential of digital, object-based, interoperable building information modeling processes and tools and modern communications methods. As defined in the original NBIMS document "A BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward." If implemented, nearly every piece of information that an owner needs about a facility throughout its life can be made available electronically. The industry, however, does not yet have the open standards and infrastructure in place to capture, organize, distribute, and mine that information. Our goal at the National Institute of Building Sciences buildingSMART alliance® is to establish, through the NBIMS-US Project, the standards needed to foster innovation in processes and infrastructure so that end-users throughout all facets of the industry can efficiently access the information needed to create and operate optimized facilities.
>
> The beneficiaries of BIM include owners, planners, realtors, appraisers, mortgage bankers, designers, engineers, estimators, specifies, safety, occupational health, environmentalists, contractors, lawyers, contract officers, sub-contractors, fabricators, code officials, operators, risk managers, renovators, first responders and demolition contractors. Each person has their own view of the information and many share the same information. Some involved supply information, some use information and some do both. For all this information to be useful, it must adhere to open standards.
>
> The NBIMS-US Project Committee (National BIM Standard-United States Project Committee), is a project committee of the buildingSMART alliance® which is a council of the Institute. Originally chartered in 2005 as the Facility Information Council (FIC), the NBIMS Committee was re-chartered as an Alliance project in 2008 in order to consolidate missions and streamline services. From 1992 to 2008 the FIC mission was to "improve the performance of facilities over their full life-cycle by fostering common and open standards and an integrated life-cycle information model for the A/E/C & FM industry." Although FIC was sunsetted in 2008 its mission continues under the governance of the Alliance. The NBIMS-US Project Committee continues this tradition by knitting

together the broadest and deepest constituency ever assembled for the purpose of establishing and managing through an Industry consensus process a series of open source National standards and guidance for all aspects of Building Information Modeling. The NBIMS Charter spells out the Committee's vision and describes the results NBIMS-US expects to achieve."[54]

5.1. EUROPEAN MANDATES FOR BIM USE

There are mandates in many European countries pertaining to the use of BIM, and this factor has clearly played a significant role in BIM adoption. There are also different levels of BIM adoption. The BIM level refers to the level of BIM maturity, and this scale ranges from level 0 to level 3 (and beyond).

- **Level 0** refers to no collaboration being done (2D CAD is used instead of 3D).
- **Level 1 BIM** is the most common level of operation—this often consists of using 3D CAD for concepting, 2D for drafting of approval documentation, and shared data in a Common Data Environment (managed by the contractor).
- **Level 2 BIM** is more advanced; each party within a team uses their own 3D CAD model, but may not collaborate in a single, shared model.
- **Level 3 BIM** refers to full team collaboration among all parties using a single, shared project model. In level 3, each party can access and modify the shared model. Level 3 may also be referred to as "open BIM."[55]

Countries such as Austria and Norway were among the first countries to establish open BIM standards and an open BIM mandate—they required level 3 BIM on public projects. Other countries—such as the Nordic countries, UK, France, and Italy—established level 2 BIM mandates and they have different schedules in place for moving to level 3 BIM. Countries like Germany and Spain have more recently introduced BIM programs, with plans for an eventual BIM mandate. Still, other countries in Europe—such as Portugal, Switzerland, and Belgium—have no plans for BIM mandates.[56] The table below outlines the countries in the EU and indicates if they have BIM mandates in place.
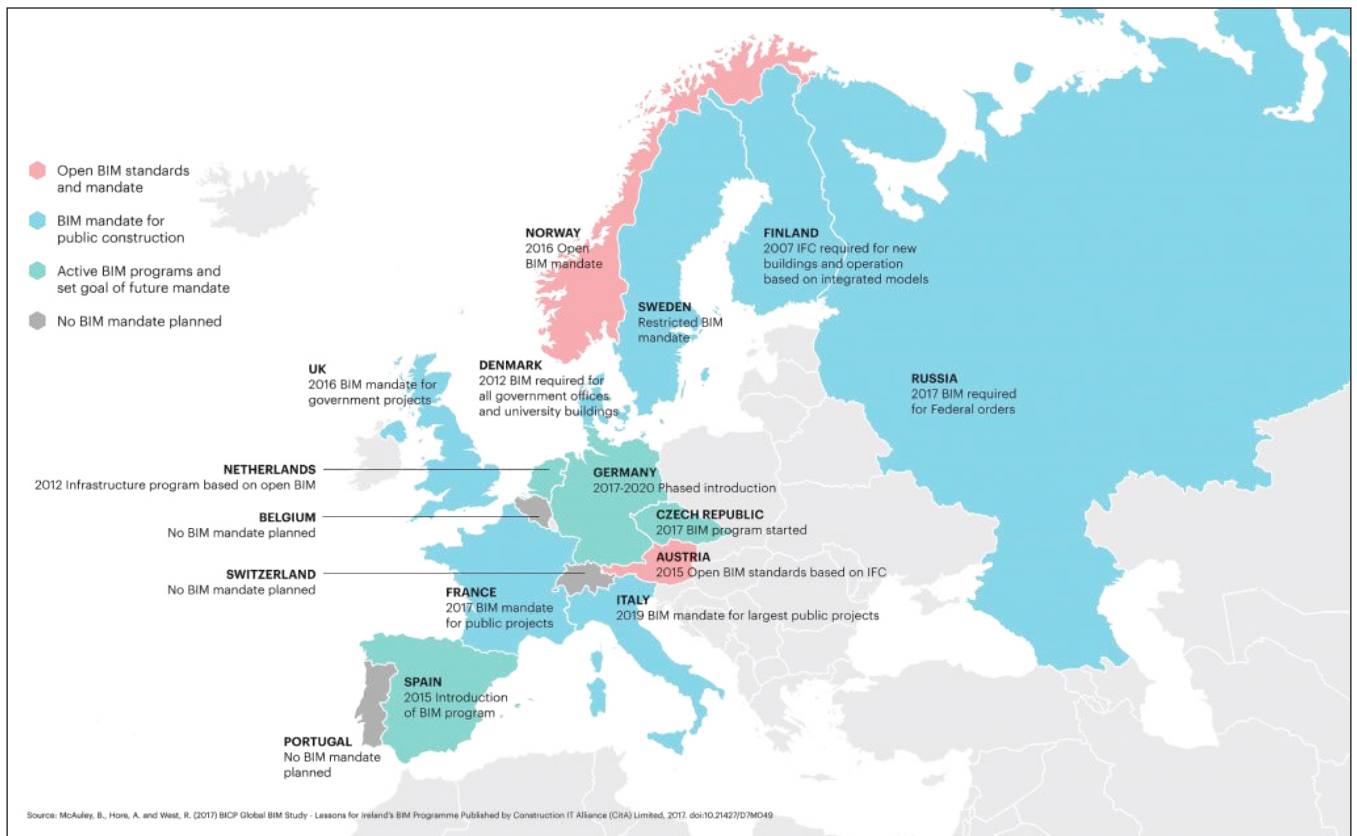
Source: McAuley, B., Hore, A., and West, R. (2017), BICP Global BIM Study –
Lessons for Ireland's BIM Programme Published by Construction IT Alliance Limited, 2017 [57]

FIGURE 8: Adoption of BIM in Europe

Table 2: Adoption of BIM in Europe

Country	BIM Mandate Status
Austria	Established open BIM standards and an open BIM mandate, requiring level 3 BIM on public projects[58]
Australia	No regulation to-date[59]
Belgium	No regulation to-date
Brazil	Roadmap is under review/consideration
Canada	No regulation to-date
Chile	BIM mandated for 2020
China	BIM required through the 12th national Five-Year Plan
Czech Republic	No regulation to-date
Denmark	Mandatory requirement since 2007; In 2012 BIM was required for all government offices and university buildings[60]
Dubai	Mandated since 2013
Finland	2007 IFC required for new buildings and operation based on integrated models[61]; BIM mandate for public construction[62]
France	Mandated since 2017 for public projects
Germany	BIM will be mandatory for all transportation projects starting in 2020[63]
Hong Kong	Mandated since 2014
Ireland	Roadmap to Digital Transition for 2018-2021
Italy	Mandated since 2019 for large public projects
Netherlands	No mandate
New Zealand	No regulation to-date
Norway	Mandated since 2016
Portugal	No BIM mandate planned
Qatar	No regulation to-date
Russia	Mandated for federal orders since 2017[64]
Scotland	Mandated since 2017
Singapore	Mandated for public projects since 2015[65]
Spain	Mandated since 2018
Sweden	Mandated for public projects since 2015 (including the Swedish Transportation Administration)
Switzerland	No regulation to-date
United Arab Emirates	Mandated for all projects that are 40-stories and higher, or 300,000 sq. ft. and larger (mandate in place since 2014)[66]
United Kingdom	Mandated since 2016 for government projects
United States	Multiple mandates through different states, but BIM is not currently mandated on a national scale

Unless otherwise noted, information in the above table is reproduced from: McAuley, B., Hore, A. and West R. (2017) BICP Global BIM Study – Lessons for Ireland's BIM Programme Published by Construction IT Alliance (CitA) Limited, 2017. doi:10.21427/D7M049[67]

Many countries around the world are enacting or entertaining the idea of imposing BIM mandates; however, the United States has not mandated BIM on a national level, despite the popularity and increasing use of BIM within the US. Why is this? The decentralized nature of the country is a factor—there is not one agency responsible for all construction within the country, as there is in the UK. In addition, many industry players do not actually want a BIM mandate. Contractors in the US view each project as a distinct challenge, and they acknowledge that a standardized BIM formula will not always work. The US has its own culture when it comes to using BIM, and this culture stems from the ground up (rather than the top down)—a government mandate may be viewed as disruptive, rather than helpful.[68] Professionals in the US are working differently than those in the UK. For example:

> "[Engineers, architects, and contractors] are now getting smart about picking up on what the other offices are doing and you are seeing these ideas go viral. These ideas will get implemented on projects in those offices, which in turn helps them go viral in those markets. When the project finishes, others begin to copy it. That's kind of the viral method that happens here as opposed to the UK, where basically a program gets laid out per the standard and people primarily learn how to do it that way."[69]

The BIM culture in the US has developed in somewhat of a piecemeal fashion, driven by local governments, individual agencies, and agencies in the private sector. States and districts have started to experiment with BIM mandates (Wisconsin requires all public works projects with a budget of over $5 million and new public construction projects with a budget of over $2.5 million to use BIM). Federal government departments are also playing a role.[70] In 2003, the General Services Administration (GSA) established their National 3D-4D-BIM Program:

> "The program promoted a policy mandating BIM adoption for all PBS projects, a mandate that required model-based design and open-standard facility management data, and encouraged projects to use mature 3D, 4D, and BIM technologies. In fact, the UK modeled its own BIM solution off of the 3D-4D-BIM Program. While less recognizable, other departments like Naval Facilities (NavFac) also have their own BIM requirements for contractors working with them. Individual companies, too, have their own BIM mandates that collaborating contractors must follow."[71]

5.2. EU BIM TASK GROUP

While there are organizations throughout Europe focusing on BIM, the EU BIM Task Group may be a particularly significant organization. The EU BIM Task Group is supporting a pan-European approach to best practices in BIM, bringing national efforts together and forming a common and aligned European approach to BIM implementation and adoption. The European Commission "awarded the EU BIM Task Group funding for two years (2016-2017) to deliver a common European network aimed at aligning the use of Building Information Modeling in public works."[72] The EU BIM Task Group has developed and published the *Handbook for the Introduction of Building Information Modelling by the European Public Sector*—a strategic document that provides recommendations for implementing BIM in Europe. This document provides the following strategic recommendations:

> › Establish public leadership. This begins with defining compelling drivers, a clear vision, and specific goals. Leaders should document the value proposition and strategy, defining the anticipated benefit of BIM in relation to the public sector organization's objectives. Finally, the last component in establishing public leadership is to identify a sponsor, funding, and stewardship team.

> › Communicate vision and foster communities. This begins with the early engagement of industry. As public leadership is being established, it is recommended that the public sector organization communicate its vision, goals, and plan of action for the introduction of BIM to the broader industry. Networks also play a key role. Public sector BIM programs are encouraged to participate in and promote the formation of groups of industry stakeholders to share best practices and lessons learned. They recommend collaborating with other countries and encouraging alignment. Finally, the use of mass communication, events, media, the web, and social media is encouraged and recommended. The use of multiple communication channels enables stakeholders and leadership to communicate to the entire value chain.

> › Build a collaborative framework. The goal is to produce a common understanding and definition of BIM. There should be support for common understanding, common data exchange, common ways of operating, and a basis for consistent up-skilling, training, and education. Standards and guides are encompassed within this strategic recommendation. The first step is to develop legal and regulatory framework. It is recommended that parties "assess and clarify the regulatory, procurement and legal contracting arrangements between clients and suppliers to facilitate the use of BIM and the exchange of digital information across the project and asset lifecycle." The next step would be to reference or develop technical and process standards. Building skills, tools, and guidance is another action item. Encouraging industry skill development and learning, as it pertains to BIM, is recommended.

> › Increase industry capacity. The first step in doing this is to promote industry pilot projects, as they represent a useful way to "test the collaborative framework (legal, data, and process standards) and to provide a practical demonstration of how BIM is to be implemented under the BIM program." The next step is to increase the use of a strategic lever to grow capacity. A "strategic lever" refers to a tool such as public procurement or a regulation that can be used to drive change or encourage a desired outcome. Finally, one must measure and monitor progress and embed change.

In addition, the document provides an overview of implementation level recommendations pertaining to policy, technical, process, and people/skills recommendations. While many countries throughout Europe may have their own roadmaps pertaining to BIM, the EU may benefit from having this cohesive guidance from EU BIM.

6.0 Energy Efficiency and BIM

Building Energy Modeling (BEM) is offered by only a few BIM suppliers. These tools help to assess energy demand, indoor air quality, carbon dioxide emission and payback periods on energy savings measures.[73] However, according to some, most current BEM tools only take into account 'passive' elements such as building envelope, rooms, structure, equipment, whereas true energy efficiency estimation must also take into account active control scenarios and real energy usage data.

DOE has developed and provides two BEM software packages: EnergyPlus and Open Studio. These are available through non-exclusive open-source licenses and support. Energy Plus interfaces with a number of other tools as represented below.
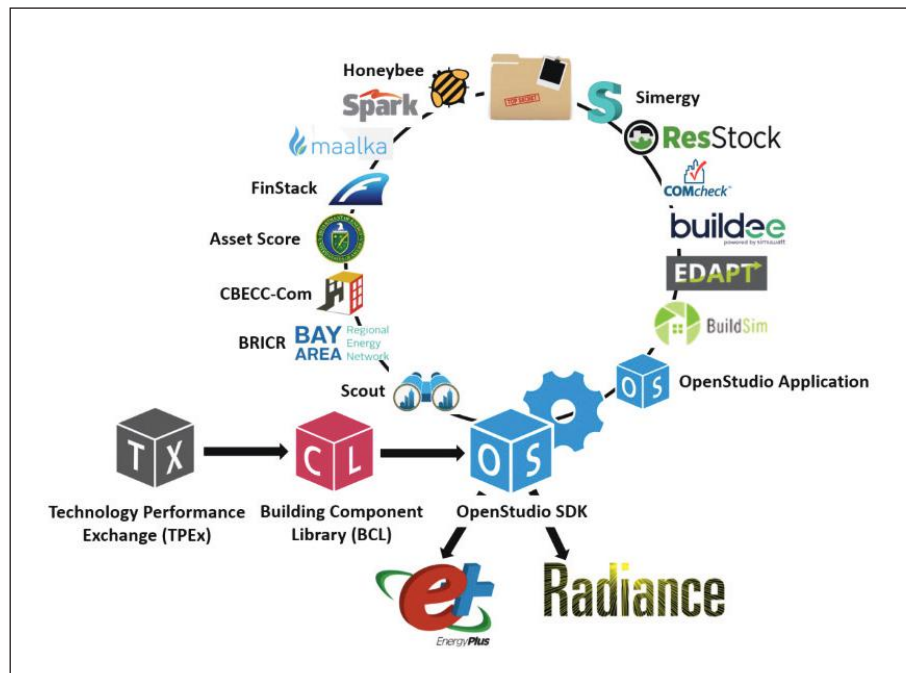
Source: Department of Energy, Building Technologies Office

FIGURE 9: Public and Private End-User Applications with which EnergyPlus interfaces

AutoDesk provides information and training through AutoDesk University on Using BIM to Streamline your Energy Modeling Workflows.[74] According to the authors of a comprehensive review of BEM, interoperability issues with BIM exist.[75] Through use of tools such as Green Building Studio (GBS), Design Builder and Integrated Environmental Solutions-Virtual Environment (IES) can work with IFC. It also appears that Green Building Studio is now the analysis engine used by Energy Analysis for Revit.

**University Professor
Director, Computer Integrated
Construction Program**

The ability to leverage data to create energy models has continuously been a challenge. Small energy retrofit projects, collecting enough data to predict an energy model can be a challenge. If you can do this, it will help you in deciding which new systems to install in the building for heating and cooling, as an example. EnergyPlus is a software tool used by DOE for energy modeling. It's a great engine but it requires an extensive amount of data input into a very rigorous structure. You need a lot of expertise and time to input the requirements for the physics engine to operate. It takes a lot of time to go from a BIM model to an energy analysis using EnergyPlus. Autodesk and Bentley are two groups in the industry that try to do this as one offs with varying degrees of success. With energy modeling, a lot of times this is done after the fact, but it really needs to be looked at earlier, during the virtual design of the building when changes can be more readily accomplished. Once you are into the build it is more difficult to modify the design.

Professor Messner believes ideal solutions should be developed through open standards. Parametric design concepts tied into energy models and aesthetics and other items. However, solutions are not currently available that way. Open standards to develop energy models could really help advance this area.

An Open standards approach would get better results. The buildingSMART alliance within the National Institute of Building Sciences (NIBS) has **a BIM Council helping to drive standards**. **They publish a national BIM standard.** One part is focused on execution standards. They also have information exchanges regarding how to create open standards to support the design for energy modeling and other items for a building. The group is just starting to look at rewriting the standard. Within their council they have been working with the UK and the **Center for Digital Built Britain, ISO 19650**[76]. The UK has very stringent standards right now in what they require, but compliance is still highly variable. If you talk to people on the street you might get a little bit different perspective than the public face. Compliance and adoption may not be as high as the group promotes. **Professor Messner would argue that BIM in the US may still be more broadly adopted across the country, although the UK is rapidly catching up.** The **US has NOT put out good standards that are readily contractable**. They need to do this. Put together a series of contractable open standards that can be leveraged across the industry.

Professor Messner brought an example of using open standards. He said the Defense Health Agency (DHA) of DoD has developed an open access of standardized objects for operating rooms. When the DoD builds a hospital, why should they redesign an operating room for a second or third hospital? Why recreate it when they've already developed a model for one project. However, this de-minimizes the value of the architect and engineer. The US Army Corps of Engineers have nine Centers of Standardization (COS). The center could put together standards, bought from the contractor, so that they could re-use their BIM models, minimizing redesign work.

6.1 Energy Models

Interviews conducted in preparation of this report indicate that although one can use energy modelers with Revit – the process of doing is considered complex. Companies sometimes prefer to develop their own tools instead of trying to learn how to use the tools which are considered expensive. Other issues relate to the availability of up-to-date codes. Inconsistency in results depending on the model used. The following comments regarding building energy modeling was extracted from the interviews.

- Energy modeling during design, using BIM tools to do is something that in theory if you have a good Revit model can be done. You can predict energy losses but it is so complex and you need additional tools for it, it's not something he is familiar with or something he has seen being done.

- Using the tools, they can perform a lot more analysis virtually, before construction takes place. Even with retrofits, there are large benefits from performing laser scanning. They send a team out to scan the building, and then convert it to a 3D model. They have customized tools added in to perform energy analysis, BIM 360 Insight or other commercial tools to run analysis. They will look at adding shade, changing glass types, changing the HVAC system – they are working internally to generate studies on this to find ways to improve it. The key issue is how much time and money does the owner want to spend up front for analysis that will provide benefits long term. How much information do they want included in the model? If an owner is not exposed to the potential benefits, does not understand the benefits of the technology, it is difficult, virtually impossible, to have them implement it in the contract.

Open standards to develop energy models could really help!

- Design fees are expensive and often a limiting factor of a project. By building our parametric systems, we are able to create a cheaper building in less time that still fits all the criteria, something that is typically financially unfeasible. We are also able to design unique and custom parts sometimes in the hundreds. With recent innovations in manufacturing technology, these can be easily manufactured at no additional cost. These unique parts can allow for easier construction, fitting together often like pieces of Lego. Our adaptation methods also allow us to make the buildings themselves more energy efficient and have lower total embodied energy costs.

- While they use the energy efficiency features already such as energy modeling and compliance, he did not feel they used them to their full extent. He imagines a day where "sensors [embedded in the building] could show how a building is utilized and would help make architects make tweaks down the road to improve utility."

- These tools are just as good as Revit, they just do it in a different way. Revit is what they use at ZGF here in the states because it's difficult to try and use other software products. Most groups in the states use Revit. Other programs, don't transfer information from one software tool to another as well as Revit does. There are issues but it works fairly well. Revit is the starting point used for the designs. Sometimes Sketchup is used before Revit, but they use Revit next. It has some data included in walls and other items, R-values are in it, but it is not the program you use for conducting an energy analysis. An energy modeler would use an export of the Revit file to their software tools. A lot of people he hears talk about doing analysis use another 3D modeling tool, Rhino3D. This is the rock star of 3D modeling. It allows you to develop any shape you want but

it doesn't include the metadata for the BIM model. Revit is better for documentation and spreadsheet versions of the model, showing things such as cost per sq. ft.

- They follow design codes such as 2018 International Residential Code (IRC) and 2020 Residential Code of NY State. (The energy codes aren't supported by ResCheck, a software tool they use to check for NY state software for energy compliance. This checks for compliance with insulation, windows, design for energy efficiency that you need to comply with in NY State. Often the software doesn't support the latest code changes and they look at things manually. An example of issues using 2D prints vs. a system with all the drawings tied together in a BIM model on a recent job, they had the drawings completed and to the contractor meeting the current required state building codes. A code change was released on three days later and the client wanted the construction to be up to date with the code changes. It had no impact on the construction build itself but did cause their firm a lot of extra time to pull up each 2D drawing and update individual and send out again.

- Innovative software hasn't really translated to cost savings or improvements to energy efficiency. More often than not, a job goes to bid before it's even fully designed. Software programs like Procore are helpful because people who are involved in the project can make changes to documents on the fly and it's easier to get important information to contractors who are working in the field. These BIM tools don't necessarily help them work faster, but they enable them to keep up. If architects did things as they used to, these software tools would make things go faster—but that's just not really the case, in practice. The software has become a bit of a crutch. Architects used to issue full documents, but now they don't because they can rely on the software to do some of this work (essentially, it would be more beneficial to contractors if they issued full documents AND used the BIM tools).

Different energy models, produce different results.

- First, you get the 3D geometry into BIM and then the data is added. This is one issue. Next, if we look at energy modeling simulation, you have more interoperability issues. What does the energy modeler need to know? For example, what is the color of paint (architect) vs. reflectiveness of the paint (energy person). Someone knowledgeable has to put the information into the BIM. A material such as concrete has some values ready to go into the model but some information has to be added. The energy modeler uses their favorite software and there are maybe half dozen different choices available out there. If you try to go directly from the BIM to the energy modeling, some stuff goes over ok, some stuff looks like it goes over but it may leave a blank or change the data. There is a huge, gigantic opportunity right there to fix things! Standards would be huge. 3D models are different for an architect than for an energy modeler. Going from BIM to BIM Energy Modeling. GREAT OPPORTUNITY! It takes an enormous amount of time to do develop the energy model. Once the energy modeler makes the changes in their software, then it is difficult to get that back into the BIM model. This creates more time re-keying the new information, another issue to address. People are working on this problem, but there is no good solution right now.

- If we look at the contractor and what they do once they have the design documents. Now they have to go out and buy the HVAC system. They might use a different energy program or purchase different products. Different energy models provide different results. Now you have changes from the original design by the architect to what is actually being provided in the field by the contractor. Who captures these changes? If it's not in the contract, it likely isn't captured. And then, many subcontractors do not use BIM at all. They get the job done but often have nothing to do with BIM.

7.0 TRAINING

A repeated theme in the interviews was the importance of training. Training is available through multiple organizations, but the challenge appears that a company must be large enough to afford paying for the time to become efficient. It's not the cost of the course per se, but the time it takes to become efficient and to change workflow. Organizations must see that there is a cost-benefit to changing their workflow. Although the General Contractor is more likely to see the cost-benefit – people further down the supply chain may not.

It's not the price of software that is keeping groups from using BIM tools. Training and understanding the full capabilities of the software is needed. A lot of it is mentality and training. Autodesk has a suite of tools to help you go all the way through. The architects work in BIM 360 Glue, now BIM 360 Coordinate, to upload models and detect clashes. In a perfect world you will have the architects and engineers using Revit and all the subcontractors using Revit with their models too, allowing them to tie in directly to the base design. In reality that does NOT happen. Many of the subcontractors were smaller firms and have NOT invested in 3D modeling, BIM capabilities.

In this project specifically, the contractor and subs came forward early on asking to work more closely together. Right away they had early discussion and drawing exchanges helping them get to Level of Design (LOD) 200 and LOD300 quickly. When you aren't working in the same space there are delays encountered because of rekeying information. When you advance to LOD 400, construction stage, there are often issues that come up. For example, the contractor might have to reconstruct the model for fabrication in another system. A subcontractor strips down the model and then builds it back up and sends it out for fabrication. A key issue is they aren't working in the same space and with the same tools. Revit is getting better at handling these different steps but more work needs to be done. In addition, contractors need to adopt and learn to use the new technologies and fabrication shops need to be able to be equipped to use the software models with their tools / machinery too. Education and training of the value of BIM tools is needed in the industry.

Purchasing and training people to use Revit is not cheap

By far, BIM has the most promise and ability to make things better in the construction industry. People need education on what it can do. They need to understand the benefits and they need training on how to use it effectively to capture the benefits. Even within their own office at ZGF, he finds that people view it as a drafting project and that's it. But there is so much more. EDUCATION – getting people to understand the benefits. BIMForum appears to be leading the charge. The definitions ZGF uses are in line of this BIMForum (https://bimforum.org/lod/).

What he sees is people have to learn a new format, a new tool and that is difficult to do. Finding people able to use the new tools are difficult and training them to use the tools can be a long, difficult process as well. It takes a very long to learn and actually take advantage of them before efficiencies are captured. A company might have the tool, a new software tool but it's a tool that just sits on the shelf.

The big companies have internal BIM experts, they have the money and resources to

train staff and customize tools and build a good model. Small firms don't pay attention to enrichment of the object because they don't have the time and money to do so and they also might not have the expertise / training available to them. In Revit you can specify if a wall is an interior wall or exterior wall. The typical Revit user doesn't utilize this parameter setting – everything is an exterior wall. This creates issues if you try to run an energy analysis or other analysis program. You will need to re-enter data and specify items such as if a wall is an interior wall or exterior wall.

Revit is the key software program they use but it creates a lot of extra work for the architect. For example, they want to draw a door in the wall but they can't just put the door in. With Revit, to enter a door in the model you have to fill out a table of information including items such as they type of door, size, which way it swings, door number, price point, and other metrics and attributes. Once they have all that done, all of this excessive data entry, you can put the door in the Revit drawing. Once you have the door and all of the data entered, you can do all kinds of things with it but it is very time consuming to do. The architect gets to build the building in a more 3D manner. The tools are immensely difficult to use, training is expensive, and there is a lot of lost time involved in getting up to speed.

The following is a listing of some of the organizations that provide training.

- The Construction Association offers training (32 hours of instruction) around the country on a regular basis and tests for certification.
- The General Building Contractors Association provides a comparable course and certification.
- The Master Builders Association provides a comparable course and certification.

Autodesk also provides a variety of training programs through Autodesk Design Academy. Many software developers that created tools used by that profession such as Grasshopper, SketchUp and the like develop BIM plugins and provide online training.

8.0 Recommended Areas for Improvement

Suggestions for areas of improvement in implementation of BIM are varied and drawn from the free-flowing discussions used in the BIM interviews conducted. The ideas range from using the Design-Build model; instead of the Design-Bid-Build model to assuring that clients understand the value of requesting a complete BIM model be delivered.

8.1 Design-Bid-Build vs Design/Build models

The Design-Bid-Build (DBB) model is the most traditional process used in the U.S. construction industry. In this model the owner contracts separately with a designer and a contractor and solicits fixed price bids from contractors to perform the work. This model results in securing low bids – but it works against collaboration[77]. An alternative model is the Design/Build model. According to the Construction Industry Institute (CII) "Under this method, an owner typically hires a single entity, the design/builder, to perform both design and construction under a single contract. Portions or all of the design and construction may be performed by the entity or subcontracted to other companies. DB is characterized by high levels of collaboration between the design and construction disciplines, input from multiple trades into the design, and a single entity bearing project risk. Typically, the general contractor is responsible contractually for this delivery method.[78] "Other recommendations are more predictable: more training; simplified tools; industry-wide standards; moving data more readily between tools. The nature of the contracts and the number of contracts involved in a build was mentioned frequently as an area which created difficulties. "Walking in another person's shoes" was also a theme – Often the software developers had no experience in construction, and this created a problem at the implementation level.

Large Architectural Firm
Corporate BIM Director

They did one job for the Department of Justice in California that made the BIM model a deliverable. They understood the potential value of using it and wanted it for long term use. Most owners do not want it. The owners often don't have the technical capability to use a BIM model and don't understand the benefits. Too often it's build the building and get people moved in it to start collecting rent, but not investing management tools that will lower lifetime operation costs. They are not looking at it long term and the value they could potentially earn over the life cycle costs. A lot of education is required by the clients to understand the benefits of a BIM model. Youtube videos to teach the industry about possible features and benefits they could extract by using a BIM model. What they are doing today and what they see in the future. It all comes back to the client and them understanding what they need or how they can use it to their benefit.

Using the tools, they can perform a lot more analysis virtually, before construction takes place. Even with retrofits, there are large benefits from performing laser scanning. HMC will send a team out to scan the building, and then convert it to a 3D model. They have customized tools added in to perform energy analysis, BIM 360 Insight or other commercial tools to run analysis. They will look at adding shade, changing glass types, changing the HVAC system – they are working internally to generate studies on this to find ways to improve it. The key issue is how much time and money does the owner want to spend up front for analysis that will provide benefits long term. How much information do they want included in the model? If an owner is not exposed to the potential benefits, does not understand the benefits of the technology, it is difficult, virtually impossible, to have them implement it in the contract.

When a project includes a BIM model, she usually sees information input take place a lot earlier in the process. Clash analysis is done early on to identify potential issues. But many teams will still wait until the construction document phase, which is too late. At that point you might have 100 clashes instead of 5 or 10 problems. This creates a much larger problem which takes more time and more money to money to fix. As long as everyone does what they are supposed to do and picks up their marks like they are supposed to it helps a lot. The earlier issues are picked up in the process the better. At HMC they are trying to develop process to look at things earlier in the process, earlier in the development of the Revit drawing, BIM model.

The following is a list of diverse comments which describe what is holding back the adoption of BIM and what could advance it.

"A simpler tool for 'average Joe's' to use to help update and maintain the "database of plans".

An area that Stephen feels could use improvement is with standards. BIM is very database driven and relationships, standards across the industry would help to improve use of BIM. He has seen more sophisticated clients begin to specify the standards they want followed, putting in the contract what the requirements are. The problem is, they are getting different requirements from different clients. When you have a lot of custom work, wide variety of clients, you get a lot of different processes to follow and a variety of requirements on information to be included in the models.

The build model used has an impact.

There is a lot of redesign, recreating drawings as the project moves along the value chain in the construction industry. These present opportunities where improvements can be made, efficiencies gained. You'll often see jobs where a planner does a great job, but no one really used what the planner provided. The designers redid everything. The owner takes this from the designer and bids it out. The contractor firm wins the project and redoes the drawings again. With BIM, in theory at least, you are able to use one model instead of four models. If the owner enforces the use of BIM processes and standards it can create a lot of efficiencies.

A big potential issue he sees is the owner might have a contract with the architect and engineer on the project and a separate contract with a General Contractor. Right from the start, this pits the two groups against each other instead of having them work like partners. It creates questions as to who owns what and who is liable for it? Changing the way contracts are written and creating symbiotic relationships between design and contracting, when this happens, when you get the natural animosity out of the system things will get a lot more efficient. You will see a lot greater adoption of BIM. The owner will help to drive this in how they write the contracts. This will lead to a lot of improvements in the industry.

A big issue limiting use of BIM is the contract. Often the contract does NOT allow them to provide the full models. The client and/or lawyers aren't allowing it to happen. We believe that if a BIM model became a "normal delivery" it would help a lot. ZGF, architects / engineers are NOT required to deliver a LOD 400 drawings / model that a contractor could build directly from. And even if we were to try and get to that point, there would be issues encountered. Architects and engineers tend to be messy in their designs. They know the contractor can't use the model anyway, that they will have to rekey it so they don't provide that level of detail necessary for fabrication drawings. The contracts call for them to provide 2D drawings, and they make those right for the contractor. The contractor takes the 2D drawings and develops their own prints for fabrication. We don't think it would be too much additional work to get to that point, but the way contracts are written, it does not allow them to do it. So the contractors, the subs, they don't receive the BIM model in most cases. They get 2D prints. It would be nice to see them use the model to bring this up to a full construction model, but it doesn't happen this way. You'd have MEP contractors say that even if they could take their model they wouldn't want to because it has 5,000+ views in it and they'd want to make sure it was correct; they'd be responsible if it wasn't right

on the build. The contractors want to start over. Each group models differently based on what they know and what they have to deliver. They do it very well and have the experience necessary to do it right.

One area that could help minimize mistakes with BIM models is more on-site construction experience. Many designers have not actually worked on a construction job site and therefore, don't understand some of the issues that can come up on a job.

Other items that may be holding back the adoption of BIM:
- Legal issues / contracts - What is the legal document used in a BIM model? Who owns the model and what does the contract ask for? What is provided at the end of the job? This has to be well defined and understood from the beginning.
- Generational gap – is there enough education and training on the technology with existing, longer term employees vs. younger employees more likely to use new computer software technologies?
- Resistance to change - often you will find people are resistant to change. Unions that may not want to be part of a change. If they've done it one way for a long time, and it's worked, why change it?

Look at where money changes hands in the process and then dig into each of these areas to understand how things can be improved.

Within the larger BIM ecosystem, bigger organizations can hire full time employees for the software because they have the money and need to be more technically capable to bid but smaller organizations may not have the financial resources to do so. To fill this gap there are there are specialists who will input the data into model if you don't have the skillset in house. These services allow smaller shops to pay someone to input their designs without having to hire a full-time employee.

A portable version of BIM software would be useful. *"I wish we could put in on an iPad so that you can have it and make changes in the field."*

Areas they felt could help to advance adoption of BIM are:
- Development of a common library of BIM elements for groups to use.
- An easier way to port from a BIM model developed by architects / engineers to the manufacturing shops and the software tools they use. They have been told data needs to be rekeyed in order to work with their machinery and tooling.
- The incentivization structure needs to be reviewed more closely. Without incentive to develop and use a BIM model, it will be difficult to drive this across the industry. One way to help with this may be with development of industry wide mandates and compliance requirements that will lead to an increase in adoption of the BIM tools.

Projects that follow a Design-Bid-Build process, groups involved are more likely to just throw it over the wall to the next group. The contractors don't know how complete the drawings are. They don't trust the accuracy of the drawings provided to them by the architects and engineers. So they draw it over on their own and use their own internal drawings – time and money. To people and cultural mindset of the industry in general. And then there are also the straight-out interoperability issues encountered. some degree, fear of litigation, legal issues in the US, have held back adoption of BIM.

Interoperability is a big problem with BIM modeling, moving from a common 3D modeling program to a BIM software program is a big problem to address. It is getting better. Straight up 3D modeling to BIM needs better interoperability tools. 3D modeling is just that – there is no information associated with that, a piece of jewelry, a house, a college campus – it's just geometry.

ARCHICAD supports using open standards and are pushing for adoption of the IFC. There is no good reason for Autodesk (Revit), a large firm with huge market share in the US, to want open standards. There are advantages to staying within one company but from an academic point of view you want people to work from a variety of software packages seamlessly. This doesn't happen now as discussed earlier. There are interoperability issues encountered. Pushing Revit as the US "standard" is not fair to competitors. Investments into artificial intelligence (AI) capabilities may help with the translation from 3D modeling to BIM and other programs such as energy modeling simulation.

It would be good to try and identify the major gap at each stage of the build process. There are a series of well-designed steps from schematic design all the way to building maintenance. Each of these steps should be broken down and analyzed to determine the key gaps at each step. And there are gaps at each step than can be improved. What is the biggest gap at each? Look at where money changes hands in the process and then dig into each of those areas to better understand how things can be improved.

9.0 Summary and Conclusion

The purpose of this report is to provide insight into a subset of questions of interest to the Building Technologies Office related to Building Information Modeling (BIM). The use of BIM represents a major cultural shift in the building construction industry. As a result there are many questions which one could ask. For this report we settled on four key questions:

- **Who are the key players in BIM?**
- **What BIM software tools are used?**
- **What are the problems and gaps where interoperability occurs?**
- **What are the opportunities for significant improvement,**
  resulting in productivity and efficiency improvements?

The key players in BIM are Autodesk and buildingSMART International (previously called the International Alliance for Interoperability). The tools developed by both are promoted by the General Services Administration which in turn has facilitated the wide use of the numerous products developed by Autodesk with Revit, being the most widely used. The Industry Foundation Classes (IFC), an open file format with a data model developed by buildingSMART, supports interoperability between software platforms. IFC was ISCO certified in 2013. The corresponding ISO standard is ISO 16739-1:2018. Other BIM models have been developed by Bentley, Nemetschek Group, Trimble and others. A description of their products is available in Appendix A. Numerous BIM plug-ins have been developed that serve different parts of the supply chain. Every profession, in an effort to be efficient and cost effective has mastered different tools that they routinely use . With architectural and engineering firms for example Grasshopper, Rhino and SketchUp are frequently used and plug-ins from these programs to BIM is very beneficial.

There are many practices in the construction industry that create interoperability gaps. A major issue mentioned numerous times was the building model used. Design-Bid-Build models are widely used in the building construction industry and do not facilitate collaboration. In this model, designs are developed by one player who has no relationship at all to the party that will actually do the build. The builder is selected via a bid process. By contrast Design-Build models facilitate collaboration as the owner typically hires a single entity, the design/builder to perform both design and construction under a single contract. To understand the gaps – one suggestion was to look at where money changes hands and then dig into each of those areas to better understand how things could be improved at the point of hand-off.

The supply chain itself also creates interoperability gaps. Each of the players in the supply chain routinely uses tools that enable them to become efficient in their role. As one moves down the supply chain the players become smaller and the amount of time they spend in front of a computer also decreases. Smaller entities simply don't have the funds to have their employees become efficient in using BIM. If required, some will hire a BIM consultant for that job, while others will simply not bid on jobs that require BIM. Large companies can afford to hire a BIM Director and several people that do nothing more than work on BIM. By contrast, small companies cannot afford to do that and have not witnessed the benefit of investing in BIM. Others have mentioned that it appears that BIM developers have not spent much time in the construction industry and therefore don't understand the workflow. Data, on codes for example, is not always kept current which forces people to turn to other tools.

A number of people interviewed indicated that the apparent lack of standards contributes to interoperability issues. Nonetheless, data from several studies reveals that BIM is increasingly used in the US and that the development of open standards and plug-ins will continue to move the field forward. Customers also don't understand the benefits of BIM and don't ask for it. Unless there is pull from the customer, builders will not deliver a BIM model.

Many suggestions were made regarding how to facilitate the use of BIM. Make a version for the average Joe that is easy to update. Have a version for your IPAD so if one makes change in the field, they can enter that into the BIM model right away. Make sure that the information related to building codes is current. Address the challenges that exists when using energy modelers with BIM. The interview data contained in Volume 2 contains many rich interviews from people that play various roles in the supply chain.

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Additional Key Players in BIM Industry

APPENDIX A

KEY PLAYERS

Additional Key Players in BIM Industry

1.1 ALLPLAN

ALLPLAN, a Nemetschek Company, is a global provider of BIM solutions for the AEC industry. ALLPLAN's software solutions are used by over 240,000 architects, engineers and contractors. The company is headquartered in Munich, Germany.[79]

ALLPLAN's product portfolio includes ALLPLAN BIMPLUS and ALLPLAN ENGINEERING. ALLPLAN ENGINEERING is used by engineers in both large and small offices. This product supports the concept, design, detailing, and production planning phases.[80] ALLPLAN ENGINEERING is a BIM solution for civil and structural engineers, structural detailers, and contractors. It supports the entire BIM process with efficient workflows.

ALLPLAN BIMPLUS is also used by engineers within large and small offices. This product supports the concept, design, detailing, and production planning phases.[81] BIMPLUS is used by architects to check BIM models, collaborate with team members and planning partners, and manage BIM models with all building information and documents (such as visualizations or quantity take-offs) in a central location. They can use the software to share tasks, revisions, and documents. Engineers can also use BIMPLUS to document on-site construction and share progress with teams easily. BIM coordinators use BIMPLUS to bring together all relevant project information in a central repository and check BIM models automatically. BIM coordinators can use the tool to manage tasks by status and priority and monitor the BIM process. BIMPLUS supports openBIM workflows.[82] Features of BIMPLUS include:

- › Team management
- › Project management
- › Model management
- › Central project document tool
- › Revision management
- › Property sets management
- › Multiple file imports (IFC, ALLPLAN, Revit, etc.)
- › BIM explorer
- › Object navigator and filter
- › Slide shows
- › Task management
- › BCF import/export
- › Object details & attachments
- › Property edits
- › Clash detection
- › IFC4 export[83]

There are Standard, Professional, and Enterprise versions of ALLPLAN BIMPLUS. Pricing for the Standard version is largely based on storage—with costs ranging from 10-70 euros (approximately $10-75) per user, per month as a starting point (app add-ons may cost an additional 10 euros ($10-$11) per user, per month). Pricing for the Professional version is, again, largely based on storage and that pricing ranges from 50-80 euros ($53-$87) per user, per month. Pricing for the Enterprise version is contract negotiable.[84]

1.2 BENTLEY SYSTEMS

Bentley Systems is a company headquartered in Exton, PA. They provide a broad range of software products for infrastructure professionals. One of their primary BIM products is MicroStation, a CAD software package with extensive BIM capabilities. MicroStation is a 3D CAD and visualization software for architecture, engineering, construction, and the operation of infrastructure. The software provides a range of capabilities such as CAD drawing and design, 3D modeling, visualization, component management and markup, and collaboration across different disciplines. Users can work more efficiently without having to constantly access many different applications. In addition, users can leverage their familiar 2D drafting and CAD design skills, but the use of MicroStation eliminates repetitive or redundant drawing workflows. Cloud services are not required for use, but they can be used if users want to enhance productivity.[85] Key capabilities of MicroStation include the following:

› Create project deliverables (generate deliverables such as paper plots, reports, 2D/3D PDFs, i-models, and 3D physical models; functionality of the software ensures that they will remain in synch with the design model during work-in-progress)
› Design in context (imagery, point clouds, 3D reality meshes, and geospatial information can be integrated)
› Design with 3D parametric modeling
› Enforce standards (users can apply templates to control geometry and data standards such as styles for dimensions, text, lines, detail symbols, etc; when designs are complete, automated tools can check drawings for standards and compliance)
› Layout and annotate drawings
› Produce animations and renderings
› Visualize and analyze designs
› Work collaboratively on designs
› Work in a personalized environment[86]

The cost of MicroStation is approximately $5,234.[87]

Bentley Systems acquired Synchro Software in June 2018—this acquisition also strengthened their position and offerings in the BIM software segment.[88] Synchro Software is headquartered in the UK, with offices in Boston, MA; San Francisco, CA; and Shanghai, China. Synchro provides an interoperable digital environment for the construction industry, evolving from 2D planning and "siloed workflows" to more cooperative and efficient 4D visual planning and project management. The Synchro software environment serves as a single technology that enables users to create, visualize, analyze, edit, and track entire projects—including logistics and temporary works. The software supports construction projects in terms of tendering, design, construction, commissioning, and handover.[89] Synchro software supports construction project logistics, safety, construction, controls, and commissioning.[90]

Synchro Pro is their 4D digital construction project management technology. Key features include:

› Leveraging Synchro's ability to auto match a BIM model to a schedule to update construction plans.
› Reducing schedule variance with look ahead reports that identify activities, work areas, and equipment—users can view a task list by contractor or work package.
› Reducing cost variance using resource planning, planned versus installed quantity tracking, project or contractor earned value, critical path, etc.

> › Leading progress review meetings using the 4D model as a hub of information for collaborative planning and decision making with all project teams and stakeholders.
> › Planning for safety hazards and risks before work begins on a job site using dynamic spatial coordination analysis that identifies work area overlap, overhead crane risks, potential for obstruction delays, and other factors.[91]

Synchro Pro can integrate with a number of other software programs, including AudoCAD, Navisworks, 3dsMax, Revit, MicroStation, and SketchUp, among many others.[92] A named user annual subscription for Synchro Pro is priced at $2,995.[93]

1.3 BLUEBEAM

Bluebeam, part of the Nemetschekk Group, is a company based in Pasadena, CA, with additional offices in San Diego, CA; Chicago, IL, Manchester, NH; Dallas, TX; Stockholm, Sweden; London, UK; Munich, Germany; Copenhagen, Denmark; and Brisbane, Australia. Bluebeam is a software company whose solutions have been adopted widely by the global AEC industry. Revu is their BIM software offering. Over 1.6 million people, worldwide, use Bluebeam Revu. They work with 94% of top US contractors, 86% of top US design firms, and 78% of top US specialty contractors.[94]

Revu is a BIM software solution that supports:

> › Design review (teams can mark up the same digital documents in real-time)
> › Quality assurance and quality control (markup and collaboration tools support more accurate quality reviews)
> › Quantity takeoffs (custom measurement tools lead to stronger bids)
> › Submittal review (simplifies submittals with markup and editing tools)
> › RFI posting (the software keeps RFIs organized with smart markup and hyperlinking functions)
> › Punch process (the software aids project teams in achieving a 90% completion rate on the first back check)
> › Project handover (smart digital O&Ms provide facility managers with easy access to important project information)[95]

Revu addresses aspects of design, construction, commissioning, and project handoff (to support facility management). Revu Standard (a solution for 2D and 3D PDF markup, editing, and collaboration) is $349 per seat. Revu CAD (a solution for CAD users that includes smart plugins for 2D and 3D PDF creation) is $449 per seat. Revu eXtreme (a more robust solution for active users who want to automate complex processes and support extensive document collaboration) is $599 per seat.[96]

1.4   GRAPHISOFT

Graphisoft (affiliated with the Nemetschek Group) is a company that operates internationally, but Graphisoft North America is based in Waltham, MA. The company introduced one of the first BIM solutions in 1984—ArchiCAD, a BIM software for architects. The company also offers BIMcloud (a real-time BIM collaboration environment), EcoDesigner STAR (a fully BIM-integrated "Green" design solution), and BIMx (a mobile app for BIM visualization).[97]

ArchiCAD 23 is the current version of ArchiCAD available. ArchiCAD is a BIM software tool designed for architects. With this software, users can work in 2D or 3D on floor plans, sections or elevations. A notable feature of ArchiCAD is that it can support collaboration with engineers. Graphisoft is a promoter and supporter of the Open BIM workflow, a universal approach to collaborative design, realization, and operation of buildings based on open standards. ArchiCAD coordinates workflows with other leading engineering software solutions based on Open BIM workflows. More than 200 applications support IFC—including ArchiCAD.[98] ArchiCAD appears to be primarily used in the design process. The product enables architects to model and create accurate construction details and estimations for reinforced concrete, complex steel, timber, and composite beams and columns. The most recent version of the software includes an Opening tool for modeling and coordinating project design voids, recesses and niches as horizonal, vertical or slanted openings across different elements, element groups or across stories. Openings can be modeled, scheduled, and documented using various tools and they can also be shared using open IFC standards.[99] The tool also provides photo-realistic real-time renderings.[100]
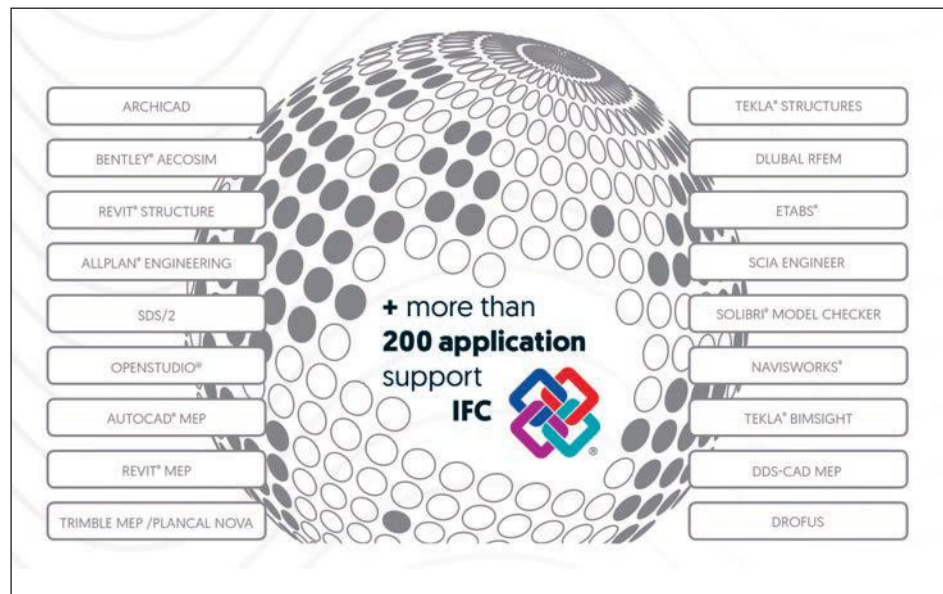
FIGURE 10: Applications that Support IFC[101]

It has been estimated that ArchiCAD has over 120,000 users.[102][103] ArchiCAD pricing is not available online. Graphisoft would typically provide a price quote based upon the plan of interest, number of licenses required, and other factors. There are different versions of ArchiCAD—a trial version, educational version, academic version, and commercial version. The commercial version has four different types of licensing—the full license, solo license, pay-per-use license, and rental license. While the current version available today is ArchiCAD 23, pricing for the commercial version of ArchiCAD 22 was roughly $3,971.[104] If a user were interested in pay-per-month pricing for ArchiCAD, pricing would be approximately $196 per month.

1.5 NEMETSCHEK GROUP

Nemetschek Group, based in Germany, is a company that focuses on software for the entire AEC (architecture, engineering, and construction) lifecycle. With 16 different brands, Nemetschek maps the entire workflow in the lifecycle of a building or infrastructure project—from architectural sketches, to construction, to managing and operating the building. BIM represents the Group's core competency. The company supports the use and refining of open standards, leading to digital workflows that are optimized across different disciplines and teams, regardless of the software provider used. Referred to as the Open BIM approach, this method encourages collaboration among all stakeholders involved in designing and carrying out construction. This, of course, benefits architects, engineers, and construction companies, as well as investors, building owners, and building operators. Through their 16 brands, the Nemetschek Group accounts for approximately 10% of the AEC market. About 5 million customers benefit from their software solutions, which provide support over the life of a building.[105]

The 16 brands within Nemetschek include: dRofus, Graphisoft, Vectorworks, SCiA, RISA, Frilo, ALLPLAN, Data Design System, SDS/2, PRECAST Software Engineering, Solibri, Nevaris, Bluebeam, Crem Solutions, Spacewell, and Maxon.[106] Graphisoft, Vectorworks, ALLPLAN, Solibri, and Bluebeam are of particular interest, as they are linked to BIM software solutions.

FIGURE 11: Overview of Brands within Nemetschek Group[107]

1.6 SOLIBRI

Solibri, a Nemetschek Group company, is a leader in model checking software for building information modeling (BIM). Their focus is on BIM quality assurance and quality control. The company provides tools for BIM validation, compliance control, design process coordination, design review, analysis and code checking. Their flagship solution—Solibri Model Checker analyzes building information models to reveal potential flaws, issues, and weaknesses in the design. The company's customers include building owners, construction companies, architects, and engineering firms in 70 countries. Solibri is headquartered in Helsinki, with additional offices in the US, UK, Germany, and Spain.[108] Their office in the US is located in Scottsdale, AZ.[109] Solibri's products include:

> › Solibri Office
> › Solibri Site
> › Solibri Enterprise
> › Solibri Anywhere

The users of Solibri Office produce information that is critical for all parties, such as on-site teams, managers, and building owners. The data is pulled from models of different disciplines, created in authoring tools and combined into one model in Solibri for checking model quality and identifying any issues with the design. Solibri Office is typically used by BIM managers, architects, and designers.[110] Solibri Site is used by site managers and others that are responsible for on-site operations. Solibri Enterprise is used by organizations that have multiple users checking BIM models for multiple projects and buildings that may differ substantially. The Enterprise solution is designed for larger companies that manage the full workflow of large construction projects, collaborating with a number of teams and responsible for ensuring that projects stay on schedule.[111] Solibri Anywhere is used to provide information to anyone who needs it for a given project. The company offers Solibri Anywhere to everyone, for free. It is designed for on-site use by those who are actually building, and it is also helpful for stakeholders such as building owners (who want to see how the models and project have evolved) and those responsible for building lifecycle management.[112]

Features

Features	Solibri Anywhere	Solibri Site	Solibri Office	Solibri Enterprise
Viewing models (IFC & SMC)	✔	✔	✔	✔
Combining multiple IFCs	✔	✔	✔	✔
Commenting issues	✔	✔	✔	✔
Creating issues	✔	✔	✔	✔
Exchanging issues with BCF Connector	✔	✔	✔	✔
Using markups & dimensions	✔	✔	✔	✔
Using classifications	✔	✔	✔	✔
Creating classifications	✘	✔	✔	✔
Taking off quantities & more	✘	✔	✔	✔
Checking models	✘	✘	✔	✔
Customizing rules	✘	✘	✔	✔
Using autorun	✘	✘	✘	✔
Scaling users flexibly	✘	✘	✘	✔

FIGURE 12: Comparison of Features for Solibri Software Products[113]

According to information from SimBim Solutions, a Graphisoft Distributor—Solibri software costs approximately $7,767 (€7,200), with tax and maintenance included.[114] According to the Solibri website, the company offers a subscription for Solibri Office. Instead of purchasing a license, users can subscribe to Solibri Office for about $140 (€130) per month (billed annually).[115]

1.7 TRIMBLE

Trimble is a publicly traded company headquartered in Sunnyvale, CA. The company has offices in at least 40 countries and annual revenue is approximately $3.1 billion. They focus on a range of industries, including agriculture, building construction, civil engineering and construction, geospatial, transportation, government, forestry, rail, field service management, telecommunications, and electric and water utilities, among others.[116] Trimble operates through four reportable segments: Buildings and Infrastructure, Geospatial, Resources and Utilities, and Transportation. The Buildings and Infrastructure segment includes Civil Engineering and Construction, as well as Building Construction. The Building Construction segment encompasses their BIM software solutions. According to Trimble's most recent Annual Report (2018):

> "The Trimble building construction portfolio of solutions for the commercial and industrial building industry spans the entire lifecycle of a building and is used by owners, architects, designers, general contractors, sub-contractors, engineers, and facility owners or lessees. These solutions serve to improve productivity and to enhance data sharing and collaboration across

different teams and stakeholders to help keep projects within cost, time, and quality targets. The suite of technologies and solutions we provide to the building industry includes program management solutions for owners, software for 3D conceptual design and modeling, ***BIM software which is used in design, construction, and maintenance***, enterprise resource planning and project management and project collaboration for general contractors, advanced integrated site layout and measurement systems, cost estimating, scheduling, and project controls solutions for contractors. The suite also includes applications for sub-contractors and trades such as steel, concrete and mechanical, electrical and plumbing, and an integrated workplace management services ("IWMS") software suite for real estate management, project coordination, capital program planning and management, and facility management for building owners and program managers. In addition, Trimble's Connect collaboration platform streamlines customer workflows and enables interoperability between Trimble's and other providers' solutions. These solutions for the building industry serve to automate, streamline, and transform work processes across the building construction industry. Our solutions provide customer benefits such as reduced costs, reduced waste and re-work, increased worker safety and efficiencies, faster project completion times, improved information flow, better decision making, and enhanced quality control."[117]

BIM software provided by the company is used in design, construction, maintenance, ERP and project management, and project collaboration for general contractors, as well as advanced integrated site layout and measurement systems, cost estimation, scheduling, and project control solutions for contractors.[118] Trimble provides solutions for different aspects and phases of the building construction process:

› SketchUp is 3D design software for the architectural design phase.
› Tekla is a BIM software suite for the structures and fabrication phase.
› Different solutions are available for General Contractors and Building owners, including Trimble General Contractors (incorporates BIM solutions), E-Builder (an end-to-end project management information solution, or PIMS, that delivers information spanning from capital planning and design through commissioning), and LeanSight (a platform to connect project managers, team members, and project partners).
› Trimble MEP addresses the MEP contracting phase. Through Trimble MEP, the company provides BIM services such as 3D coordination services, 3D laser scan and scan modeling services, 3D modeling services, and fabrication and documentation services. Trimble MEP also offers electrical, mechanical, plumbing, sheet metal, and HVAC BIM collaboration software.
› ViewpointOne is a solution for construction management that supports not only project management, but also materials management, service management, construction finance, and equipment management.
› Trimble Real Estate & Workplace offers IWMS and CAFM technology for the planning and management of real estate, workplace, and facilities management. They offer solutions for maintenance management, project management, and energy management. Manhattan is an IWMS software solution for planning and managing real estate and workplace portfolios, while CenterStone is a CAFM software tool for streamlining the management of spaces and facility building processes.

Trimble General Contractors offers BIM solutions—including Vico Office for Design, Vico Office for Cost, and Vico Office for Time. Trimble Vico Office is an integrated platform that brings together construction estimating, scheduling, and design management. Users can work through focused Vico Office modules—focusing on Design,

Cost, and Time, or they can work inside a fully-integrated Vico Office Suite.[119] Trimble sells Vico Office through a distribution partnership with BuildingPoint. It appears that pricing information is not publicly available—those interested have to request a demo to receive information on pricing for this product.

Trimble MEP offers hardware and software solutions for the electrical, mechanical, plumbing, sheet metal, and HVAC segments. In addition, they provide BIM services. Their BIM collaboration software tool is called Trimble Connect. Electrical, mechanical, plumbing, sheet metal, and HVAC contractors can take advantage of BIM through Trimble Connect, which serves as a "glue" between software and hardware products across the MEP workflow. It connects different stages of a project and the different contractors involved in it. Pricing is available by reaching out to the company for a demo.[120] Trimble SysQue is another offering from Trimble MEP. This software tool provides MEP designers and contractors with a workflow that spans from design, through fabrication, and to construction. Users can design in Autodesk's Revit using materials and sizes based on actual manufacturer products, they can easily collaborate and work from one Revit model, work from a continuously evolving database, and leverage smart reporting to enhance functionality. SysQue allows professionals to design with "real-world, manufacturing-specific content."[121]

Tekla refers to a BIM software product family. It includes Tekla Structures, Tekla Model Sharing, Tekla PowerFab, Tekla Structural Designer, Tekla Tedds, and Trimble Connect. Tekla Structures is an advanced structural BIM software solution that enables users to create, manage, and share multi-material 3D models with valuable construction information. Tekla Structures can be used throughout a project—in conceptual planning, fabrication, construction, and maintenance—and for design, detailing, and information management.[122] Tekla Model Sharing is an innovative BIM collaboration tool that is designed to increase the productivity of Tekla Structures users. Teams can use this tool to work on the same model at the same time, without encountering work interference.[123] Tekla Structural Designer is a software product that provides engineers with the ability to analyze and design buildings more efficiently. This software tool can save design and drafting time, as the model can start in Tekla Structural Designer, Tekla Structures, or Autodesk Revit. Tekla Structural Designer was designed to leverage BIM— it maximizes collaboration between project partners, collaborators, technicians, fabricators, and architects.[124] Tekla PowerFab is a comprehensive software suite for steel fabrication management. Steel fabricators can manage their entire fabrication process in one software suite and it can integrate with other leading software and equipment.[125] Tekla Tedds is a structural analysis software for engineers. With Tedds, users can quickly produce code-compliant designs and create, save, and share custom calculations. Calculations are available for a range of international design codes, including those for the US and Canada.[126]

1.8 VECTORWORKS

Vectorworks, part of the Nemetschek Group, is a company based in Columbia, MD. The company has developed Vectorworks Architect, a BIM software solution that leverages 2D and 3D technologies and data to improve the design process. Vectorworks supports everything from 2D drawing, to 3D modeling, to fully-integrated BIM. The company provides Vectorworks Architect (for architects and designers to sketch, draw, and model in an integrated BIM workflow), Vectorworks Landmark (a single solution for landscape design and planning), Vectorworks Spotlight (design software for the entertainment business), and Vectorworks Fundamentals (general design software). In total, Vectorworks has approximately 685,000 people using their software tools.[127]

Vectorworks Architect supports conceptual design, fully-coordinated BIM models, and the development of construction documents. This BIM software tool addresses the design phase, but product literature does not mention its use to support manufacturing and fabrication, commissioning and assessment, or code compliance. The software does enable precision drawing, creating modeling, site modeling, building information modeling, algorithmic design, and graphics and presentation. Vectorworks enables users to easily share files with others on their team—coworkers, consultants, and clients. They default import/export capabilities, as well as support for Open BIM and IFC. The product can directly link with Revit, SketchUp, Rhino, Photoshop, and Cinema4D.[128] The cost of a perpetual license for Architect is $3,715 with maintenance or $3,045 without maintenance. This is a one-time purchase price, not annual (though it appears maintenance costs may be annual, if you select a perpetual license with maintenance). Users can also purchase the software through a subscription—either monthly or annual. A monthly subscription is $153 per month and yearly subscription is $1,530 per year (or $128 per month).[129]

APPENDIX B

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ISO STANDARDS PERTAINING TO BIM USE

ISO is an independent, non-governmental international organization with a membership of 164 national standards organizations. Leveraging the expertise of its members, ISO brings together experts to share their knowledge and develop voluntary, consensus-based International Standards that support innovation and provide solutions to challenges that exist, worldwide. The Central Secretariat for ISO is based in Geneva, Switzerland. ISO has 23,266 International Standards covering nearly all aspects of technology and manufacturing. As noted—there are 164 member organizations and 787 technical committees and subcommittees that contribute to standards development.[130] This website includes a lengthy table outlining all of the countries and their respective standards organizations (for example, ANSI in the US) that are members of ISO. The following map also outlines countries that participate in ISO.

Figure 13: ISO Member Countries[131]

ISO has a series of standards that pertain to BIM. The ISO 19650 series of standards includes:

ISO 19650-1:2018
Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 1: Concepts and principles

Abstract: "This document outlines the concepts and principles for information management at a stage of maturity described as "building information modelling (BIM) according to the ISO 19650 series". This document provides recommendations for a framework to manage information including exchanging, recording, versioning and organizing for all actors. This document is applicable to the whole life cycle of any built asset, including strategic planning, initial design, engineering, development, documentation and construction, day-to-day operation, maintenance, refurbishment, repair and end-of-life. This document can be adapted to assets or projects of any scale and complexity, so as not to hamper the flexibility and versatility that characterize the large range of potential procurement strategies and so as to address the cost of implementing this document."[132]

A preview of this standard is available here.

ISO 19650-2:2018
Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 2: Delivery phase of the assets

Abstract: "This document specifies requirements for information management, in the form of a management process, within the context of the delivery phase of assets and the exchanges of information within it, using building information modelling. This document can be applied to all types of assets and by all types and sizes of organizations, regardless of the chosen procurement strategy."[133]

A preview of this standard is available here.

ISO 19650-3
Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 3: Operational phase of the assets

*This standard is currently under development

ISO/WD 19650-4
Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 4: Information exchange

*This standard is currently under development

Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 5: Security-minded approach to information management

Abstract: "This document specifies the principles and requirements for security-minded information management at a stage of maturity described as "building information modelling (BIM) according to the ISO 19650 series", and as defined in ISO 19650-1, as well as the security-minded management of sensitive information that is obtained, created, processed and stored as part of, or in relation to, any other initiative, project, asset, product or service. It addresses the steps required to create and cultivate an appropriate and proportionate security mindset and culture across organizations with access to sensitive information, including the need to monitor and audit compliance. The approach outlined is applicable throughout the lifecycle of an initiative, project, asset, product or service, whether planned or existing, where sensitive information is obtained, created, processed and/or stored. This document is intended for use by any organization involved in the use of information management and technologies in the creation, design, construction, manufacture, operation, management, modification, improvement, demolition and/or recycling of assets or products, as well as the provision of services, within the built environment. It will also be of interest and relevance to those organizations wishing to protect their commercial information, personal information and intellectual property."[134]

A preview of this standard is available here.

It has been stated that the ISO 19650 series of standards are essentially an international version of the UK's BIM Level 2, with the same principles. What was initially a UK requirement for government-funded construction projects has since transitioned into these international ISO standards. According to Lloyd's Register, the ISO 19650 standards are international standards for managing information over the whole lifecycle of a built asset, using BIM. The ISO 19650 standards contain the same requirements as BIM and they are closely aligned with UK1192 standards. The first two standards in the ISO 19650 series—ISO 19650-1 and ISO 19650-2—are based on the UK's standards for information management using BIM—BS 1192:2007 + A2:2016 and PAS 1192-2:2013, which have been superseded. BS 1192 is "an overall standard that lays out the best practices for managing construction information, while PAS 1192-2 is a specification that deals with information management during the capital/delivery phase."[135] Both of these standards "were made public by the British government to help construction companies meet their BIM Level 2 mandate."[136] In addition, ISO 19650-5 will be based on, and replace, PAS 1192-5. ISO 19650-3 (currently in development) will ultimately replace PAS 1192-3.[137] The UK BIM Alliance reiterates much of this information—please refer to their website.

A January 2019 article from *Construction Dive* discusses the connection between ISO BIM standards and BIM standards in the UK. The article continues on to discuss BIM mandates and how that has impacted adoption:

"Some authorities have already mandated some level of BIM use. Starting this year, architects in Abu Dhabi, United Arab Emirates, must use BIM for all major projects.

In addition, the United Kingdom, in an effort to achieve better efficiencies in the maintenance of public projects, rolled out a Level 2 BIM mandate in 2016. All construction stakeholders — architects, engineers, material vendors — are required to communicate via common file formats like Construction Operations Building Information Exchange (COBie) or Industry Foundation Class (IFC). This does not involve the modeling that is often associated with BIM, but lays a firm foundation for future expansion of the requirements.

Unlike in the U.K., there is no single agency that handles public work in the U.S., so the establishment of one federal BIM standard is unlikely. However, that doesn't mean that some public entities haven't adopted its use."[138] [One example is the Los Angeles Community College District—which established a BIM mandate for its $9.5 billion construction and modernization program[139]]