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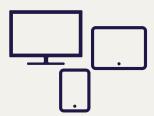


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COOPERATIVE RESEARCH PROGRAMS

CRP SPECIAL RELEASE 4

Lifecycle BIM for Infrastructure

A BUSINESS CASE FOR PROJECT DELIVERY
AND ASSET MANAGEMENT

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Subject Areas
Highways • Construction • Data and Information Technology



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FORFWORD

By Roberto Barcena Staff Officer Transportation Research Board

This report presents a state-of-the-art guide and resources to support and enhance the adoption of Building Information Modeling (BIM) in infrastructure. This report will be of interest to transportation agencies and policy-makers to assess and understand the costs and potential benefits of BIM implementation at an enterprise level.

BIM has been implemented successfully in transportation, vertical construction, and other industries as an asset lifecycle management methodology. This success is due to BIM's capabilities and tools, such as access to advanced digital applications, large data repositories, enhanced visualization, and flexibility to embrace new and existing business processes.

The architecture, engineering, and construction industry has used BIM for planning, design, construction, and operation of many facilities. In general, BIM implementation in infrastructure projects has decreased project costs, increased productivity and quality, reduced project delivery time, and provided information to make business decisions. However, BIM's benefits have not been fully realized due to the lack of standardization of processes in infrastructure. Additionally, there is a perception that the implementation and use of BIM is an expensive business proposition.

Under CRP Project TFRS-02, "Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management," HDR was asked to evaluate the business case for BIM in the United States by quantifying how adopting enterprise-wide BIM systems can lead to increased agency efficiencies and improved cost savings, as well as foster advanced, comprehensive lifecycle management of enterprise assets.

The benefit-cost analysis framework and the detailed case studies developed in this project examine the opportunities, risks, costs, and benefits of BIM adoption and operation in transportation. The research findings will also help transportation agencies establish baselines, set targets, and quantify how adopting enterprise BIM systems can lead to increased agency efficiencies, as well as advanced and comprehensive lifecycle management of their infrastructure assets.

The BIM Multi-Media Toolkit was developed to complement and support the project's report. This toolkit provides resources that can be used to inform stakeholders about tangible business cases for adopting lifecycle BIM. The BIM ROI Tool and BIM Assessment Matrix are spreadsheets created to evaluate the costs and benefits of implementing BIM for Infrastructure and identify the current level of BIM maturity within a transportation agency, respectively. The BIM Multi-Media Toolkit, BIM ROI Tool, and BIM Assessment Matrix are

available on the National Academies Press website (nap.nationalacademies.org) by searching for *CRP Special Release 4*. The multi-media toolkit includes

- Frequently Asked Questions,
- BIM graphics,
- Presentations (directed to technical staff, managers, and executives),
- Webinar presentation, and
- Video interviews.

The videos and assessment matrix are linked separately, while the other supplementary materials are included in a zip folder.

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The Transportation Research Board (TRB) has provided customer-focused, applied-research program management services since the founding of the National Cooperative Highway Research Program (NCHRP) in 1962. Over the course of those 60 years, other programs have been funded including current cooperative research programs for transit, airports, and behavioral traffic safety. The well-established procedures developed and refined in the NCHRP serve as the foundation for each of the programs that comprise the Cooperative Research Programs division (CRP) of TRB. These procedures ensure a competitive, merit-based selection of research institutions to conduct the research; outcome-based research project oversight; and dissemination of research results. Probably the most important factor contributing to the success and longevity of CRP is the emphasis put on stakeholder involvement from beginning to end—from the identification and selection of research topics through to participation on advisory panels to guide the work and implementation of final results.

From time to time, CRP is asked to take on the management and oversight of projects from outside organizations. One such organization is the U.S. Federal Highway Administration (FHWA), with whom TRB has had a long and productive relationship. FHWA's Research, Development, and Technology (RD&T) Program staff routinely solicit advice from TRB, particularly from the Research and Technology Coordinating Committee (RTCC), a federally mandated TRB committee that provides review and guidance on FHWA's research activities.

Early in 2019, FHWA asked TRB to manage an undefined number of projects on behalf of RD&T. The initiative was named the TRB-FHWA Research Support Program; research projects are managed by NCHRP staff and program oversight is provided by the RTCC.

The initial projects requested by FHWA originated from RD&T's Office of Infrastructure Research and Development, which conducts and oversees research and development programs and projects that address critical highway infrastructure needs and priorities of national importance. Studies focus on the design, materials, construction, operation, and preservation of highway pavements, bridges, culverts, tunnels, and other structures.

The first two infrastructure projects initiated at FHWA's request concern quality assurance aspects of performance-related specifications and building information modeling for infrastructure.





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SUMMARY

Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management

The adoption of Building Information Modeling (BIM) to improve delivery of transportation infrastructure projects has been shown to yield significant benefits, and the value of using asset information during operations remains a pivotal opportunity for highway agencies. BIM allows project teams to improve the overall quality of the planning and design of projects, as well as more efficiently construct the project through improved planning, cost control, and automation, such as machine-guided equipment. While these benefits during delivery have been demonstrated on individual megaprojects, the much larger opportunity lies in using the information throughout the entire lifecycle of transportation assets, including use cases for maintenance, asset inventory management, inspections, and planning and designing future projects. This longer-term vision for lifecycle information management requires the development of detailed asset management strategies informed by a structured business case for a transportation agency.

Outcomes of Project TFRS-02, "Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management," include resources developed to support adoption of BIM by highway agencies, such as supporting resources for an agency to initially create a business case for BIM founded on projected benefits and costs for adoption. In addition, an approach to developing an asset information management strategy is presented that focuses on leveraging asset information throughout the entire lifecycle. To support adoption, a media kit is available to clearly communicate the value of transitioning to lifecycle asset information management practices and an approach for making the transition. Finally, case studies are presented that demonstrate the value and challenges associated with transitioning to common delivery and operations practices that leverage BIM. A summary of each of these outcomes follows.

It can be challenging for a transportation agency to develop a comprehensive business case to evaluate the costs, benefits, and projected economic return on investment for transitioning to BIM practices. The benefit-cost analysis framework helps agencies overcome this challenge. The framework was developed by leveraging a significant volume of literature focused on efforts to identify both quantitative and qualitative benefits and costs for adopting BIM. Since there is limited quantitative information for highway projects, the literature analysis evaluated vertical and horizontal construction projects along with U.S. and international studies. From this evaluation, a common framework for the cost and benefit categories was developed as an interactive spreadsheet. This framework allows agencies to review each cost and benefit category and enter their own unique assumptions to evaluate the impact of expanding the use of BIM in both project delivery and operations.

To support adoption, an asset data management planning approach centered on BIM was developed to help agencies create high-level implementation strategies. This planning

approach leverages procedures from the International Organization for Standardization (ISO) 19650 information management standards, combined with practical guidelines for adoption. One challenge identified by transportation agencies is establishing consistent requirements to leverage activities within the delivery phase and obtain valuable information that can be used during the operational phase of the assets (roads, bridges, signs, etc.). The planning approach can guide agencies through a process to identify future steps needed to support the business case.

As part of the research project, five detailed case studies were compiled to gain insights into the business case for BIM adoption. Three case studies focus on U.S. highway agencies, one focuses on an international highway authority (Highways London), and one focuses on an airport authority (Denver International Airport Authority). These case studies demonstrate the business value of BIM adoption in both delivery and operations. They also highlight key lessons learned and strategies used by the various transportation agencies.

Finally, the BIM multi-media toolkit provides resources that can be used to inform a variety of stakeholders about business cases for adopting lifecycle BIM. This includes a high-level BIM roadmap to communicate the core concepts of lifecycle BIM adoption. Videos and responses to common questions are also included. This toolkit can be downloaded and broadly shared within transportation agencies as well as with supplier partners. To access the toolkit, visit the National Academies Press website (nap.nationalacademies.org) and search for CRP Special Release 4: Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management.

This report draws to a close with summary-level conclusions and recommendations for future research studies. Since the lifecycle adoption of BIM remains relatively new in the transportation sector, there are clear opportunities for future research and development activities to increase the business value and ease of adoption. These include efforts to support openBIM standards for interoperability, expanded definitions of clear BIM use cases, and the development of process standards and practices to ease adoption. It is encouraging to see the rapid expansion of research and development in these areas through various industry organizations, which will continue to improve the business case for BIM.



CHAPTER 1

Background

1.1 Objective

The objective of Project TFRS-02, "Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management," was to evaluate the business case for Building Information Modeling (BIM) for infrastructure projects in the United States by analyzing and quantifying how adopting enterprise-wide BIM systems can provide increased agency efficiencies and foster advanced, comprehensive lifecycle management of enterprise assets. The data for this research were gathered using domestic and international examples, with findings targeted for the U.S. market and transportation agency stakeholders.

1.2 Motivation

BIM is one of the most promising developments in the architecture, engineering, and construction (AEC) industry and has been used for planning, design, construction, and operation of many types of facilities. BIM can help stakeholders visualize what will be built in a simulated environment to identify potential design, construction, or operation issues. BIM offers the potential to decrease project costs, increase productivity and quality, and reduce project delivery time.

BIM has been a beneficial project delivery approach in the building industry, where the practice originated. The technology to support BIM in civil infrastructure is available, and consensus within the industry is that BIM for infrastructure is a good idea; why then do state departments of transportation (DOTs) continue to struggle to implement BIM as a standard practice? The answer lies in the complexity and perceived cost to move an organization forward. In a world of dwindling public funds, it can be difficult to invest in all initiatives while also maintaining a large and deteriorating transportation infrastructure. Thus, gaining executive support to invest in BIM deployment is unlikely without a robust business case that demonstrates its value.

The costs associated with BIM as a new technology are a great concern for owners making decisions. However, until this study, no comprehensive or systematic evaluation of costs and benefits had been performed outside of vertical construction or isolated use cases. There is a strong and timely need for a solid framework for determining a repeatable approach to calculating the return on investment (ROI) for adopting BIM for infrastructure and strategies for a strong business case.

Project TFRS-02 explored the costs and benefits of using BIM through documented literature and anecdotal accounts of pilot projects internationally and in the United States. This information was used to answer the following questions:

- Can the benefits of BIM be quantified?
- Are the benefits of BIM substantial enough to justify the investment required by implementation?

- What is the cost of doing nothing?
- How can stakeholders realize the maximum benefit of BIM?

1.3 Scope of Work

The work for this study was performed in two separate phases that emphasized the work in three major areas:

- 1. Conducting research and gathering data,
- 2. Analyzing ROI, and
- 3. Creating marketing materials for communicating project findings.

The work during Phase I focused on gathering information to help draft the methodology used in Phase II to develop the final products. During Phase I, the research team

- Examined the use of BIM in construction of buildings, highways, and bridges to identify benefits and costs related to implementation of the technology.
- Explored whether the benefits and costs of implementing BIM as documented in the buildings industry could be applied to civil infrastructure.
- Identified lead organizations that could participate in case studies, and selection criteria were developed to narrow down the potential case studies.

In Phase II, the research team conducted case studies, refined the business case methodology, developed a tool to estimate the ROI of BIM adoption, drafted recommendations for BIM implementation to support asset data management, and produced a multi-media package to communicate the benefits of BIM to decision-makers.

This research report describes the goals and motivations for the study, the research approach, findings, and conclusions. The report also provides case study technical briefs on the uses of BIM, its costs and benefits, and challenges and lessons learned for each of the five asset owners interviewed during the study, as well as high-level recommendations for implementing BIM for Infrastructure to support the development of an asset data management plan. Other project deliverables include the following:

- BIM ROI Tool: A workbook (spreadsheet model) and user guide that can be used to evaluate the costs and benefits of implementing BIM for Infrastructure.
- Multi-Media Toolkit: Marketing and educational products that can be used to educate various stakeholders. These products include the following:
 - Interactive infographic describing the relationship between a project information model (PIM) and an asset information model (AIM).
 - Three separate lesson plans and sets of slide deck presentations, including speaker notes that can be used to conduct BIM for Infrastructure educational workshops for three different audiences (i.e., executives, managers, and technical staff).
 - Recorded webinar presentation on the findings of the study.
 - Two video podcast interviews with members of the research team and project panel members.
 - Frequently Asked Questions document listing general questions and facts regarding BIM for Infrastructure.

1.4 Organization of Report

This report is organized into six chapters and several appendices:

• Chapter 1 provides an overview of the problem and motivation for the study, the objectives and scope of the completed research, and a summary of the tasks performed to gather necessary data to inform the business case methodology and creation of final products.

- Chapter 2 is a synthesis of the literature reviewed during Phase I of the study.
- Chapter 3 presents a summary of each case study conducted and the BIM expert validation
- Chapter 4 presents the benefit and cost data captured during the case studies, validation of assumptions from the panel of expert workshops, and the business approach for analyzing benefits and costs of BIM deployment.
- Chapter 5 contains a high-level plan for the steps to implement BIM to support asset management.
- Chapter 6 states the conclusions from the study and recommendations for future work.
- Appendices A through E each describe or contain an additional product from the study:
 - Appendix A: Multi-Media Toolkit,
 - Appendix B: ROI Workbook and User Guide,
 - Appendix C: Glossary,
 - Appendix D: Mapping of Use Cases to Benefits, and
 - Appendix E: BIM Maturity Matrix for Transportation Agencies.



Literature Review

2.1 Overview

The objective of the literature review was to provide the background information required for comprehensive development of an ROI tool to support transportation agency decision-making. The literature review also includes information that can be used to communicate benefits and overall impact to decision-makers. To support these goals, the literature review includes a summary of the status of BIM adoption in infrastructure, along with various BIM use cases for infrastructure. Previous studies on BIM ROI are also presented, including an analysis of ROI studies from both infrastructure and the vertical building sector.

These studies were used to develop the BIM ROI tool. BIM assessment approaches that have been used for both organizational and project-level adoption are analyzed in terms of the best approaches for assessing an overall level of BIM adoption for both organizations and projects. This chapter concludes with representative BIM adoption case studies, along with overall recommendations and lessons learned from the literature review.

2.2 BIM Adoption in Infrastructure

BIM has been widely implemented within some sectors of the design and construction industry. BIM is a collaborative process that covers business drivers, automated process capabilities, and open information standards. It is a facility lifecycle management tool of well-understood information exchanges, workflows, and procedures (National Institute of Building Sciences 2015). BIM includes a wide variety of tools encompassing emerging technologies and practices that can be applied to infrastructure projects to improve predictability, performance, and transparency during stages of planning, operation, and maintenance. However, few infrastructure projects or agencies have broadly adopted BIM to date.

While BIM has gained significant adoption within the vertical building sector of the construction industry, adoption levels within the infrastructure sector are more varied. This section outlines literature related to the current level of BIM adoption within the infrastructure sector and the driving forces and challenges within this adoption. For example, McGraw-Hill Construction reported great variability in BIM usage among project stakeholders in the 2017 SmartMarket Report.

Level of BIM Adoption in Infrastructure

It is somewhat difficult to define the exact implementation levels for BIM within the infrastructure sector of the construction industry because levels of BIM adoption can vary significantly from project to project and organization to organization. The adoption of BIM is not a singular item; instead, increasing the level of digital modeling within projects and organizations is an ongoing journey. Within the literature, some of the most interesting data associated with BIM adoption levels originate from the McGraw-Hill SmartMarket reports, now called Dodge Data & Analytics SmartMarket reports, which are freely available.

These reports are developed through survey data collection from individuals within the construction industry, and they capture current implementation data along with industry perception of the future. A number of the BIM SmartMarket reports are from before 2017, but they still provide valuable context for understanding BIM adoption. The 2012 and 2017 SmartMarket reports are focused on BIM adoption specifically for the infrastructure sector and show the trends for adoption. However, it is important to note that BIM use in the transportation sector is growing at a rapid pace, so relying on 2017 data may not provide an accurate indication of current market status.

According to published SmartMarket reports, organizations of all sizes predicted that their level of BIM implementation would increase to more than 50 percent of their infrastructure projects between 2009 and 2013. However, the size of the organization affected the pattern of high BIM usage in infrastructure over the five-year span (McGraw-Hill Construction 2012). Midsize organizations show a pattern of greatest growth, more than quadrupling the percentage of high-level implementers from 2009 to 2013, with the small-medium groups expanding from 11 percent to 47 percent and medium-large organizations rising from 13 percent to 58 percent. The report predicted that small organizations would lead the way in high-level implementation by 2013, with almost two-thirds (65 percent) of small organizations predicting they would be practicing at a high level by then. Almost half (46 percent) of the firms reported using BIM on their infrastructure projects, up from 27 percent in 2010 (McGraw-Hill Construction 2012).

Architectural/engineering (A/E) firms and infrastructure owners reported the fastest adoption growth rates (McGraw-Hill Construction 2012). In 2010, 73 percent of BIM users in A/E were either not using BIM for infrastructure or using it at a low level. The expectation was that by 2013 the trend would be reversed, with 78 percent expecting to use it on more than 25 percent of their projects. A/E owners went from 74 percent with low/no levels of use in 2009 to 84 percent using BIM on 25 percent or more of their projects by 2013.

Few infrastructure projects or agencies have broadly implemented BIM throughout multiple phases of their project delivery or across multiple departments within their organizations. In general, there is a growing level of BIM adoption for infrastructure with the development and advancement of technologies in recent years. According to Dodge Data & Analytics (2017), there has been a significant growth rate of BIM adoption globally; in 2017, 55 percent of infrastructure projects in the United States used BIM compared to 27 percent in 2015. In addition, the state of BIM adoption varies widely among agencies; while some agencies are using BIM technology for most of the project delivery process, others are adopting BIM only for a few use cases.

State DOTs have widely used near real-time geospatial data within Geographic Information Systems (GISs) as a result of the integration of advanced communication networks, information technology (IT) infrastructure, and geospatial technology (Mallela et al. 2019). GIS data is one essential aspect of the information required to support the built infrastructure project. Although some DOTs have implemented Civil Integrated Management tools and functions in several projects, agencywide implementation still has a long way to go (O'Brien et al. 2016). From the asset management perspective, transportation asset management (TAM) has been a focus area of the U.S. transportation community for more than two decades and it has received increased attention (Spy Pond Partners et al. 2018). BIM can play a significant role in providing the data and information needed to support effective TAM.

DOTs have adopted BIM for targeted use cases. Some documented implementation approaches include the following:

- Iowa Department of Transportation (Iowa DOT) has used 3D models for visualization and constructability reviews.
- Michigan Department of Transportation and Oregon Department of Transportation (Oregon DOT) have statewide 3D engineered model development programs, which aim to use 3D models for visualization and constructability reviews as well as surface modeling for automated machine guidance (AMG).
- New York State Department of Transportation (NYSDOT) has applied 3D models on some projects, such as the NY-17/I-81 interchange and Kosciuszko Bridge.
- Texas DOT has applied 3D visualization on several projects, with the Horse Project I-35/I-30 interchange as an example.
- Connecticut DOT has also used discipline-specific 3D models for visualization in projects, including the I-95 New Haven Harbor Crossing (Federal Highway Administration 2018).
- Oregon DOT implemented five BIM-related technologies, including an upgraded lidar (light detection and ranging) mobile mapping system, 3D Engineered Models (3D-EM), AMG, Engineering Data Management, and e-construction (Sillars et al. 2017).
- Indiana DOT used Intelligent Design and Construction, which involves intelligent 3D computer-aided design (CAD) models, to support the lifecycle of transportation assets for roads and bridges (Fuller et al. 2019).

These are several examples of implementation of BIM use cases within DOTs, and there are many more examples that may not be well-documented throughout the literature.

Despite rapid growth, it is difficult to measure the specific levels of adoption of particular BIM use cases within these data. For example, a project could adopt BIM throughout the entire design and construction process, or the implementation may be limited to a more targeted number of BIM use cases within the project, such as 3D coordination or quantity take-offs (QTOs). This was also found in a study by Mostafa and Leite (2018) that analyzed 28 representative case studies and found that, on average, projects have used BIM for four use cases. This study suggests an increase from a previous study conducted a decade earlier, which found projects were using BIM for one to two use cases. This level of detail for the level of BIM adoption is not always clearly presented, and it is important to consider that the data collected are survey data, with limited validation of the actual implementation levels.

Drivers and Challenges to BIM Adoption

The advancement of BIM in the construction industry is transforming the process of project delivery. Arayici et al. (2011) indicates that government policies have placed the industry under pressure to provide more value for the invested funds and deliver higher levels of sustainable design and construction, all of which are directly related to the use of BIM. Current clients are putting pressure on contractors to increase their BIM capabilities and deliver successfully managed BIM projects (Eadie et al. 2013).

Ruikar et al. (2005) concluded that although historically there is no industry requirement for BIM adoption, the main driver is the aspiration to be at the forefront of this aspect of industry. Project stakeholders use the most advanced BIM products to deliver real whole-life value to clients by delivering environmental, energy, schedule, cost, and spatial analysis (Azhar 2011). BIM models can offer walk-through visualizations to assist clients in the decision-making process; and real-time, online contributions from designers can streamline design activities and improve design quality (Eadie et al. 2013). BIM models allow visualization of the construction sequence, and the construction process can be made intrinsically safer (Kiviniemi et al. 2011).

BIM offers contractors an additional means of communicating with their workforce. Sacks et al. (2009) have shown that designers and construction planners are able to communicate the sequence of operations because of the capability of 4D BIM to display animated construction sequences on-screen. A report on the Mortenson Group found that the use of BIM reduced requests for information (RFIs) by 32 percent (Applied Software Technology 2009), which can lead to efficiency and cost savings through adoption of BIM. A study by Azhar et al. (2008) revealed that BIM can produce up to an 80 percent reduction in the time taken to generate a cost estimate. In addition, 4D BIM offers detailed scheduling tools that can accurately predict the duration of each construction task as well as plan upcoming tasks and the associated resource requirements. Azhar et al. (2008) found that clash detection can offer savings of up to 10 percent of construction contract value and reduce project duration by up to 7 percent. BIM enables the team to generate new delivery schedules for each scenario enacted, therefore creating efficiencies in document generation and distribution (Azhar 2011).

Despite many perceived benefits of using BIM technology, several studies have shown that the rates of adoption in the AEC industry still seem to vary greatly among stakeholders and the different phases of a project cycle. Challenges still exist and deter the adoption of BIM in projects. As a new technology, costs and training issues have been the greatest hurdles on the path to adoption. The SmartMarket reports consistently show that obstacles facing BIM adoption include finding adequate training, obtaining senior management buy-in, and the overall cost of software and hardware (Dodge Data & Analytics 2017; McGraw-Hill Construction 2008). Design and construction firms are also concerned about the lack of demand by clients. For owners, poor internal understanding of BIM has been identified as the top reason for delaying the use of BIM on projects (McGraw-Hill Construction 2012).

From the previous literature, some researchers identified additional challenges in adopting BIM. Common challenges include the cost and benefit of implementation; lack of standards, training, and education; and selection of software and hardware (Both 2012). Bosch-Sijtsema et al. (2017) share similar perspectives with Both and found a few adoption challenges, such as lack of client demand, limitations in information availability, and not understanding the legal aspects of implementation. In addition, Matarneh and Hamed (2017) highlighted culture change and its effect on the business environment. Moreover, Chan (2014) identified the lack of supply chain, contractual agreements that consider BIM, and professional indemnity insurance limitations as BIM adoption challenges. Kekana et al. (2014) discovered staff resistance, lack of knowledge of BIM, ownership and intellectual property, and product liability risks as the greatest challenges of BIM adoption. Lindblad (2013) found authenticity and legal uncertainties. In addition, Eadie et al. (2014) identified the lack of senior management support as a BIM adoption challenge. Finally, Hamdi and Leite (2014) point out that BIM implementation presents a set of challenges, ranging from technical to contractual and personal challenges, that extend beyond the design and construction phases to the post-delivery phase. They provide evidence of those challenges, with a focus on BIM-related contractual challenges and sources of disagreements.

BIM Use Cases for Infrastructure

The implementation of BIM on a project is not a simple decision of whether to implement; instead, the project team must clearly identify the use cases they will implement and be intentional about their implementation to better plan for it. There have been significant efforts made to define BIM use cases, with a heavier emphasis on vertical buildings than transportation infrastructure. From the literature, one example BIM use case is to author 4D modeling, which focuses on linking individual components of the BIM model with the corresponding processes of the construction schedule. This allows for visualization of the schedule. Another example is to author a cost estimate, which refers to BIM-based QTO as a basis for cost estimation. 10

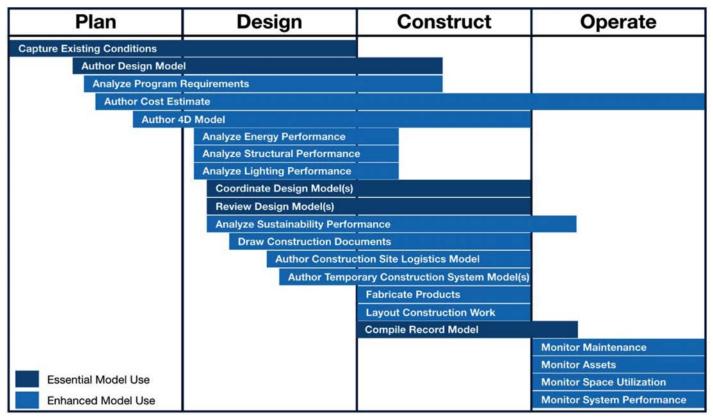
As shown in Figure 2-1, different BIM uses can be mapped to different project phases within a project lifecycle (i.e., plan, design, construct, and operate).

While there have been varying approaches to categorizing BIM use cases, currently there is not a generally accepted list of BIM uses that specifically apply to infrastructure or, more specifically, highway projects. There are some resources that do identify a series of these BIM uses, such as the Industry Foundation Classes (IFC) Roads project within buildingSMART International. This IFC Roads project focused on defining a standard process (Figure 2-2) with identified information exchanges for road projects, and then defining the information exchange specifications. Therefore, the process highlights common use cases considered within the IFC Roads interoperability project. A series of 30 use cases were defined within the IFC Roads project, and each was categorized as Must Have, Should Have, Could Have, or Won't Have within the IFC Roads project. Table 2-1 summarizes IFC Roads "Must Have and Should Have" use cases. A table for all 30 use cases was identified by the buildingSMART International team, and the categories are identified within the table; Figure 2-3 shows part of that table (Moon et al. 2018).

It is important to note that the IFC Roads project is focused on strategic briefing and design processes, which emphasize design within their stages. IFC Roads documents seven stages, but most use cases are defined within the initial four stages.

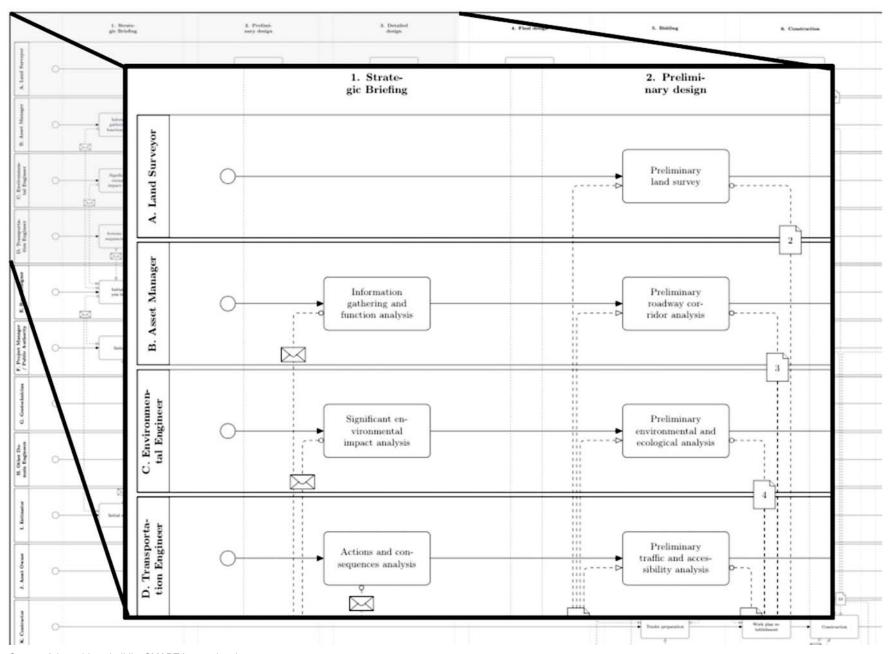
The seven stages include

- Strategic Briefing,
- Preliminary Design,
- · Detailed Design,



Source: Messner et al. 2021.

Figure 2-1. Common model uses by project phase.



Source: Adapted from buildingSMART International.

Figure 2-2. IFC Roads process with expanded section.

Table 2-1. IFC Roads project "Must Have and Should Have" use cases.

Phase I	Phase II
R02: Coordination/Collision Detection	R03: 4D Construction Sequence Modeling
R04: Quantity Take-off	R07: Code Compliance Checking
R09: Design-to-Design (Reference Model)	R11: Progress Monitoring
R10: Machine Control and Guidance (During Construction)	R12: As-built vs. As-planned Comparison
R13: Handover to Asset Management	
R14: Handover to GIS for Spatial Analysis	
R15: Initial State Modeling	
R25: Earthworks Cut and Fill Design	
R26: Geotechnical Investigations	
R27: Geotechnical Constructions	

- · Final Design,
- Bidding,
- · Construction, and
- Asset Management and Maintenance.

It is also important to note that the IFC Roads process does not aim to be comprehensive in the identification of all use cases for BIM, and it does not focus on the construction and operations phase of road assets. Instead, its purpose is to identify and define fundamental information exchanges. The process identifies 11 information exchanges or models, including initial state model, survey model, corridor model, environmental model, traffic model, and roadway design model.

After reviewing the various use case approaches, the research team developed a simplified list of use cases for evaluating the case study projects within an ROI analysis. These use cases were divided into four categories: project delivery core, asset management core, project delivery extensions, and asset management extensions. Then the use cases were mapped against four project lifecycle phases: plan, design, construct, and operate (Figure 2-4).

BIM Uses by Project Phase for Infrastructure

These use cases do not aim to be comprehensive; instead they focus on the primary uses documented throughout the literature at a level of detail that can be analyzed within the case study projects. In the project delivery core, BIM use cases include capture existing conditions, author design model, analyze engineering performance, coordinate design models, and review design models. The asset management core includes compile record model, maintain roads/bridges, and inventory roads/bridges. Project delivery extensions include create quantities and cost estimate, author 4D model, layout construction work, and automate equipment guidance. The asset management extensions currently include inspect assets, although there are potentially many more BIM use extensions.

The following bullets provide concise definitions of each of the BIM uses identified in Figure 2-4.

- Analyze Engineering Performance: a process in which intelligent modeling software uses the BIM model to determine the most effective engineering method based on design specifications (Messner et al. 2021).
- Author 4D Model: a process in which a 4D model (3D model with the added dimension of time) is utilized to effectively plan the phased occupancy in a renovation, retrofit, or addition, or to show the construction sequence and space requirements on a building site (Messner et al. 2021).

No	Use case name	Description	Purpose	IFC exchange scenario	Required geometry representation	Required semantic information	Priority	Complexity	MoSCoW
R01	Visualization	3D technical visualization and presentation of the road project	Communication of design solutions between project partners and to third parties, including the public. Visualisation of how drivers perceive the road.	Design application to Visualization application	TIN, BRep, Sweep geometry where suitable	Road breakdown structure, Object Types, Material (opt), Colours (opt)	high	low	MUST HAVE
R02	Coordination / Collision detection	Coordination of domain-specific sub-models	Transfer and combine models to detect interferences (clashes)	Design application to Design/Checking application	TIN, BRep, Sweep geometry where suitable	Component types, Classification, Relationships between entities (IfcRelConnects)	high	low	MUST HAVE
R03	4D Construction Sequence Modelling	4D technical visualization of the construction phases	Organization of construction site and construction activities	Design application to 4D scheduling application	TIN, BRep, Sweep geometry where suitable	Road breakdown structure, Object Types, Temporal information	medium	low	SHOULD HAVE
R04	Quantity Take-Off	Determine quantities (volumes and surfaces) from the model	Basis for cost estimation and cost calculation	Design application to QTO application	TIN, BRep, Sweep geometry where suitable	Material, Classifications	high	low	MUST HAVE
R05	Structural Analysis	Structural analysis of pavement and sub-grade	Ensure stability of the structures	Design application to Structural analysis application	Analytical Model	Analytical Model	medium	medium	COULD HAVE

Source: Moon et al. 2018.

Figure 2-3. Partial table of BIM use cases in IFC Roads project specifications.

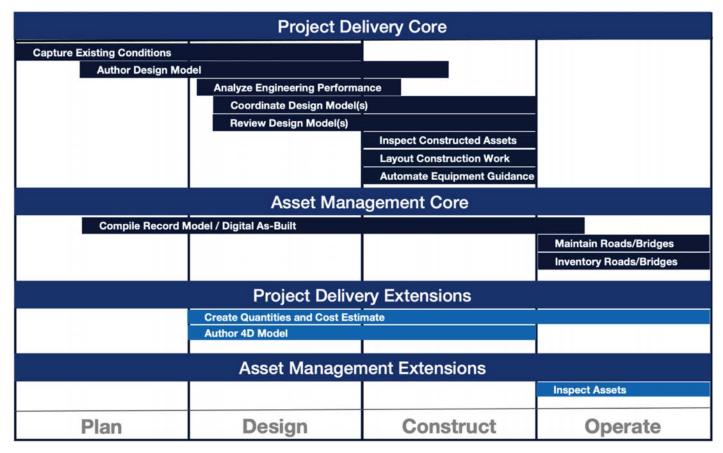


Figure 2-4. Model BIM uses by project phase for infrastructure.

- Author Design Model: using BIM authoring software to develop a model with 3D and additional attribute information for a road/bridge design, leveraging a library of parametric design elements (Messner et al. 2021).
- **Automate Equipment Guidance:** using information from a model to guide or control excavation for road and bridge construction equipment on the jobsite.
- Capture Existing Conditions: using 3D information-capture approaches and BIM authoring software to develop a 3D model of the existing conditions for a site, roads/bridges on a site, or a specific area within a road or bridge (Messner et al. 2021).
- Compile Record Model/Digital As-Built Model: a process for obtaining information about the elements, surrounding conditions, and assets of a road or bridge (adapted from Messner et al. 2021).
- Coordinate Design Models: using 3D coordination software to compile a federated model of design models for performing automated 3D collision detection to identify potential coordination issues, and performing a visual analysis to identify potential spatial design issues (Messner et al. 2021).
- Create Quantities and Cost Estimate: a process in which BIM can be used to assist in the generation of accurate QTOs and cost estimates throughout the lifecycle of a project (Messner et al. 2021).
- **Inspect Assets:** using the model to inform the inspection of bridges and roads during the operational phase of the assets.
- **Inspect Constructed Assets:** using 3D models to verify location, elevation, and quantities of installed assets against contract requirements.

- Inventory Roads/Bridges: using information extracted from a model to document and track conditions and quantities assets.
- Layout Construction Work: using model information to lay out road/bridge assemblies or automate control of automated equipment on a construction project (adapted from Messner et al. 2021).
- Maintain Roads/Bridges: using information from road or bridges models to monitor status and schedule maintenance activities for a road or bridge (adapted from Messner et al. 2021).
- Review Design Models: reviewing a building information model with project stakeholders to gain their feedback and to validate the design, construction, or operational aspects of a project (Messner et al. 2021).

In summary, there has been a clear increase in BIM adoption throughout the infrastructure sector of the construction industry. For transportation agencies, there are significant challenges that would need to be overcome to broadly implement BIM. It is also important to recognize that BIM is adopted at the level of BIM use cases, with varying approaches to defining such use cases. A systematic approach toward understanding the ROI in adopting use cases is important. The next section focuses on previous studies that have investigated ROI for targeted BIM uses.

2.3 ROI Analysis for BIM Adoption

As described later in Chapter 4, there is no industry consensus on what constitutes ROI analysis for transportation programs. Generally, ROI measures the amount of financial return on an investment relative to the investment's cost. The returns may be a single payment or a stream of payments (Spy Pond Partners et al. 2018). Within this report, the research team focuses on the ROI for transitioning from a more analog approach to implementing an activity within a project lifecycle to a more digital (or model-based) approach to performing that activity.

The following sections discuss previous studies that clearly identify the benefits and costs of adopting BIM. These categories were developed from a detailed content analysis of BIM literature for all sectors of the construction industry, not just infrastructure. The goal of this analysis was to identify benefits and investments for developing the BIM ROI Tool. The final parts of this section focus on published ROI studies for the adoption of BIM for various use cases.

Benefits of Adopting BIM

Previous studies demonstrate that BIM can provide many benefits to a project by improving asset data and information sharing between all project stakeholders during the design, construction, and operations phases of assets. Moreover, BIM adoption promotes communication and collaboration because it brings people, processes, information, and technology together. This section first focuses on benefits that have been identified for owner organizations, followed by benefits identified for the end users and project delivery team.

Benefits in Asset Management by Owners

BIM can provide benefits for managing the capital facility assets of an organization. The use of data and digital models for asset management can enable organizations to optimize cost, risk, and performance over the lifecycle of their assets. Analysis of the literature shows that BIM adoption can offer significant benefits for asset management in cost savings, staff time savings, ancillary organizational benefits, and benefits for end users. BIM benefits in asset management are summarized in Table 2-2, Table 2-3, and Table 2-4.

Table 2-2. BIM cost-savings benefits in asset management by owner.

Direct Inspection Costs	Direct Maintenance Costs	Direct Operational Costs
Improved engineers' inspection capabilities and enhanced quality assurance, thereby increasing efficiency and optimizing resources (Parve 2013).	 Asset integrity (Love et al. 2013). Enhanced, real-time emergency management (Terreno et al. 2015). More accurate information from a data-rich asset (Jackson 2020; Terreno et al. 2015). Richer data asset at handover (Terreno et al. 2015). More proactive maintenance (Terreno et al. 2015). Controlled whole-life costs and environmental data (Azhar 2011). Improved inventory management (e.g., spare parts) (Love et al. 2014). 	 Improved energy management (Terreno et al. 2015). Enhanced, real-time space management (Terreno et al. 2015). Shorter response time in operations (Terreno et al. 2015). Space optimization (e.g., smart algorithms) (Love et al. 2014). Configuration management (e.g., impact/functional conflicts) (Love et al. 2014). Utility costs reduction (i.e., make informed choices by simulating options in relation to energy efficiency) (Love et al. 2014). Reduced storage needs, eliminated leased buildings/rental office space, or increased effective use of office space (Shah et al. 2017). Reduced paper, printing, and distribution (i.e., postage) (Shah et al. 2017).

Table 2-3. BIM staff time-savings benefits in asset management by owner.

Data Entry	Maintenance Information Retrieval Time	Programmatic Information Retrieval Time	Safety Code Compliance Costs	Design Time in Early Design Phase
Reduced manual data entry and data redundancy (Shah et al. 2017). Richer data asset at handover (Terreno et al. 2015).	Reduced time to find maintenance information (Manning and Messner 2008). Easier data retrieval (Jackson 2020; Terreno et al. 2015). Increased access to documents (Shah et al. 2017). Reduction in misfiled and lost documents (Shah et al. 2017). Accessibility of reliable information for asset maintenance and operation (Shah et al. 2017). Reduced time in accessing documents (Shah et al. 2017). Reduced time in accessing documents (Shah et al. 2017; Love et al. 2014).	Accurate digital record of the asset conditions for potential use in augmenting programmatic asset inventory (Jackson 2020; Shah et al. 2017). Increased employee productivity and efficiency (Cai et al. 2015; Terreno et al. 2015). Facility management (FM) labor utilization savings (Love et al. 2014).	Reduced costs for regulations compliance (e.g., auto-checking building and safety codes) (Love et al. 2014).	Improved design quality (Messner et al. 2021). Reduced rework in design (Messner et al. 2021). Greater efficiency on the job (Mallela et al. 2019; Sillars et al. 2017; Terreno et al. 2015).

BIM ancillary organizational benefits in asset management by owner.

Reputation and Level of Public Trust	Business Operations
Better company image (McGraw-Hill Construction 2014). Improved client satisfaction (Azhar 2011; Newton and Chileshe 2012).	 Improved business growth (Love et al. 2013). Firm growth (Bryde et al. 2013). Improved learning for younger staff (McGraw-Hill Construction 2012). More detailed strategic planning with holistic considerations (Terreno et al. 2015). Improved hiring and controlling of subcontractors (Bryde et al. 2013). Improved change management (Terreno et al. 2015). Improved asset management (Fanning et al. 2015). Improved sustainability management (Terreno et al. 2015). Improved profit margin for project team members (Bryde et al. 2013).

Benefits for End Users of Facilities

Implementation of BIM in infrastructure has been shown to improve comfort management by promoting improved productivity (Love et al. 2014); enhance fuel and material savings by facilitating less travel and waste (Love et al. 2014); provide clearer facility management (FM) requirement definitions for design and construction (Terreno et al. 2015); and improve monitoring and management of related health and safety issues for users (Fanning et al. 2015). For highway projects, it is assumed that there would be additional end user and society benefits related to reduced emissions. These benefits are due to efficient maintenance and construction processes, although no specific studies were identified in this area.

Benefits in Project Delivery: Design and Construction

The benefits of BIM adoption are apparent in project delivery, and more studies have focused on project delivery than on asset management. Implementing BIM enables project stakeholders to reap the maximum benefits for effective project management in the design and construction processes. Previous studies demonstrate the BIM benefits in design and construction, specific to project costs (see Table 2-5, Table 2-6, Table 2-7, and Table 2-8). These benefits include

- Shorter delivery time,
- Design process efficiency,
- Construction process efficiency,
- Reduced field conflicts,
- Improved visualization for planning,
- Improved safety,
- Reduced waste,
- Project delivery cost savings,
- Clear process definition, and
- Asset turnover efficiency.

Literature analysis also revealed the following ancillary benefits:

- Increased quality (Barlish and Sullivan 2012; Newton and Chileshe 2012).
- Increased quality management (Shah et al. 2017).

Table 2-5. Project cost savings due to shorter delivery times, process efficiencies in design, and construction.

Shorter Delivery Times	Design Process Efficiencies	Construction
Accelerated project delivery through improved collaboration, easier information sharing, etc. (Shah et al. 2017). Improved schedule (in days) (Barlish and Sullivan 2012; Bryde et al. 2013; Khanzode et al. 2008). Improved sequence coordination (Barlish and Sullivan 2012). Allow for simulation (Barlish and Sullivan 2012).	 More detailed and extensive design reviews, moving toward more seamless lifecycle integration (Terreno et al. 2015; Won et al. 2016). Integration of several design processes together, resulting in better and faster designs at a lower cost (Parve 2013). Automatically updated model (Terreno et al. 2015). Improved interoperability due to better planning (Terreno et al. 2015). Improved information sharing (Newton and Chileshe 2012). Easier data retrieval (Terreno et al. 2015). Seamlessly integrated software (Terreno et al. 2015). Reduced RFIs (Barlish and Sullivan 2012; Staub-French and Khanzode 2007; Walasek and Barszcz 2017). Faster turnaround times for document review and approval (Shah et al. 2017). 	 Increased prefabrication (Barlish and Sullivan 2012; Khanzode et al. 2008; Staub-French and Khanzode 2007). Improved constructability (Newton and Chileshe 2012). Ability to produce inhouse shop and supplemental field drawings from the BIM effort (Giel and Issa 2013). Automated assembly (Azhar 2011). Improved productivity (Barlish and Sullivan 2012; Mitchell et al. 2019; Newton and Chileshe 2012; Staub-French and Khanzode 2007).

Table 2-6. Project cost savings due to reduced field conflicts and improved visualization for planning.

Reduced Field Conflicts	Improved Visualization for Planning
Design errors can be identified prior to construction (Staub-French and Khanzode 2007).	Improved 3D visualization (Barlish and Sullivan 2012; Newton and Chileshe 2012).
 Reduced change orders and claims from field conflicts (Barlish and Sullivan 2012; Khanzode et al. 2008; Staub-French and Atul 2007). 	Accelerated discovery of dimensional discrepancies in the construction documents (Giel and Issa 2013).
 Reduced rework (Barlish and Sullivan 2012; Khanzode et al. 2008; Staub- French and Khanzode 2007; Walasek and Barszcz 2017). 	
 Reduced 3D geometric clashes (Giel and Issa 2013; Khanzode et al. 2008; Newton and Chileshe 2012; Walasek and Barszcz 2017). 	
Elimination of field interferences (Staub-French and Khanzode 2007).	
 Reduced field labor costs due to a reduction in field conflicts (Barlish and Sullivan 2012; Khanzode et al. 2008; Staub-French and Khanzode 2007). 	

Table 2-7. Project cost savings due to improved safety and reduced waste.

Improved Safety	Reduced Waste
 Reduced field injuries (Khanzode et al. 2008). Improved worker safety during maintenance and operations inspections due to fewer worker inspections (Shekargoftar et al. 2022). Improved safety for construction staff due to reduced exposure to heavy equipment (Choe and Leite 2017; Mitchell et al. 2019). 	Reduced construction waste: The amount of waste prevented by a BIM-based design validation process was estimated based on the amount of construction waste that otherwise might be generated because of design errors (Bryde et al. 2013; Guerra et al. 2020; Won et al. 2016).

Table 2-8. Project cost savings due to project delivery method cost savings, clear process definitions, and asset turnover efficiency.

Project Delivery Method Cost Savings	Clear Process Definitions	Asset Turnover Efficiency
Increased bidding competition (Mitchell et al. 2019). Reduced amount of errors in bids (Shah et al. 2017). Accuracy of cost estimate improved to within 3 percent (Love et al. 2013). Contractors perceived lower bidding risk (Mitchell et al. 2019). Reduced time required by 80 percent for developing a cost estimate (Love et al. 2013). Reduced time in posting bid results to contractors (Shah et al. 2017). Reduced amount of incomplete bids (Shah et al. 2017).	Improved consistency and standardization/streamlining of processes (Mallela et al. 2019; Shah et al. 2017). Incorporation of requirements into contract documents (Terreno et al. 2015).	Reduced requirement for data reentry (Terreno et al. 2015). Improved as-built information (Barlish and Sullivan 2012; Khanzode et al. 2008; Taylor et al. 2020; New York State Department of Transportation 2019).

- Improved design and engineering quality (Barlish and Sullivan 2012).
- Improved plan quality (Mitchell et al. 2019).
- Scope clarification (Bryde et al. 2013).
- Better-performing completed infrastructure (McGraw-Hill Construction 2012).
- Integration of project systems (Love et al. 2014).
- Improved accuracy (Sillars et al. 2017; Newton and Chileshe 2012).
- Risk reduction (Bryde et al. 2013).
- Lower risk and better predictability of outcomes (McGraw-Hill Construction 2012).
- Coordination between different disciplines' documentation and the discovery of major contradictions during pre-construction (Bryde et al. 2013; Giel and Issa 2013; Leite 2019).
- Improved communication (Barlish and Sullivan 2012; Bryde et al. 2013; Guerra and Leite 2020).
- More collaborative approach to projects and problem-solving (Sacks et al. 2018; Terreno et al. 2015).

- Improved sustainability (Guerra et al. 2020; Newton and Chileshe 2012).
- Improved energy efficiency (Walasek and Barszcz 2017).
- Enabled use of information for maintenance (Barlish and Sullivan 2012).
- Improved competitiveness (Newton and Chileshe 2012).

Investment to Adopt BIM

In an ROI analysis, the benefits of a proposed investment are compared with its costs. BIM investments can potentially have direct and indirect effects on organizational and asset management costs as well as direct and indirect effects on project delivery. These effects include reductions in staff time and maintenance expenditures. Investment costs are required inputs to any ROI assessment and should include costs over the entire analysis period (Spy Pond Partners et al. 2018).

BIM investment costs fall into two categories: investment in organizational and asset management, and investment in project delivery. Both types of costs can be broken into two primary categories: 1) non-recurring costs, which may be initial or renewal investments, and 2) recurring costs that are part of operating and maintaining the BIM investment.

Table 2-9 lists costs that may occur over the lifecycle of BIM investments in organizational and asset management (Spy Pond Partners et al. 2018). Table 2-10 lists costs that may occur over the lifecycle of BIM investments in project delivery.

Return for Adopting BIM

For transportation assets, initial costs are monetary expenditures that are invested in the near term. In contrast, returns can accrue over years and may produce benefits such as improved organizational image, which would ultimately have a positive influence on a highway agency in the long term. The particular characteristics of agencies and their level of experience with

Table 2-9. Costs for lifecycle BIM investments in organizational and asset management.

Human	Direct		
Non-recurring Investments			
 New staffing requirements (McGraw-Hill Construction 2014). Pre-implementation planning consultant (Mitchell and Lee 2017). 	Hardware and other technical infrastructure (McGraw-Hill Construction 2014; Mitchell and Lee 2017). Software (Dodge Data & Analytics 2017). Development costs (Parve 2013).		
Recurring Investments			
Staff training (McGraw-Hill Construction 2014). Potential design cost increase (Parve 2013).	Software licenses and maintenance (McGraw-Hill Construction 2014; Mitchell and Lee 2017). Managed services support following implementation and upgrade (Mitchell and Lee 2017). Hardware and other technical infrastructure (McGraw-Hill Construction 2014; Mitchell and Lee 2017). System integration services to configure, test, deploy, and support the new system and its upgrade (Mitchell and Lee 2017).		

Table 2-10. Costs for lifecycle BIM investments in project delivery.

Human (Recurring Investments Only)	Direct (Non-recurring Investments Only)		
BIM coordinator salary (Lee et al. 2013).	Hardware and other technical existing condition model costs (Hoffer et al. 2013). Startup costs (Hoffer et al. 2013). Design coordination costs (Lee et al. 2012). Increased contract value (Giel and Issa 2013). Construction costs (Barlish and Sullivan 2012).		
	Design model generation costs (Lee et al. 2012).		

computer-based decision support will influence the returns realized on their investments (Spy Pond Partners et al. 2018). In the literature review, returns that can be realized because of BIM are divided into two categories: organizational level and project level. The following list provides examples from both categories.

- Organizational level.
 - Improved collaboration with owner or design firms (McGraw-Hill Construction 2014; Sacks et al. 2018).
 - Enhanced organizational image (McGraw-Hill Construction 2014).
- Project level.
 - Productivity gain (Poirier et al. 2015).
 - Reduced printing use costs (Becerik-Gerber and Rice 2010).
 - Reduced document shipping costs (Becerik-Gerber and Rice 2010).
 - Reduced travel costs (Becerik-Gerber and Rice 2010).
 - Fewer approved change orders (Becerik-Gerber and Rice 2010; Hoffer et al. 2013; Lee et al. 2013).
 - Reduced claims and disputes (Becerik-Gerber and Rice 2010).
 - Reduced errors and omissions (Becerik-Gerber and Rice 2010).
 - Improved information control and communications (Qian 2012).
 - Reduced rework (Hoffer et al. 2013; McGraw-Hill Construction 2014; Qian 2012).
 - Improved collaboration (Hoffer et al. 2013).
 - Reduced RFIs (Barlish and Sullivan 2012; Giel et al. 2009).
 - Reduced project delay (Giel et al. 2009).
 - Capability for clash detection (Azhar 2011; Leite 2019).
 - Reduced contractor costs (Barlish and Sullivan 2012).
 - Reduced direct and indirect costs (Lee et al. 2012; Salih 2012).
 - Duration improvement (Barlish and Sullivan 2012).

Quantitative Performance Metrics

There have been significant disparities between the ROI figures with BIM adoption, as there is no standard approach for collecting and evaluating the data used to calculate ROI. To address the issue, Love et al. (2013) identified the following quantitative performance indicators when measuring ROI for BIM:

- Quality control (QC) (rework reduction).
- On-time completion (reduction in delay).
- Overall cost (cost reduction).

- Units (square feet or meters) per person or per hour.
- Dollars per unit (square feet or meters) per person or per hour.
- Safety (reduction in lost person-hours).

Barlish and Sullivan (2012) also identified a few tracking metrics for ongoing projects to consistently compare similar projects with and without BIM carried out under the same owner and contractor:

- Change orders as a percent of standard costs.
- Avoidance log and associated costs.
- RFI quantities in non-BIM versus BIM projects.
- Offsite prefabrication person-hours from contractors.
- Owner Controlled Insurance Program (insurance headcount dollar savings as a percent of offsite hours).
- Reconciliations of savings from contractors/designers using BIM.
- Actual durations as a percent of standard duration.

Varying degrees of visibility and availability of information limit individual project stakeholders' abilities. For example, it is difficult for owners to be aware of a contractor's field productivity rates; therefore, the contractor's savings may seem lower than the actual savings. Nevertheless, contractors know how much they spend or save due to BIM and how much of the savings they will pass on to the owner. These performance indicators help stakeholders track a project's progress status and know the benefits introduced by BIM adoption quantitatively, allowing all stakeholders to make better decisions.

Previous ROI Analysis Results in Literature

Azhar (2011) investigated four case studies that quantify BIM benefits in different projects. The data used in these case studies were collected from Holder Construction Company, a general contractor based in Atlanta, Georgia. General information regarding these case studies is summarized in Table 2-11.

Table 2-11. General information on four ROI calculation case studies.

	Case Study 1	Case Study 2	Case Study 3	Case Study 4
Project Scope	\$46 million, 484,000-square foot hotel and parking structure	\$12 million	\$111 million, five-star mixed- use hotel	\$35 million, LEED-certified, 110,000-square foot facility on Emory University campus
Delivery Method	CMAR	CMAR	CMAR	CMAR
Contract Type	Guaranteed maximum price	Guaranteed maximum price	Guaranteed maximum price	Guaranteed maximum price
BIM Scope	Design coordination, clash detection, and work sequencing	Planning, value analysis	Planning, construction documentation	Sustainability analysis
BIM Cost	\$90,000 (0.2% of project budget)	\$5,000	\$1,440	N/A
Cost Savings	Over \$200,000 attributed to clash elimination	\$1,995,000	\$15,000	N/A

Note: CMAR = Construction Manager at Risk; LEED = Leadership in Energy and Environmental

Design; N/A = not applicable.

Source: Adapted from Azhar 2011.

In the first case study, cost and time savings were calculated using clash detections that could be avoided by using BIM. In the second case study, BIM was implemented during the planning phase to choose the most economical building layout. For each building layout, the BIM-based cost estimate was calculated in three cost scenarios, including budgeted, midrange, and high range. In the third case study, the design team was able to finish the project on time and within budget because of using BIM. In the fourth, the architect used BIM to choose the best building orientation and envelope and to conduct daylight analysis. These measures helped save costs by avoiding redesign.

Azhar (2011) also presented different BIM ROIs for several projects, which varied from 140 percent to 39,900 percent. However, these numbers cannot be extended to other projects because BIM was implemented under varying conditions and different use cases. Also, different methods were used to calculate ROI. For instance, ROI was calculated based on cost avoidance from clash detection in some projects, while savings from planning or value analysis were considered in others. Moreover, none took into consideration the indirect cost savings.

In another study, Barlish and Sullivan (2012) proposed a framework to calculate BIM benefits. They used different return metrics, including RFIs, change orders, and duration improvements. Investment Cases included costs for design, A/E, 3D background model creator, construction, and contractor. To build the BIM benefit business case, non-BIM and BIM project metrics were compared in three cases from a company. In case one, returns were calculated based on two non-BIM historical projects and two BIM pilot projects in similar functional areas. In case two, investments were calculated based on a current project utilizing both non-BIM and BIM in the same three functional areas. In case three, both returns and investments were investigated in only one functional area, based on two historical non-BIM and BIM projects. This case provides a baseline for both investments and returns. According to the findings, in the first case, there was a 42 percent decrease in standard costs due to reduced change orders. In the second case, there was a 5 percent saving in contractor costs. In the third case, there was a 29 percent increase in A/E costs, a 47 percent increase in 3D model creator costs, and a 6 percent decrease in construction and contractor costs. When totaled in dollar value, there was 1 percent savings in design and construction costs.

Giel and Issa (2013) studied three case studies on three sets of similar projects, each one including one recently constructed BIM-assisted project and one earlier, similar project that did not implement BIM. They used several return metrics, such as schedule changes, RFIs, and change orders. The first case study compared two small commercial warehouse projects that used tilt-up wall construction. The second case study comprised two assisted-living facility projects, and the third case study focused on two large mid-rise commercial condominium projects. The BIM ROI calculated in these case studies varied between 16 percent and 1,654 percent. The main reason behind this wide range of ROI was the different levels of BIM implementation on these projects.

Lee et al. (2012) present the D³ project in Seoul, South Korea, as a case study, which included six mid- and high-rise buildings. They calculated BIM ROI based on prevented costs of rework caused by design errors and discrepancies. To analyze the impact of design errors, the direct costs caused by each design error were estimated. Afterward, ROI was calculated based on savings from reduced direct costs and indirect costs, which was considered as 11.4 percent of direct costs. Using a probabilistic approach, the BIM ROI was calculated to be from 22 percent to 29 percent.

According to the results, the BIM ROI increases if the impact of design errors on the schedule intensifies. For instance, if a one-week schedule delay (caused by rework) is prevented, the overall ROI is 172 percent to 247 percent. Similarly, if a monthly delay is prevented, the overall ROI is 624 percent to 699 percent.

Lee and Lee (2020) propose a framework for BIM ROI calculation. Their proposed framework comprises three phases, including assessment planning, primary BIM ROI calculation based on prevented rework, and integrated BIM ROI calculation. The first phase, assessment planning, aims to assess project location, construction type, and duration of BIM application as well as identify BIM uses and their impact on the project. During the second phase, primary BIM ROI is calculated based on preventing rework. This phase implements the method presented in Lee et al. (2012) and makes it more accurate by categorizing the error detection probability into three levels: Level 1 is 25 percent or below, Level 2 is between 25 percent and 75 percent, and Level 3 is 75 percent or above. In the third phase, integrated BIM ROI is calculated. Quantifiable BIM impacts are identified first, then the weighting value of the impacts is estimated through the analytic hierarchy process (AHP) questionnaire. AHP is a decision-making tool that breaks down a problem into smaller issues and prioritizes those issues based on expert knowledge. Afterward, the identified economic impacts are monetized, considering the weighted value. Finally, the integrated BIM ROI is calculated by dividing net profit by investment costs. Their framework was utilized to calculate the BIM ROI for a case study, a public sports facility in South Korea, in which BIM was implemented only in the construction phase. According to the findings, primary BIM ROI was 168 percent and the integrated BIM ROI was 477 percent.

Stowe et al. (2015) conducted 51 workshops with BIM user participants in eight countries: the United States, Canada, the United Kingdom (UK), Australia, Singapore, Malaysia, the Philippines, and Sweden. The participants included project teams, companies, and agencies that use BIM on their projects. The main objective of the workshops was to help project teams identify economic impacts of implementing BIM on their projects and assess BIM ROI. During the workshops, participants estimated BIM ROI of their projects using actual project case study data. They took five steps to measure BIM ROI. First, the waste in their workflow (without using BIM) was identified. Second, teamwork and collaboration benefits were analyzed. Afterward, they assessed how the monetary benefits would be divided among the stakeholders. Then the benefits were prioritized and the calculation process was modified. Finally, the ROI was calculated. According to the results, the more a company leverages BIM on projects, the higher the BIM ROI, which can create cost savings of up to 10 percent.

2.4 Measuring BIM Adoption in Organization and Projects

There have been several efforts to quantitatively evaluate the degree of BIM adoption at various levels within the industry. These efforts include assessment matrices for organizations, projects, teams, and individuals. This section outlines several important assessment approaches for organizations and projects. These have been analyzed for consideration within the ROI framework. This evaluation focuses on assessment tools that have been highly rated in previous research efforts, along with tools that may be particularly helpful in measuring BIM adoption for ROI calculations. Team and individual levels are not specifically addressed in this section.

Organizational Level

Several valuable efforts have been made to measure the level of BIM adoption within an organization. In this section, the following organizational BIM maturity tools are introduced:

- BIM Excellence Online Platform (BIMe OP) by ChangeAgents AEC.
- BIM Compass by BIM Supporters.
- BIM Compass developed by Constructing Excellence, hosted by the Scottish Futures Trust (SFT).

- BIM Online Maturity Assessment by the National Federation of Builders (NFB) and Construction Industry Training Board (CITB).
- Construction Project Information Xchange (CPIx) BIM Assessment Form by the Construction Project Information (CPI) Committee.
- Maturity Matrix: Self-Assessment Questionnaire by Project 13, Institution of Civil Engineers.
- National Building Information Modeling Standard (NBIMS) Capability Maturity Model (CMM) by the National Institute of Building Sciences (NIBS).
- Organizational BIM Assessment by Pennsylvania State University.
- Supply Chain BIM Capability Assessment by Wates.
- Vico BIM Scorecard by Vico Software (now part of Trimble).
- Slimgim-T CMM.

BIMe OP

BIMe OP is used to assess the BIM maturity of organizations. This tool contains 57 competency items within eight categories: managerial, administration, functional, operation, technical, implementation, supportive, research and development. While this assessment approach contains valuable items, it is not openly published, and it is used for consulting service delivery for clients of Change Agents AEC (Succar et al. 2013). Therefore, the research team did not consider this assessment tool for use in evaluating adoption within the ROI framework.

BIM Compass by BIM Supporters

The BIM Compass developed by BIM Supporters is an online questionnaire used to assess BIM capacities and compare industry benchmarks. It is intended to assess organizations over four chapters, including organization and management; mentality and culture; information structure and information flow; and tools and applications. In addition, there are 10 "aspects": company culture, employee education, employee mentality, internal information flow, organization, partners, resources, strategy, use and application of open standards, and use of tools (BIM Supporters n.d.). Organization capability is the focus for most of these assessment areas and items. The BIM Compass is often used along with the BIM Execution Plan (BEP) Generator, a tool that assists with creating a BEP (Kassem and Li 2020).

BIM Compass by Constructing Excellence

The BIM Compass developed by Constructing Excellence and hosted by the SFT assesses BIM compliance and adoption in eight capacity areas across five unlabeled but progressive levels (Sebastian and van Berlo 2010).

BIM Online Maturity Assessment

BIM Online Maturity Assessment, developed by NFB and CITB, measures the maturity of an organization around collaborative work and BIM, and it provides an action plan for the organization to progress. The assessment focuses on an organization's level of BIM awareness and the competencies and knowledge of people and processes, systems, and technology to support collaborative work with BIM (CITB 2016).

CPIx BIM Assessment Form

CPIx BIM Assessment Form, developed by CPI Committee, is a self-assessment tool that offers a meaningful approach for company BIM representatives to assess the BIM competence and maturity of a project member. The form is structured in two stages: The first stage is to ask "BIM Gateway Questions" focusing on what the company does with BIM, such as training, qualifications, compliance with British Standard BS 1192, etc. The second stage involves "12 Areas of BIM," requiring respondents to describe their understanding of model uses and provide evidence (CPI Committee 2011).

Maturity Matrix: Self-Assessment Questionnaire

Maturity Matrix: Self-Assessment Questionnaire was developed by Project 13, Institution of Civil Engineers. It is an online self-assessment questionnaire that assesses five areas, including governance, organization, integration, digital transformation, and capable owner. The self-assessment enables infrastructure project and program partners to know the collaborative maturity (Institution of Civil Engineers 2018).

NBIMS CMM

The U.S. National BIM Standard (NBIMS) includes a CMM (NIBS 2015). This model was developed to measure a "minimum BIM" score for a project, but it is important to note that the elements within the CMM focus on organization-level implementation items. This tool includes 11 assessment categories: data richness, lifecycle views, change management, roles or disciplines, business process, timeliness of response, delivery method, graphical information, spatial capability, information accuracy, and interoperability or IFC support. The tool contains quantitative values to weight the ratings for each of the categories. While this tool can provide insights into project implementation, it does not directly relate to the ROI approach being developed in this research.

Organizational BIM Assessment

Organizational BIM Assessment is a CMM developed by Pennsylvania State University to measure the level of BIM adoption and readiness in an organization (Messner et al. 2012). It includes six categories: strategy, BIM uses, process, information, infrastructure, and personnel. A user rates each item on a 0–5 scale (0 = nonexistent, 1 = initial, 2 = managed, 3 = defined, 4 = quantitatively managed, and 5 = optimizing), as shown in Figure 2-5. Kassem and Li (2020) noted in their review that the level of detail is sufficient for an organization to be able to select a consistent score with different assessors. This relatively brief assessment tool could allow an organization to measure adoption within the ROI framework, although the tool would need to be modified for use within the transportation sector.

Supply Chain BIM Capability Assessment

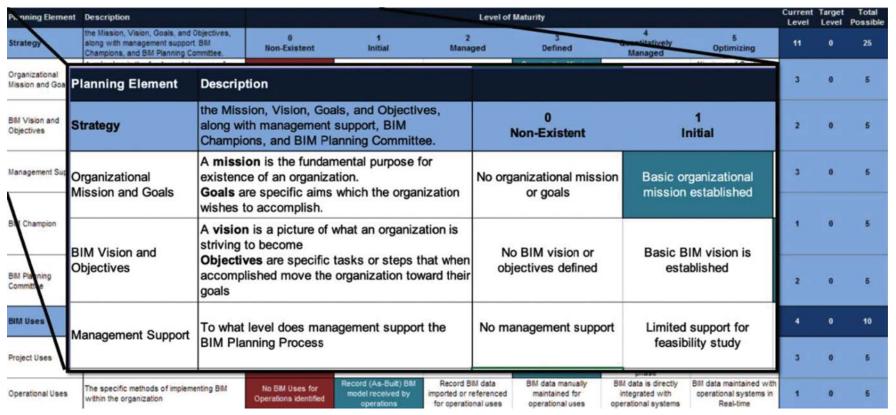
Supply Chain BIM Capability Assessment was developed by Wates to assess organizations wanting to become a member of its supply chain for BIM projects (Wates n.d.). As this assessment tool is not typically used in the infrastructure sector, the research team did not use this approach for the ROI analysis.

Vico BIM Scorecard

Vico BIM Scorecard, developed by Vico Software, is an online survey designed to determine how many BIM capacities organizations are using in daily operations, with a focus on general contractors (Vico 2019).

Slimgim-T CMM

The Slimgim-T CMM was developed to assess GIS maturity capability. The standard framework offered by the Slimgim-T Maturity Model allows for comparing and evaluating best practices identified from the GIS literature. The Slimgim-T model was created to allow a transportation agency to review each category and complete the maturity matrix. Users completed their assessment by using a spreadsheet. There are five assessment areas within the Slimgim-T model: 1) organizational structure and leadership (Figure 2-6), 2) corporate culture, 3) organizational capability, 4) enterprise GIS sustainability, and 5) foundational data and technologies, with each category containing between four and eight specific factors that an organization rates



Source: Adapted from Messner et al. 2019.

Figure 2-5. Capability maturity model.

Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management

al Structure and Leadership	Maturity	Likelihood
ger or coordinator		962
on has a permanent Enterprise GIS management function and position.	0	0
oritative		
s been recognized as a critical component of business systems and should work seamlessly	0	0
siness systems and the software.	-	0.75
S governance		
vernance is established which may include committee structures, user groups and working		
structure is in place to coordinate long range planning, stakeholder satisfaction and ability to	0	0
are in place in some organized manner.		
ce allocation		
as in place policies, procedures, and sufficient resource allocation to maintain GIS related	0	0
2	XXXX	1000
& comprehensive use		
s committed to EGIS and fostering the participation of users in EGIS activities. They have	-	
ster awareness of the benefits and encourage innovation. Strategic plans are in place that	0	0
ensive use of spatial data. Enterprise planning processes align with EGIS strategic goals		
rtment cooperation		
placed on integration and coordination of inter-departmental activities. There are processes		
s in place for inter-departmental conflict management and to prevent duplicative efforts.	0	0
The place for inter-apparational continue management and to provent adplicative choice.		
align with enterprise vision		
ng undertaken work seamlessly within the enterprise framework and aim to help the agency work	0	0
re efficiently.	2000	LNDC
of GIS by senior management	12	
nent recognizes EGIS as a strategic technology.	0	0
	cognizes EGIS as a strategic technology.	2015 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1 N P 1

Source: http://www.slimgim.info.

Figure 2-6. Sample of one category within the Slimgim-T CMM.

on a maturity level from a score of one (ad hoc) to five (optimized). The assessment also includes a rating for the likelihood of the agency improving the factor, with a rating scale from one (extremely unlikely) to five (extremely likely). The overall ratings can be used by an agency to inform the development of a plan for increasing GIS adoption (Abrams 2018).

In summary, after reviewing the 11 organizational assessment tools and performing a detailed review of the comparative report from Kassem and Li (2020), development of a modified Organizational BIM Assessment tool for transportation organizations may be the most appropriate tool for measuring BIM adoption within a transportation agency. There are aspects of other assessment tools that could be considered if modifications are made to the assessment tool. The Organizational BIM Assessment tool was developed and released under a Creative Commons license that would allow for modifications to be made and freely distributed.

Project Level

In addition to measuring adoption at an organizational level, several assessment approaches have been adopted for quantifying the level of BIM integration at a project level (Kassem and Li 2020). The following six project BIM maturity tools were evaluated:

- 1. BIMe OP by ChangeAgents AEC. (An explanation of BIMe OP can be found in the previous section.)
- 2. BIM Maturity Assessment Tool (BMAT) by the University of Cambridge.

- 3. BIM Maturity Measure by Arup/Institution of Civil Engineers.
- 4. BIM Working Group BMAT by the Public Sector Working Group.
- 5. Dstl BIM Maturity Measurement Tool by Dstl.
- 6. Virtual Design and Construction (VDC) Scorecard by the Center for Integrated Facility Engineering (CIFE), Stanford University.

BMAT

BMAT was developed by the University of Cambridge. The tool measures BIM development maturity and supporting processes and offers separate assessment for different stakeholders; it is intended for tracking the evolution of the BIM maturity construction phase to handover (Institute for Manufacturing 2023). The tool is not mainly focused on infrastructure, so the research team did not cover much of this assessment tool in this BIM ROI framework.

BIM Maturity Measure

BIM Maturity Measure, by Arup, can be used to assess the BIM maturity of projects within different disciplines. This tool is intended to assess a wide range of projects and highlight good practices and areas for improvement (Arup 2012). Of all the tools evaluated, this tool is most consistent with the desired measurement while also being publicly available and published. The tool would need to be customized for transportation projects if it is used to evaluate the level of BIM adoption on a road/bridge project.

BIM Working Group BMAT

BIM Working Group BMAT, by the Public Sector Working Group, assesses BIM procurement/ employer engagement; BIM delivery; data verification and validation; collaborative working; visualization/stakeholder engagement; discipline-based model authoring; construction; and model-based estimating and change management (Kassem and Li 2020). This assessment tool is not available publicly, so the research team did not use this tool in this ROI framework.

Dstl BIM Maturity Measurement Tool

Dstl BIM Maturity Measurement Tool is amended from the U.S. government's BMAT tool and follows the same method of assessment. It uses a questionnaire to ask project teams about the same eight areas assessed by the BIM Working Group BMAT assessment tool (Wu et al. 2017).

VDC Scorecard

CIFE of Stanford University developed VDC Scorecard to evaluate the maturity of VDC based on an industry performing rate framework. It measures the degree of VDC performance in four areas: planning, adoption, technology, and performance (Stanford University n.d.). However, the current VDC innovation and its assessment are primarily focused on the building sector, so this assessment approach may not apply to the BIM ROI analysis for infrastructure.

2.5 BIM Adoption in Published Case Studies

Case studies in previous literature that implemented BIM were identified, including both domestic and international cases. This section presents a review of select case studies with BIM adoption from previous publications. It is important to note that there are many case studies that include BIM for various use cases; this section does not aim to be comprehensive in the identification of case studies, but instead to provide a representative sampling of interesting projects.

Domestic

In the United States, stakeholders seek ways to merge BIM into their workflows, from complex megaprojects to standard roadway work.

The Wisconsin Department of Transportation (WisDOT) used design and construction BIM models to reduce costs, compress schedules, improve plans quality, and streamline collaborative workflows for its Southeast Freeways projects. This approach was applied as a pilot in 2011–2012 to construct the \$162.5 million Mitchell Interchange, and then fully throughout the project during 2012–2018 to design and construct the \$1.7 billion Zoo Interchange. On the Mitchell project, BIM modeling was done pre-construction award primarily for visualization and visual clash detection. WisDOT identified a percentage of potential cost reductions through comparison of the developed 3D model and traditional 2D plans during construction and 3D modeling results where a majority of cost gains were found in roadway/drainage and general structure components and not earthwork and excavation alone.

The success of this pilot led WisDOT to use BIM on a majority of Southeast Freeways megaprojects and major projects, as well as smaller projects less than \$100 million. On the Zoo Interchange project, the team was able to start earlier and create a robust multidisciplinary BIM model, including all major disciplines used for design-construction review, clash detection, constructability staged models, 4D simulations, contractor bidding, AMG, e-construction, and reuse of BIM models available for as-builts. The Zoo Interchange project only had a change order value of 3.43 percent, which yielded an estimated cost savings of \$28.2 million, whereas similar projects using traditional non-BIM construction typically have change order percentages greater than 7 percent, such as Marquette Interchange at 7.09 percent and I-94 North–South/Mitchell Interchange at 7.20 percent (Parve 2013; Parve 2020).

Massachusetts Department of Transportation applied BIM innovation on the Fore River Bridge Replacement in Quincy. The design calls for a vertical-lift bridge with towers that are nearly 300 feet high. BIM technology allowed for real-time feedback of mechanical, electrical, and plumbing (MEP) replacement; streamlined the process; and helped speed up the process internally (McGraw-Hill Construction 2012).

While large, complex roadway projects potentially benefit more from BIM use, some firms adopt BIM on small projects. Clark Nexsen used 3D modeling on two intersection projects for the City of Chesapeake, with combined design and engineering fees of less than \$100,000 (McGraw-Hill Construction 2012). The team first modeled the roadway and performed stormwater design analysis based on the engineering model. Modeling the project improved visualization of what needed to be built, enabled faster design reviews, enhanced coordination, ensured better constructability, and increased collaboration.

A case study by Fanning et al. (2015) compares two bridge construction projects under Kiewit Construction for asset owner Colorado Department of Transportation (CDOT): Fort Lyon Canal Bridge (did not implement BIM) and Pecos Street over I-70 Bridge (implemented BIM). RFIs and change order metrics evaluating cost, area, and traffic information decreased in the ranges of 12–87 percent and 22–89 percent between the two projects. Findings suggest that BIM may have provided cost savings of approximately 5 percent during construction by contributing to reduced change orders and rework. Specifically, the ability to provide accurate and realistic visualizations of the project to the public before the construction phase enabled the level of public engagement and support necessary for success. Performance metrics—including investment construction costs and return indicators of RFI, change orders, and schedule—were used to track the project status and evaluate ROI.

To manage projects better, many airport authorities encourage designers and contractors to collaborate in BIM. Satterfield & Pontikes (S&P) offered project-control services for the

\$1.2 billion Delta Air Lines Redevelopment project at John F. Kennedy International Airport in New York City. To better monitor all contracts and keep stakeholders informed, S&P modeled the project, providing estimate and scheduling analysis and cost controls. The teams were able to conduct visualization, coordination, and constructability reviews, with 4D scheduling capabilities and 5D cost estimates, which allowed the team to better track production (McGraw-Hill Construction 2012). On the \$1.2 billion Green Build project at San Diego International Airport, major contractors on separate contracts worked in harmony through BIM. The BIM use process significantly accelerated the program, trimming costs and keeping more of the airport open for business. The team was able to start foundations at the 30 percent construction documents phase with the assistance of BIM tools (McGraw-Hill Construction 2012).

BIM is of more interest to public entities that own, operate, and maintain dams, canals, and levees. Panama Canal Authority added BIM to the workflow for its ongoing \$6 billion expansion project. The team's primary focus for modeling was the reinforced concrete structures that retain the water, as well as earth dam components. All mechanical systems and electrical controls for the complex were also modeled. BIM models enabled the team to create construction documents and provide rough QTOs for estimating (McGraw-Hill Construction 2012).

Primary design and construction firms explore ways to maximize model use within the design-bid-build (DBB) delivery system on water and wastewater projects. The Okaloosa County Water and Sewer Department in Florida selected CDM Smith to design, construct, and outfit, as well as conduct performance tests and obtain permits for, the new Arbennie Pritchett Water Reclamation Facility, which can process 10 million gallons per day. The team used BIM throughout the project lifecycle, including the delivery of a model for operations and maintenance (O&M). Through a design-build (DB) process, the team used BIM to help compress the design schedule to just over five months, reviewing models with the client throughout. The construction team was provided with an early start-package generated from the model, which consisted of building foundations, plumbing, and electrical underground utilities. This enabled the team to start site work two and a half months before construction documents were complete. The model was used to create bid packages for subcontractors, who also used it in the field to aid in construction and coordination efforts. Upon completion, the model was connected to an electronic O&M system that helps manage data equipment, datasheets, and manuals. It was also used for training staff at the new plant (McGraw-Hill Construction 2012).

International

BIM can also be implemented in road projects, as a road use case in Australia demonstrates (Chong et al. 2016). In this example, BIM was used on a project to upgrade an existing highway. The scope of the project was the expansion of approximately 4.2 kilometers of the highway from four to six lanes; construction of a central median along the length of the upgraded section; upgrading major intersections to allow for wider circles of turning movements; and addition of bus lanes, on-road cycling facilities, and a continuous pedestrian path. The project was completed approximately three months ahead of the target completion date with implementation of BIM.

BIM tools used in this road use case example include Autodesk AutoCAD Civil 3D, Navisworks, and 12D Model and Bentley MXRoad. BIM uses in the pre-construction stage included engineering analysis, QTO, clash detection, transportation management/traffic impact simulation to predict the volume, and saturation on the highway. BIM uses in the construction stage included conducting field survey and quality management. BIM uses in the post-construction stage included road management and geospatial issue tracking.

BIM has been actively used in numerous types of infrastructure projects in China as well. In a 2016 study, Chong et al. (2016) highlighted a project located in Shanghai due to its high profile and media coverage. BIM tools used in this project include Autodesk Revit, Navisworks, Robot Structural, Ecotect Analysis, and Infrastructure Modeler. The new road was constructed for four lanes in each direction. BIM uses in the pre-construction stage included 3D modeling, QTO, and clash detection. BIM uses in the construction stage included tracking on-site construction progress. This was the first infrastructure road project in which BIM was used by the contractors involved. Some BIM uses were not applied, particularly in operation and maintenance following completion and handover of the project data, such as subsequent traffic management.

BIM has also been widely used in transportation projects in Sweden; an example reviewed in the literature is the Slussen project. The project scope was to construct an effective and safe junction for pedestrians, cyclists, and public transport with the capability to accommodate 480,000 travelers per day, including the construction of a steel bridge over Söderström (140 meters long, 45 meters wide). Clients made performance requirements for BIM and VDC innovation on this project, which included coordination and visualization in 3D, review of the design in 3D, procurements with 3D models, simulation of construction schedule, calculating cost estimate, and handover to FM (Foster + Partners 2022).

Another project that was reviewed involved a road improvement for Regional Road 22 (Rv22) in Norway. It was a large transportation route expansion, including a new bridge. BIM was implemented for the early stage of design, and the team was able to use BIM for 3D visualization, which resulted in better collaboration among stakeholders and significant cost savings (Autodesk n.d., accessed 2020).

2.6 Conclusions and Observations

Currently, the AEC industry around the world is attempting to adopt BIM as the future standard for building design, construction, and operation. Drivers of adopting BIM technology include owner requirements, aspiration to be at the forefront of BIM in industry, ability of BIM to streamline design activities, improved efficiency and cost savings, and reduction of disputes prevalent within the construction industry.

Despite many perceived benefits of using BIM technology, several studies have shown that the rate of adoption in the AEC industry still seems to be lower than expected and varies greatly among stakeholders and different phases of a project lifecycle. There are problems and challenges that deter the adoption of BIM in projects. Barriers of BIM adoption in the AEC industry include legal issues, the high cost of BIM software and hardware, the high cost of training on BIM tools, lack of skilled personnel, lack of skills and knowledge for company staff, resistance to change, lack of demand from owners, lack of awareness about BIM benefits, lack of expertise, current shortage of BIM applications, and lack of support from governments. It is important to note that no single barrier is solely responsible for hampering BIM adoption. Instead, the potential for these barriers to be able to impact adoption is project specific (Walasek and Barszcz 2017).

Cost is an important factor taken into consideration when an owner is determining whether to implement BIM tools. ROI analysis is often used to compare the returns from multiple investments. BIM offers the management of information through the whole lifecycle of a built asset; it delivers value by underpinning the creation, collation, and exchange of shared models and corresponding intelligent structured data. Benefits of implementing BIM are summarized in this report, including benefits in asset management by owners (e.g., cost savings, staff time savings, and ancillary organizational benefits), benefits for end users, and benefits in project delivery (e.g., project cost savings and ancillary project benefits). The investment to adopt BIM is also analyzed, including investment in organizational and asset management and investment in project delivery. The return on adopting BIM tools is also summarized from literature on both the organizational and project levels.

Walasek and Barszcz (2017) found that design fees will most likely increase for companies working with BIM, as a result of the greater workload occurring during the earlier phases of a project designed using collaborative tools. The owner can potentially gain the most from deciding to implement BIM in a project, and therefore, should be encouraged to implement it. In many countries, local governments are committing to BIM by requiring that all new public projects be completed using BIM at a specific level.

Giel and Issa (2013) recommend improvements for better benchmark BIM-assisted projects, including keeping accurate VDC RFI logs that document problems discovered with the assistance of BIM and tracking the corresponding resolution of those problems and their costs. According to Giel et al. (2009), a greater ROI was achieved on the larger and more complex construction projects, while the smaller projects benefit greatly from BIM implementation but had lower direct savings. Therefore, it is suggested that when deciding to invest in BIM, owners should consider the size and scope of their projects.



Case Studies and BIM Expert Validation Panel

3.1 Overview

To achieve the objective of this research project, researchers were interested in using case studies to explore the economic impact of implementing BIM within an organization to deliver and maintain projects. Therefore, the unit of analysis for a case study selected for this effort was an individual project. However, to understand each case study project, it was also necessary to investigate the organization to gain insights into the longer-term costs and benefits associated with BIM implementation. A total of five projects were selected for investigation. To help normalize data for the ROI calculator, the research team selected four domestic projects and one international project.

Several selection criteria and characteristics were identified for evaluating potential case study projects and organizations. These criteria were developed to provide a diverse set of case studies that cover a breadth of BIM use cases. The criteria identified for consideration include the level of BIM adoption, data availability, ability to share case study information, geographic location diversification, size, complexity, and project delivery method.

Selected Case Studies

- Case Study 1: New York State Department of Transportation—Kew Gardens Interchange Program.
- Case Study 2: Utah Department of Transportation—Digital Delivery Experience (multiple projects).
- Case Study 3: Colorado Department of Transportation—I-70G Edwards Spur.
- Case Study 4: Denver International Airport—Hotel and Transit Center Program.
- Case Study 5: Highways England—A556 Dual Carriageway.

The researchers also worked with a group of BIM subject matter experts to validate the data collected during the case studies.

3.2 Case Study 1: New York State Department of Transportation—Kew Gardens Interchange Program

Introduction

The NYSDOT BIM journey dates to late 2009 when the agency began promoting the use of digital design data for layout, AMG operations, and global positioning systems (GPS) equipment for construction inspection (New York State Department of Transportation, n.d.). Since then, NYSDOT has launched several initiatives to advance the use of BIM, including but not limited to

- Programmatic upgrades of construction surveying equipment (e.g., GPS, robotic total stations, and digital levels);
- Training courses for design staff to create 3D-EM for construction;
- · Collaboration events with industry, peer agencies, and FHWA; and
- Pilot projects to evaluate different BIM use cases (e.g., 3D, 4D, and 5D models and digital as-builts).

Early pilot projects focused on creating accurate geometric models of roadways, utilities and drainage, and 3D solids for some bridge elements. The intended uses of the 3D models (BIM use cases) for these early pilots were to help construction activities with automation tools for stakeout, AMG, inspection verification, and quantity measurements. Later pilot projects tested the capture of 3D digital as-built models in real time that could be exported to GIS. In 2014, NYSDOT piloted the use of 4D models on the Kosciuszko Bridge, or K-Bridge, the first DB contract with BIM requirements. The Kew Gardens Interchange (KGI) improvement was the next large, complex project with BIM requirements, and it is the focus of this case study.

The next generation of pilot projects for NYSDOT to advance the use of BIM is model-based delivery, in which the 3D model becomes the legal contract document. The first-ever NYSDOT project in which the 3D model has been issued as the contract document is the Route 28 bridge over the Esopus Creek, which was awarded in Spring 2020 and is now under construction. The agency is currently documenting lessons learned on that project. A second project with a model as the legal contract document was planned for Spring 2021.

Case Study Overview

NYSDOT has funded several operational improvements for the KGI, which is a complex intersection connecting the Grand Central Parkway, Van Wyck Expressway, Jackie Robinson Parkway, and Union Turnpike. The KGI serves the region by carrying almost 600,000 vehicles daily. Improvements to the KGI have been broken down into a total of four phases, three of which have been completed and one of which is under construction. Each of the phases was advertised under a separate contract.

- Phase 1. The scope of work was to widen the Van Wyck Expressway in the southern portion of the interchange. The work included reconstruction of five bridges and rehabilitation of two bridges, as well as the relocation of two subway entrances. This \$152 million contract was advertised as a DBB project. There were no BIM requirements for Phase 1.
- Phase 2. This \$106 million DBB contract was for the improvement of the northern portion of the interchange; the scope of work was similar to Phase 1. This project was the first contract that included BIM requirements.
- Phase 3. This \$105 million DBB contract was for overall improvement of the southbound viaduct, and it expanded the BIM requirements.
- Phase 4. This \$365 million DB contract is the largest and most complex of all of the Kew Gardens improvements. Improvements for this project address operational and geometric deficiencies in the project area, including elimination of three existing stop conditions and improving non-standard lane and shoulder widths, stopping sight distance, and acceleration/ deceleration lane length. The scope of work also includes replacement of several structures, including 11 new bridges; realignment of several roadways, including creation of 20 new alignments; drainage improvements; installation of lighting systems; intelligent transportation system upgrades; extensive relocation of utilities; and landscaping work. Additionally, the project includes improving pedestrian access with the addition of an ADA-compliant shared use path. Operationally, the reconstruction included in this contract is expected to improve traffic flow between connections within the interchange and reduce congestion on upstream segments of roadway.

BIM Requirements Overview

Phase 1 and Phase 2

The first two phases of the project did not initially have any BIM requirements. However, during Phase 2 a 4D model requirement was added after a construction contract was awarded.

Phase 3

The BIM requirements for KGI Phase 3 included the delivery of a 3D model from the design as supplemental information. For the contractor, the contract required the development and maintenance of 4D and 5D animation models during the construction phase to compare the planned and completed work against a critical path method schedule. There was also a separate requirement to deliver an as-built 3D computer-aided design and drafting (CADD) record model.

To capture asset information, a GIS dataset for major asset classification—including bridges and bridge spans, abutments, pavement, overhead signs, noise barriers, retaining walls, guide rail and bridge rail, and large and small culverts—was created. This GIS model included data attributes tracked by NYSDOT in asset management databases.

Phase 4

The project team used BIM as part of the design process and to meet specific contract requirements. These BIM requirements are very similar to those requested in previous phases of the improvement and include the development, utilization, and maintenance of 3D CADD files to produce contract plans as well as 4D and 5D animation models.

In Phase 3 and Phase 4, requirements include level of development (LOD) specifications as shown in Table 3-1.

The requirements do not specify intended use cases for these models. The contract also requires the delivery of a combination of traditional as-builts (i.e., marked up plan sheets) and digital as-builts at the end of the project.

BIM Uses

Phase 2

A 4D model was used to determine locations for crane placement and sequencing of construction activities, as well as a constructability review. The constructability review resulted in modifications to the design prior to the start of the project.

Phase 3

A 3D model was used for communicating design intent and served as the basis for the 4D model. The 4D model was used as a project management tool to understand the construction sequence of activities and schedule progress. The project management team held model management meetings on a quarterly basis. During these meetings, the team would compare the baseline and actual schedules and discuss courses of action. The 4D model was crucial for communication, coordination, and risk management review during construction. It is important to note that the contractor performing the work had experience with BIM. A 5D model (a 4D model tied to a loaded schedule) was also used to manage resources and determine payments.

Phase 4

While intended uses for the BIM deliverables are not specified in the requirements, the 3D models were highly beneficial to the design team, mostly for conflict analysis during design

Table 3-1. NYSDOT Kew Gardens LOD specifications.

LOD	Model Content Requirements	Authorized Uses
100	Overall massing indicative of height, volume, location, and orientation. Massing will be 3D and may include other data.	Limited analysis, aggregate preliminary cost estimating, conceptual level scheduling and staging.
200	Elements are modeled as generalized assemblies or systems with approximate quantities, sizes, shapes, locations, and orientations. Attributes may be linked to model elements.	Preliminary analysis, accurate for cost estimating and scheduling.
300	Elements are modeled as specific assemblies and are accurate in quantity, size, shape, location, and orientation. Attributes may be linked to model elements as required by the engineer.	Construction documents, detailed QTOs, analysis and project management and controls.
400	Requirements per LOD 300, plus complete fabrication, assembly, and detailing information.	Model-based fabrication, actual cost-tracking look-aheads and virtual mock-ups.
500	Elements are modeled as constructed or as-built, field-verified accurate assemblies, quantities, dimensions, shapes, locations, and orientations. Major transportation asset class attributes are linked to modeled elements as required by the engineer.	Maintenance and operations asset management applications and future planning.

development. The design team developed 3D models for roadway and bridge structures. The model was developed as part of the requirements for submitting a bid. The 3D model prepared as part of the proposal was leveraged by the project team as part of the final design.

The project team used the 3D model specifically for

- Communicating design intent to the contractor;
- Analyzing potential conflicts with substructure elements, such as foundations and piles;
- Identifying staging conflicts and analyzing complicated geometry (e.g., gore areas);
- Determining vertical and horizontal clearances as well as providing bridge deck elevations values at the 10th point along the beam and grading elevations;
- Estimating earthwork quantities and analyzing significant areas of earthwork cut/fill;
- Coordinating with other disciplines (e.g., drainage, structures, roadway) to inform their designs;
- · Optimizing lighting design and placement; and
- Producing 4D simulations to communicate project status to the owner.

Benefits and Costs

Researchers interviewed agency representatives and the design team separately. The following section is a summary of the identified benefits and costs.

Benefits

- Time savings from improved design efficiency. Incorporating 3D modeling into the highway design workflow allowed corridor designs to be optimized. Multidisciplinary collaboration and 3D coordination enabled the team to check potential issues and manage risk. The 3D models allowed reviewers to visualize the design and check not only the corridor design but also the corridor's interaction with other nearby corridors, structures, and so on. Some of the specific tasks included reviewing complex geometry within the project. A 3D representation of the design allowed for a full 360-view and interaction with the design and other existing or proposed elements. The 3D model was also used to verify elevations for vertical clearances and structure deck elevations as well as check contours for drainage, among other uses. Roadway modeling was integral in evaluating potential alternatives during the design. The team was able to model a few alternatives for multiple notice-of-design changes to provide the contractor with a full picture of potential design, cost, staging, and quantity impacts, which expedited the decision-making process for approving and issuing design changes. The project team was able to adjust the schedule of activities after identifying potential work conflicts. The most notable benefit was identifying an alternate construction option for building the viaduct. The project team determined the viaduct could be built in one piece instead of two.
- Time savings on completing design quantities. Using model-based design not only saved significant time but also dramatically increased quantity accuracy. It took about three days to compile and check the earthwork quantities from over 20 roadway corridors at each milestone. Without BIM, the team would have used representative cross sections to quantify cut and fill for each corridor. For a project of this magnitude and complexity, with numerous overlapping alignments and intersections, the cross-section method would have likely taken two weeks, with a significant margin of error.
- Time savings from reusing previous BIM content for future similar work. The team used the NYSDOT standard template library for corridor modeling as well as additional content developed by the consultant during the proposal phase. Between these two resources, the team already had 80 percent of the 3D roadway content developed. The NYSDOT template library aided in copying unique design objects, such as barrier, curb, and grading. The team estimated that with these templates, updates took between 4 to 6 hours per corridor. If the designs had been started from scratch, the level of effort would have doubled (i.e., 8 to 12 hours per corridor). With 20 corridors to update on the project, this translated to approximately 80 to 120 hours saved due to the use of standard 3D roadway modeling content.
- Cost savings from avoided change orders. The 3D model enabled the team to catch up to 11 conflicts in design, which allowed for mitigation prior to releasing plans for construction. This process also allowed the team to document design elements, such as temporary vertical clearances, to check calculations while responding to the contractor's RFIs or noncompliance reports.

Costs

- Staff training. Informal trainings were provided by agency staff. It was estimated that three team members received approximately 40 to 60 hours of training on how to model corridors. This training was provided by more experienced peers in the agency.
- **BIM requirements.** The cost of maintaining the 3D, 4D, and 5D models and the cost of delivering a 3D as-built during Phase 3 was approximately \$500,000, which translates to about 0.50 percent of the entire construction contract value.

Challenges and Lessons Learned

The following is a list of the top three challenges identified by the owner.

• **Institutional communication in a large organization.** NYSDOT is a large organization, and many different activities are simultaneously conducted by various departments. Communication is often siloed, making it difficult to coordinate activities.

- Change management and institutional inertia. There is always some resistance to change; it takes a long time to initiate change and move initiatives forward.
- Industry buy-in. It can be difficult getting the contracting community to adopt BIM, depending on location. Because there is more open land in upstate New York, contractors in that part of the state have invested in AMG equipment for earthwork activities. However, it is difficult for contractors to use AMG in New York City because the projects do not lend themselves to this type of technology.

The following list includes some of the lessons learned by designers.

- Standardization of BIM tools saves time. When the owner has a standard library for developing 3D content, it prevents design teams from having to make manual adjustments to 3D surfaces in the design software.
- Developing 3D models for all non-roadway features (drainage, lighting, signage, guide rail, etc.) prior to releasing plans for construction is critical. When 3D models are created after plans have been signed and sealed for construction, it is too late to perform 3D coordination. Interim modeling deadlines may have helped avoid further impacts from issues discovered after plans had been submitted or during construction.
- Structural BIM software lacks the functionality for parametric design. When the software lacks this functionality, it is difficult to use BIM beyond coordination using 3D solids.
- Contractors with less BIM experience affect optimization of benefits. When a contractor is not familiar with all BIM uses and potential benefits, it can be difficult to adopt the technology. Specifically, when the model is not contractually binding, a contractor will defer back to the traditional signed and sealed plans to plan and execute the work.

3.3 Case Study 2: Utah Department of Transportation— **Digital Delivery Experience**

Introduction

Utah Department of Transportation (UDOT) has been a leader in the implementation of BIM, starting the journey to adopting BIM in 2013. UDOT set an agency goal to develop processes and procedures to advertise projects with the model as the legal document. The agency was a leader in 3D-EM for construction in FHWA's Every Day Counts initiative, round two, which started UDOT's efforts to develop detailed 3D engineering models for construction (FHWA 2017). To do so, the agency developed an implementation plan to make models as legal documents for construction.

After exploring BIM efforts at Iowa DOT, UDOT developed a short-term implementation plan to make electronic files available for current projects, collected lessons learned, and initiated a series of workshops. During the initial workshop, the agency brought in approximately 60 to 70 experienced people to gain insight into the risk of not delivering models as legal documents. The following week, UDOT met with a separate group to identify the perceived risks regarding the adoption of hardware and software in the field. This eventually led to the adoption of a digital delivery process with model-based contracts.

UDOT's initial implementation of the model-based contracting approach started with a small project in southern Utah that was relatively straightforward. The agency decided to use a Construction Manager/General Contractor (CMGC) delivery approach to manage the project's primary risk by ensuring high-quality digital model development. UDOT had challenges with the earlier versions of 3D modeling software used to create the contractual models. Even when considering these challenges, due to BIM and the collaborative nature of the contract delivery method, the project duration was shortened by almost 25 percent for the initial pilot project.



Source: HDR.

Figure 3-1. 3D BIM model of I-80 bridge.

After piloting the model-based contracting approach on a small CMGC project, UDOT pursued the process on projects with increasing levels of complexity, including an interstate project. At the same time, the agency performed two DBB projects with the model as the legal document. UDOT has continued to use this model-based delivery strategy over the last five years and expanded the approach for all project types. Currently, UDOT uses mobile devices to access needed information in the field, and no longer develops cut sheets for the projects. The first project performed without cut sheets was 90 South, a landmark for UDOT.

More recently, UDOT received a grant to focus on the development of a detailed GIS approach to collecting, managing, and using asset information for lifecycle asset management. This expansion into the coordination of final asset information will help UDOT improve its information management within the asset management phase.

Overview of Case Study Projects

UDOT has awarded 14 projects using modeling to create the legal document. Five of those were CMGC, and seven have been done using cut sheets. The following three projects were identified by UDOT as examples for review during this case study:

- I-80 auxiliary lanes;
- SR-68, Bangerter Highway to 12600 South; and
- SR-209, 90th South to 7th East.

These case study projects are representative of the scope of work performed by UDOT. One project example is shown in Figure 3-1 and Figure 3-2. UDOT typically performs projects that



Source: HDR.

Figure 3-2. Actual I-80 bridge after construction.

range from approximately \$5 million to \$50 million for DBB delivery. In rare instances, the agency might implement a project approaching \$1 billion using CMGC or DB delivery.

BIM Requirements Overview

As discussed earlier, UDOT defines the design model as the contractual design, thus requiring the construction to be consistent with the design model. Currently, UDOT has digital as-built requirements, but the agency is continuing to develop its ability to leverage information for asset management. Contractors are required to give UDOT an as-built model developed from the original design model, although there are remaining QC concerns regarding model updates. UDOT also has additional electronic submittal requirements, but the quality of these submissions remains inconsistent. UDOT continues to expand its efforts in these areas.

BIM Uses

This section provides information on the primary BIM uses that are frequently adopted or required on UDOT projects.

- Capture existing conditions. UDOT has used lidar (light detection and ranging) for the past 10 years as a tool to collect information on existing conditions for projects. Lidar enables project teams to capture aboveground features and geospatial locations on the site. On many projects, they are also using drone imagery to create photogrammetry models. They expect to get information from design to construction for an existing condition database. In the future, they are expecting to leverage their as-built models to support existing conditions
- **Estimate quantities.** UDOT performs detailed QTOs from the models. Project teams have found the quantities to be accurate, and through collaboration with design and construction professionals, they have also found greater levels of trust in the quantities. They are continuing to develop their use of these quantities in the bidding process.
- **Utilize layout and AMG.** The contractors are leveraging 3D geospatial information for automated equipment guidance. UDOT can provide the contractors with the actual geometry created with the modeling process. The surveyors can extract the information needed from the 3D models and perform QC on the data. These data can then be used for AMG and for general layouts within surveying equipment.
- Coordinate design models. The design models are coordinated to remove any potential field conflicts between various design elements in the model. This can include newly designed assets or existing conditions.

Benefits and Costs

Researchers interviewed agency representatives and the design team separately. The following section is a summary of the identified benefits and costs.

Benefits

- **High-quality design.** One of the identified benefits is the higher quality of the overall design model. There are many elements integrated into the 3D model, including utilities, drainage, and sections grade, and therefore a detailed conflict analysis can be performed to ensure the quality and accuracy of the 3D model. In addition, the model allows for high-quality visualization, which facilitates decision-making.
- Time savings from avoided design rework. By developing the 3D model, potential conflicts can be identified early, during the design phase. This helps avoid the need for more detailed design rework compared to a more traditional process, where conflicts may be identified later.

BIM Use Cases

- · Capture existing conditions.
- Author design model.
- Estimate quantities.
- Layout and AMG.
- Coordinate design models.

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- Cost savings from avoided change orders. With BIM, project teams can identify issues that are typically not found until construction, so they have significantly fewer change orders during the project, specifically regarding clash detection. In the SR-209 (90th South) project, there were very few change orders. Decision-making is easier when everything is transparent and visible in a 3D model. UDOT has also gained more accurate quantities from the BIM process.
- Time savings from improved design efficiency, including parametric design and avoided design rework. In the agency's previous traditional design using CAD, UDOT spent 50 percent of the time on developing the design and 50 percent on sheet production. UDOT now spends far more time on design (which is positive), and less time is spent on drawing production, which leads to fewer reworks. With a more accurate design, UDOT can be more precise in identifying what is needed rather than overestimating and purchasing more than is needed, which translates to direct dollar value.
- Time savings during construction inspections from utilizing 3D digital design data. When everyone uses BIM with proper training, information is centralized and more easily accessed through digital retrieval on mobile devices. It can be easier to track certain information, turn on and off certain features in GIS or BIM, and navigate by using the software. BIM makes it easier to edit designs in the field (i.e., while looking at the project). It is easier to track up-to-date locations in the plans using local GPS when workers are in the field, and it saves time to see information on one screen instead of looking through plan sheets.
- Time savings on completing design quantities. The amount of time required to develop QTOs for the projects has been reduced. In addition to model-based take-offs, rovers are sometimes used to collect actual field data for quantity analysis. Whenever there is a quantity dispute, pulling data from GPS aids in timely resolution.
- Improved worker safety during maintenance and operations inspections. UDOT representatives believe this is a likely benefit, but they do not know how to quantify it. Even though maintenance crews have been using drones for inspection, they do not have quantitative data to demonstrate safety improvements. However, the use of drones allows for additional inspections.
- Time savings for agency staff from not having to track down as-built information for scoping projects. UDOT saves staff time on project scoping by using UPlan, a web mapping application in which asset data are stored and available for anyone to access (including the public). UPlan contains information about the state's transportation plans for construction improvements, pavement management, safety and crash analysis, bridge locations, bike lanes and routes, and more. Some project teams use UPlan to access information and view an asset with the layers of data selected, which helps with clash detection. UDOT aims to transition the database from static to real time for asset maintenance. UPlan is not mandated to be used for all projects, so at first only a few regions used it. As project teams have started observing how UPlan makes looking up data much easier, more regions have started using it.
- Cost savings from avoided change orders. UDOT has seen fewer change orders for design errors and omissions since adopting BIM. Most importantly, BIM has facilitated communication and coordination between different disciplines, which resulted in reduced numbers of change orders. The adoption of BIM also caused a reduction in material overruns, which led to cost savings from the optimization of construction material use.
- Cost savings from improved project schedule/accelerated delivery. UDOT has not noticed accelerated project delivery that was directly due to BIM implementation, but the agency has seen improved design schedules. It is faster to accomplish the tasks with BIM, but project teams frequently invest the time savings into developing more detailed and improved designs. Acceleration of the construction process is more likely in a DB project than in a DBB delivery approach. UDOT is continuing to explore approaches in this area.

Costs

- · Additional spending on IT resources or infrastructure for BIM. UDOT has incurred additional software investment costs, and the agency pays each year for additional digital storage. UDOT has seen some cost savings from reduced paper since adopting BIM, but this reduction was small because the agency had already transitioned to a paperless process before transitioning to BIM. UDOT has not seen any avoided operational costs due to geometric analysis because the agency had been using InRoads and modeling for about 20 years before BIM adoption.
- Cost of initial comprehensive staff training. There is an initial investment of staff time required for training. UDOT has internal training within the GIS department, and sometimes staff perform training with outside contractors. BIM authoring software training led by the software vendors is another incurred cost. Training has been conducted virtually, including two courses for internal training on BIM design: one for primary users and another for advanced users. Each course lasts four workdays, for a total of 32 hours per course. UDOT also provides internal training on how to use GIS tools when a project starts. UDOT also maintains a website with suggestions for digital delivery. UDOT has contractors train inspectors in the field.

Challenges and Lessons Learned

The top challenges identified by UDOT and project teams were staff training and learning curves.

- Staff training. Training is a struggle from several different aspects. It is complicated and challenging to train agency staff as software continues to be frequently updated with new features. UDOT aims to train staff when they are not as busy. However, as their programs have expanded, they have had several simultaneous projects, which limits the time available for training. The agency also sometimes places training responsibility on a contractor. For example, UDOT uses GPS equipment for inspection tasks, and contractors are required to offer 50 hours of training to the field crews on use of the equipment.
- Learning curves. Sometimes there is an issue with a contractor's learning curve and desire to revise existing methods. There is a higher upfront time investment required when learning how to use new processes and tools.

The following list includes some of the lessons learned that were shared by UDOT and project teams.

- Continuously requiring new human tasks can be limiting. UDOT is interested in leveraging new technologies, such as machine learning, to aid in improving the agency's process using an automated approach.
- Not enough time for clash detection. With fast design schedules, it can be difficult for project management staff to allot the time needed to effectively coordinate the design.
- Not enough confidence with using BIM. There is still a challenge with some designers not trusting the modeling software, which can reduce efficiency in modeling.

3.4 Case Study 3: Colorado Department of Transportation—I-70G Edwards Spur

Introduction

CDOT has been using 3D model-based design for roadways for a long time, and the agency is moving toward inclusion of 3D models from other disciplines, such as drainage and dry utilities. So far, CDOT has not officially implemented a BIM program. This is mainly due to 44 Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management

a lack of awareness on the multiple benefits of BIM. CDOT's construction program typically includes maintenance-type projects, such as resurfacing and pavement repairs and bridge rehabilitation.

However, CDOT is in the process of implementing its collection of digital as-builts, a BIM-specific use case, as part of FHWA's Every Day Counts initiative, round six. Digital as-builts are considered living records that are updated during construction to support effective lifecycle asset and performance management. Specifically, one of CDOT's main motivations to implement digital as-builts is to mitigate utility strikes during construction. The CDOT digital as-built program is thus a prevention management strategy to improve safety and save costs associated with such incidents.

The department is in the process of building a statewide digital as-built database in which subsurface utility records will be hosted to make the data available to project teams in the future. CDOT anticipates that the initiative to establish, populate, and create a data management plan for digital as-builts will take approximately five years. It is CDOT's desire to incorporate data from design and construction, including permitting and existing CAD and legacy utility information. CDOT's vision for a mature subsurface utility system of record is to use the information to verify or supplement field surveys.

Case Study Overview

CDOT has funded several projects within the I-70 corridor to improve many intersections, as this is a critical corridor within the interstate system. It is a tourist travelway with many connectors and great importance to the community. The I-70G Edwards Spur Road Improvement, Phase II, is one of many I-70 corridor improvements. An atypical project for CDOT, Phase II of the I-70G Edwards Spur Road Improvement leveraged BIM for design, construction, and record modeling. This \$21 million project was funded for improvements to the intersection of I-70G Spur Road and U.S. Highway 6, which included converting a signalized intersection to a two-lane roundabout; replacing one bridge and widening another; and installing pedestrian bridges, a drainage network system, lighting, signage, striping, and guardrail. The scope also included roadway widening, along with utility upgrades and relocation. The project was delivered through a CMGC delivery contract. The construction phase was completed in October 2020, approximately two years after initial groundbreaking. This project has recently been awarded the Colorado Department of Transportation Best Environmental Project.

BIM Requirements Overview

CDOT does not currently have any agencywide BIM requirements that are adopted on every project. The design team used the 3D-design capabilities of the software to create corridors, surfaces, and solids of infrastructure objects to perform clash detection and prepare traditional 2D plan sets. CDOT is investigating the development of a set of core BIM requirements. To date, CDOT has invested in the development of a subsurface utility and drainage analysis library, containing standards for 3D objects for drainage and utilities, to be used in future projects.

BIM Use Cases

- Author design model.
- Analyze engineering performance.
- Coordinate design models.
- Author 4D model.
- Compile record model.

BIM Uses

Although CDOT does not have extensive experience with BIM, the project team decided to use a 3D model-based design approach beyond the traditional roadway modeling as a risk mitigation strategy. The team modeled more than is typically done on a CDOT project to understand the location of utilities and coordinate elements of construction related to phasing. The team started with an existing condition model created from aerial lidar and ground survey data.

The existing condition model included traditional survey mapping deliverables, such as a digital terrain model, or 3D surface, and 2D geometry displaying the topographic features. There were no 3D reality models or 3D solids requirements for survey deliverables for this project.

The design team created 3D models for bridges and other structures (e.g., retaining walls), roadways, subsurface utilities, and drainage. During design, the only data property added to the 3D modeled objects was the utility owner information. The 3D model was helpful in automating the calculation of earthwork quantities needed for construction phasing of the roundabout, but due to the limitations of the technology being used (i.e., Bentley's InRoads SS2), the team used traditional 2D methods to estimate other quantities.

The most beneficial use of BIM on this project was the ability to analyze the engineering design. Traffic modeling showed that the peak traffic time was during the school year. Because this was the main road to take kids to school, the project had to be completed over the summer (10 weeks). A major component was the ability to visualize the design alternatives between the original signalized intersection and the proposed two-lane roundabout. Visualizing traffic movements was helpful for the design team to understand how traffic could be least impacted during construction. Coupled with this analysis, the use of BIM becomes increasingly more valuable when it is used for coordinating work or activities.

The CMGC delivery approach gave the project team a unique opportunity to work with the contractor during the design of the project. The design team held working meetings with the contractor to get as much input as possible. During these project team meetings, the 3D model was used to identify the best construction phasing approach. The model was put on the screen and the designer walked through the 3D model to help the team make decisions in real time. It was through this process that the team was able to review various design alternatives to manage the construction phases for the roundabout area. The roundabout construction portion of the project was originally scheduled to take place in four phases. Through the use of BIM, the team was able to find design alternatives and traffic phasing that allowed the construction to be reduced to only two phases. This two-phase construction option helped to reduce time and project cost, providing a more positive traveling experience for the public.

A new effort within CDOT related to use cases is the approach the department took to record the as-built model of installed utilities. CDOT is in the process of implementing specific data collection requirements for digital as-built information for utilities and buffer zones. The department is piloting a new system in which data from the model will be pushed to a mobile application during construction. Because this effort to collect information for digital as-builts is new at CDOT, the project team was only able to collect a digital as-built for the waterline work. The data collected with GPS technology was imported into a legacy database instead of the new system.

This new digital, as-built system is based on GIS technology. Field staff were equipped with GPS equipment for field data collection. The new CDOT system, which the department calls PointMan, is a GIS database developed in-house for use by field construction personnel. Trimble Catalyst, a geospatial application that uses a GPS receiver connected to a mobile device, will be used to collect precise GPS positions for each asset location. CDOT will be connecting the information collected in the field from Trimble Catalyst to PointMan to obtain an accurate record of the asset locations.

Benefits and Costs

The following list includes benefits and costs identified by the agency representatives and design team.

Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management

Benefits

- Time savings from improved design efficiency. The project team estimated staff time savings between one and two weeks (about 40–80 hours) from using BIM. Design team members indicated they were able to avoid multiple roundabout redesigns by working within a 3D environment. Although the design team had a learning curve on this project because team members were new to BIM, they were still able to expedite the process of design updates. Visualization of the design is powerful and allows the design team to make updates to the design more efficiently. The design team indicated that the process will become more efficient once everyone reaches proficiency in using the BIM software. Another area that translates into improved design efficiencies is coordinating BIM and CMGC processes across disciplines. Since the project team had many sessions to coordinate on models, it is hard to estimate the amount of time savings due to this coordination. While clash detection can be performed without using BIM, it is an extremely time-consuming process that requires the designer to manually look for utility conflicts. By using BIM clash detection, design team members estimate they may have saved about one week.
- Time savings from improved design efficiency, including parametric design and avoided design rework. While this particular benefit was not observed directly on this project, the design team indicated the new BIM design software has new functionality that includes dynamic parametric design. This means that every time a design change is made to the controlling geometry, the software automatically propagates the changes throughout the design files. This enhanced functionality in the software will result in significant time savings in future projects. The team used traditional design software to design road corridors parametrically. This functionality has been in the software for decades, but the parametric design had been limited to pavement layers.
- Cost savings from avoided change orders. The use of 3D modeling for existing and proposed underground utilities enabled the design team to perform clash detection, which helped to mitigate potential field conflicts during the design phase. In this project alone, there were 123 different conflicts identified during clash detection. A clash detection report was produced directly from the authoring software (InRoads SS2) to provide a clash detection matrix to be used for utility coordination. The team was able to adjust during the design phase to eliminate conflicts. Project team members estimate they might have only identified about one-third of these conflicts without using BIM. They also attributed the reduced conflicts to the CMGC delivery method, which allows for an extra set of eyes on the design. However, they are unsure how much of this clash detection improvement was due solely to BIM because both the designer and the contractor were able to collaborate to identify these risks and make corrections quickly. This corridor was in a location of high risk for underground utility conflicts. The design team estimated that each conflict would have cost between \$5,000 and \$50,000. The project team estimated that a magnitude of up to \$1.5 million in conflicts (high end) was avoided. This estimated value assumes the worst-case scenario, which would include moving the utility entirely rather than addressing each conflict individually. It is important to note that during this project, there was only one change order, in the value of approximately \$5,000 due to utility conflict, which is highly unusual. For example, on another project with similar circumstances, CDOT experienced a higher number of change orders and overall cost. Although it is difficult to put a value on it or equate a change order to damage prevention, CDOT staff indicated it is valuable to leverage BIM for this purpose.
- Fewer quantity overruns. Earthwork quantities can frequently cause conflict on a project, but staff indicated this was not the case for this project. The designer indicated all earthwork calculations were directly derived from the model. Some project staff members mentioned

- earthwork quantities on this project were relatively straightforward, and they did not have any issues with the contractor regarding those quantities.
- **Cost savings from improved schedule management.** The most significant benefit achieved through BIM was the improvement and acceleration of the project. CDOT was able to use BIM to optimize the schedule by reducing the number of phases specific for the construction of the roundabout. The impact to roadway users was also minimized.
- Cost savings from optimization of construction material and design options. The project team was able to influence scope optimization by evaluating multiple design options. Specifically, the design team used BIM to optimize profile changes and minimize the amount of pavement material for the road. The material savings enabled the project team to switch the budget to replace the bridge, instead of widening, without any significant budget increase. It is important to note that the long-term benefits outweigh any immediate project benefits, as the agency was able to optimize the overall lifecycle cost of the structure. Instead of repairing a bridge that would have needed regular routine maintenance due to its age, CDOT was able to construct a new bridge that has a 100-year lifespan.
- **Safety benefits.** Other benefits of design optimization due to scope change include safety benefits for bike/pedestrian lane users by adding a separate bike/pedestrian bridge and removing it from an at-grade condition. The 3D model enabled the designers to analyze the design and provide the best possible solution to place pedestrian facilities in this heavily traveled roadway. The project was completed at the same cost, with more savings over the bridge's lifecycle due to the use of BIM to analyze design performance.
- Time savings from avoiding the search for as-built information during operations in the future. This is one of the most significant BIM benefits identified by the project team for the future. CDOT wants to leverage BIM for accurate, reliable digital records. This will help the agency with investigations in the future, including what happened, when it happened, and how it happened.

Costs

- Initial BIM hardware investments or upgrades. As CDOT deploys the new OpenRoads Designer (ORD) software, it may be necessary to purchase new computers that can handle the additional processing requirements for BIM visualization and parametric design modeling.
- Staff training. The agency is expecting to incur initial training costs to bring all project teams internally up to speed with the new ORD Connect software. The upfront training will take approximately one week (40 hours) for the designers who perform roadway modeling.

Challenges and Lessons Learned

In general, this project is considered to be very successful. BIM was used as a tool to communicate the design intent, find the best design solutions to ease congestion, and improve safety along the corridor. All project stakeholders were pleased with the results of the project, and CDOT received very positive feedback.

The top challenge identified by the owner and project team was learning curves. The biggest challenge for the design team was learning the process of model-based design. There was a lot of experimentation and new concepts to learn and put into practice. Once everyone achieved BIM proficiency, the team was able to realize more benefits.

One lesson learned that was shared by the owner and project team was staff training. Because BIM is new to CDOT, it would be beneficial to evaluate an overall training program that incorporates the use of technology (ORD software), effective processes and methods for BIM, and the value of using modeling standards.

3.5 Case Study 4: Denver International Airport— Hotel and Transit Center Program

Introduction

Denver International Airport (DEN) in Colorado first opened in 1995, capturing attention with its unique structural design and use of technology. In 2019, DEN serviced 69 million passengers. As of 2021, DEN is the fifth-busiest airport and the largest in terms of area (53 square miles) in the United States (Ball 2015). DEN generates more than \$33.5 billion in revenue for the region every year, making it Colorado's largest revenue generator. Originally built to service 50 million passengers, the airport has increasingly been exceeding its original capacity and is in need of major expansion. There are many ongoing large projects, including expansion and enhancement of Concourses A-West, B-West, B-East, and C-East. Work also includes improvements to the existing infrastructure in each concourse. There are approximately 80–200 ongoing concurrent projects, including civil projects (Denver International Airport n.d.).

DEN was one of the early adopters of BIM among airport agencies. The BIM journey dates to August 2007, when the agency recognized the need to collect as much information about its assets as possible. The main objective of the DEN BIM program is data collection for improved decision-making, specifically for preventive maintenance of airport assets. DEN began implementing BIM in 2010 with its Hotel and Transit Center (HTC) project, the first of many expansion projects to increase airport capacity and operational service. While at first the BIM implementation was very project-driven, the agency has since mandated the use of BIM on all its projects, institutionalizing its use in all lifecycle phases (McCuen and Pittenger 2016). In addition, the airport authority has invested in an organizational BIM deployment strategy that enables the standardization of project deliverables by leveraging in-house resources to manage the overall program. BIM program staff provide technical support, assist with project prioritization, develop and conduct training, and assist project teams with the BIM process.

Case Study Overview

This case study focuses on the use of BIM during the HTC Program. This \$720 million project included the construction of a commuter rail transit center and a 519-room hotel. DEN chose to pilot BIM on this project as a strategy to manage project risk. BIM has proven to be beneficial on large and complex capital improvement projects like the HTC Program. DEN hoped to realize the benefits promised by the BIM model-based approach, including improved collaboration between disciplines and avoidance of change orders. The project size, scope and complexity made it ideal for a BIM model-based approach.

The project used the CMGC delivery method. The design team collaborated with the contractors during the design phase to receive input and adjust the design.

BIM Requirements Overview

Like many large institutional owners, DEN started its BIM implementation without the use of any BIM requirements. In the absence of DEN-provided BIM requirements, the design firm used its own standards to develop design models. In 2009, DEN hired a BIM consultant to help develop the agency's first set of standard BIM requirements. BIM requirements for civil works were added to the standard requirements in 2016 and 2017. As of 2021, DEN has a complete set of standards for the use of BIM published in Design Standards Manual: Digital Facilities and Infrastructure. The manual provides minimum requirements for the use of BIM on all design, facilities, and infrastructure projects at DEN, including

- Policy regarding the information management process,
- Information modeling requirements,
- Project execution planning,
- Modeling standards and naming conventions,
- Plan preparation and technology procedures, and
- Quality management best practices.

BIM Uses

Several primary BIM uses are frequently adopted or required on DEN's projects (see BIM Use Cases text box).

BIM was implemented in the design phase as much as possible within the project's organizational and contractual structure. While the design model was used to create quantities and cost estimates, it was difficult for design teams to trust the calculations performed under their new approach. BIM was implemented for 3D coordination to improve design accuracy. This was accomplished through the strong leadership of key design champions. BIM information made creating sheets from models easier, although that was not the case at first. However, by the end of the project, all sheets were created from the design model. Although drawings were the contractually binding documents, models were still shared with constructors. Surprisingly, these contractors were more comfortable with BIM than DEN expected, although there was an inconsistency of tools used for developing 3D models between contractors and the design team. The design team used Revit while the contractors used 3D CAD tools for reviewing and developing 3D models.

The 3D models and the construction schedules were used to develop 4D models to visually track the progression of construction. BIM was also used as the primary source of data for FM during operations. DEN personnel were able to access asset information. Examples of information that was available through BIM data exchanges include date of purchase, cost, specific asset location, when it was installed, and the maintenance schedule.

The BIM program launched as part of the asset management program, although there was no coordinated program before 2012. The BIM model was used for "everything" related to an asset. The 3D models were used for maintaining critical systems—mechanical, electrical, plumbing, and security. The process focused mainly on developing a detailed model to inform all ongoing actions instead of creating visualizations. DEN's priority in implementing BIM was to capture asset tracking. Then DEN pushed information into the GIS (a priority use) and information for downstream tenant projects (tenant improvements or renovation). For example, there are frequently tenants that will be performing projects within a space soon after projects are delivered, and the ability to provide a detailed model to the designers of these projects is very valuable. Design-intent models are continuously updated as new projects are performed.

Benefits and Costs

Researchers interviewed agency representatives, and the following section is a summary of the identified benefits and costs.

Benefits

· Cost savings and avoided time spent tracking down information needed for routine maintenance. The BIM process employed for the design and construction of this project greatly improved ongoing FM and maintenance. DEN's efforts to implement BIM for maintenance are strategic for long-term benefits. With BIM adoption, the building model was

BIM Use Cases

- Author design model.
- Create quantities and cost estimates.
- Coordinate design models.
- Author 4D model.
- Inspect constructed asset.
- · Compile record model.

- carried throughout the whole lifecycle of the project, leading to reduced redundancy. In the HTC Program, DEN implemented BIM for daily asset management of the entire airport facility with hopes that the BIM system will make maintenance of the airport infrastructure more efficient, which in turn saves time and money and improves quality.
- Cost savings from reduced paper and reduced physical storage needs. Without coordinated models, DEN would have needed to collect, store, share and secure thousands of paper documents (plans and specifications) onsite. Not only was a great reduction in paper redundancy achieved by electronic file sharing, but also the possible need for a trailer for drawings onsite was eliminated.
- Time savings in document review and approval due to faster turnaround time by using **cloud-based software.** BIM contributed to staff time savings. Updating the digital drawing sets through BIM technology saves time for all parties compared to physically updating plan sets. It was estimated that document review and approvals using BIM helped reduce approval time by up to 20 percent.
- Improved worker safety and time savings during maintenance and operations inspections. Since documents are always up to date and accessible, commissioning information and linked documents can be used as the deliverable for handover and facility operations. The field data management system compiles quality, safety, and commissioning checklist results. Gathering quality assurance/quality control (QA/QC) information can help proactively identify trends and minimize risk for the contractor and project. BIM helps to create work-to-complete lists for traders and other parties. Modeling also helps with time savings because more punch list items are completed earlier through the effective management of issues and checklists in the field. Checklists help make inspections faster, more consistent, and more thorough.
- Improved worker safety during construction inspections due to increased use of automation and having workers onsite for a shorter duration. BIM provides automated, bidirectional information exchange between the BIM model and the FM platform, which significantly reduced risk and resulted in time and cost savings on accuracy. Digital mobile devices like iPads allowed for updating coordinated models and sharing electronic files, making models accessible to workers and trades. For workers actively involved in an onsite task, such as tying rebar, visualizing the 3D model via an iPad, panning around, and seeing the plan in context to where they were standing were perceived as positives. The time savings and increased safety achieved by reducing workers' exposure to live working zones were far beyond dollar values. For example, by viewing the model on an iPad, a worker can pre-inspect the work without being exposed to a live working zone. Everyone involved in the activity can easily visualize the model and understand how their work fits into the overall process, and therefore identify problems well in advance (Ball 2015).
- Time and cost savings from avoided change orders. BIM promoted the development of a fully integrated FM workflow, which provided opportunities for housekeeping and content management. Digital transition engaged all disciplines (i.e., civil, infrastructure, and vertical design, as well as construction groups for each of those) through the lifecycle of the project. There were fewer issues due to communication between constructor and designer during the design phase. With a seamless flow of models, disconnects between the design and the final finished buildings do not exist, overcoming issues around ownership and liability. BIM enables collaboration among different disciplines, reducing the time and cost that jobsite changes would cause otherwise (Ball 2015). Cloud-based BIM management solutions transform BIM collaboration by simplifying multidiscipline model coordination and clash detection and providing access to BIM models and intelligent object data anywhere for the entire project team. It helps architects, engineers, owners, and builders across the globe collaborate in real time in more than 50 different file formats. Clash detection in ductwork and piping led to significant time reduction and cost savings in construction. Significant issues of building performance occur because of isolations among different disciplines in traditional management

methods. For example, jobsite changes can impact mechanical performance when they are not entirely constructed as designed. As a result, rework is costly and time-consuming if a contractor installs the ductwork and piping differently. Besides, identifying design issues in early design review provides significant savings by modifying the design phase compared to redoing the work later. DEN has already saved 6,000 hours in labor by creating O&M asset information in Maximo. BIM allowed DEN to shave three months off the schedule for the HTC project. BIM 360 Glue Coordination saved 8 hours per worker per week in design and construction (8,000 hours saved in total). BIM 360 Field saved 2 hours per issue and 1,100 hours in the first six months. It has been reported that BIM reduced RFIs, change orders, and rework by 40 percent (Autodesk n.d.).

- Time savings from reusing previous BIM content and experience. In-depth feasibility studies based on a detailed model of what currently exists can help avoid lengthy and expensive consultant time on feasibility studies in the future, which adds to significant time savings (Ball 2015).
- Reduced frequency of non-scheduled maintenance due to improved BIM collaboration processes. DEN has been doing a better job at tracking the types of maintenance being done and the associated costs, although not all assets are created with BIM. DEN determined that corrective maintenance costs five times as much as preventive maintenance on a personhour basis on an airportwide scale. Therefore, DEN's goal is to reduce the amount of corrective maintenance required. For each 5 percent reduction in annual corrective maintenance, \$5 million in cost savings will be generated.

Costs

- Software costs. DEN estimates that there were additional BIM-related software costs incurred due to the new BIM 360 platform. These are annual costs on top of software subscription costs prior to implementing BIM.
- Hardware costs. DEN also incurred additional hardware costs, including a lidar scanner.
- **New staff positions.** New staff positions were required to support the BIM program. While several of these positions were filled by existing staff, three new employees were hired to support the program.

Challenges and Lessons Learned

The following section lists top challenges identified by DEN.

- People and inertia. People were identified as the most significant challenge, and the second biggest challenge is inertia because people tend to be resistant to change. One example provided was that while the model can be used to create quantity and cost estimates, it was difficult for design teams to trust the calculations performed under the new approach.
- Lack of sufficient and valid historical data. A change management process is needed when implementing BIM because ROIs require valid historical asset data (McCuen and Pittenger 2016).
- Learning curves. Learning curves are an issue, especially for new providers. While there are clear benefits to learning new processes, there are also many hurdles. The education process matters because people need to remain engaged as things develop in order to catch up with technology changes. Things could fall apart if project timelines are as long as two or three years (the average learning curve for an organization) and there are no technicians to follow through.

The following section includes some of the lessons learned that were shared by the owner.

 BIM requirements. The bid process has become more inconsistent with the addition of detailed BIM requirements; since some organizations are still not familiar with BIM processes, there can be large variations in cost projections in estimates. DEN aims to address this issue through outreach and by simplifying BIM requirements. DEN is seeing experienced companies lowering costs, especially for designers. Contractors are also lowering prices but at a slower pace. MEP/Arch designers shared a 40 percent reduction in their costs from their early experience working with DEN requirements through the current requirements. There were also significant reductions in costs associated with certain required tasks, such as laser scanning.

- **BIM requirements need to evolve.** BIM processes and methods continue to mature, therefore BIM standards need to be continuously reviewed and constantly evolving. Staff also must stay up to date on the latest standards, and training may be required.
- Increased design fees. There is a significant difference in design fees between BIM-savvy
 designers and those who are not savvy with BIM, which can be attributed to the anticipated BIM learning curve for designers and clients who lack experience with BIM tools and
 processes.

3.6 Case Study 5: Highways England— A556 Dual Carriageway

Introduction

Highways England is a government-owned company and the largest road authority in the UK. It works closely with the Department of Transport and operates as a company on behalf of the UK government to maintain the Strategic Road Network.

Highways England's BIM journey dates to 2011, when the UK first mandated the use of BIM on public projects. BIM was first used during project delivery to improve the management of large, complex projects. During the early planning, efforts were not supported by a dedicated budget or strategic plan for BIM adoption and execution, although more recent efforts have supported the planning initiatives.

The construction industry in the UK saw the opportunity to use BIM as a risk management tool and adopt more integrated project delivery approaches, such as DB delivery. Costain, a contractor in the UK, sought to use BIM to deliver projects better, faster, and cheaper. In 2012, a Lean Six Sigma group was developed within Costain to investigate the company's BIM deployment strategy. Part of this evaluation included smaller working groups to investigate technologies, such as 3D modeling and Common Data Environment (CDE) processing. The company started to transform its process from developing CAD standards to adopting BIM processes. The adoption of BIM by Costain on highway projects was accelerated due to the government mandate for BIM Level 2 requirements that was released in early 2016.

Case Study Overview

This case study is based on the highway project A556. The site is in Cheshire in Northwest England. This 7.6-kilometer stretch of highway serves as one of the primary routes into Manchester City. The project objective was to expand the highway capacity of the congested corridor and improve the geometry of the 7.6-kilometer section connecting the M6 Junction 19 near Knutsford with the M56 Junction 7 near Bowdon. The project was procured as a DB delivery, a newer delivery approach for Highways England. The scope of work included significant roadway work to convert the existing undivided highway to a divided facility. Also, the project included the construction of seven new bridges, one pedestrian underpass, and refurbishment works to two existing bridges (England Highways Agency 2014). The total project cost was £200 million, including the construction cost of £107 million. The timeline included three phases: 1) 18-month planning phase; 2) 18-month design phase; and 3) two-year construction phase.

BIM Uses

Several primary BIM uses were frequently adopted or required on this project, as seen in the following examples.

Author 3D Model and Design Review

From a technology standpoint, the initial bridge and highway design models were developed by the design engineers on this project using 3D parametric modeling software. The bridge models were then exported into openBIM data files (IFC) to allow for further design review. The designs were reviewed by leveraging a nonproprietary 3D viewer to show design, properties, and ownership (Petri et al. 2017). The team delivered the design through a federated 3D model.

A new approach was adopted by the design engineers for this project. To meet the project schedule, the design needed to be complete prior to starting construction. This required revising the detailed 3D modeling process, the overall design process, and design reviews with stakeholders, which helped to identify potential future issues.

One benefit of this approach was the identification of a massive utility that would have been diverted around if discovered later. The design team was able to demonstrate the value to the owner of leaving the utility in place because of the modeling approach and investigation of existing utility locations, since the entire team could visualize the utility conditions and impact. This decision is estimated to have saved £1 million in cost with reduced redundancy since they were able to plan properly. Without this process, they would have diverted around the utility. The lead designer perceived that early contractor involvement, with the right parties on board from the outset informing the design, makes a huge difference.

Estimate Quantities

The construction team performed some 3D modeling during the construction phase, partially focused on developing the target price for the construction estimate. This model content was then used to develop and extract quantities for the estimated costs. One example provided by the team was related to the modeling of fencing. On a typical project of this scale, it might take three days to perform a detailed take-off of the construction fencing; but after developing the model, the take-off only took three minutes to extract the modeled quantities.

3D Coordination

The IFC models of the bridges were used for performing detailed 3D coordination. The models were used within an automated collision detection software to identify 3D geometric clashes. The clashes were then resolved prior to construction.

The contractor reflected upon a previous project for which the management of RFIs was a full-time job, referring to the previous project as "chaotic." This was avoided in the A556 project by getting parties involved earlier and leveraging model content to resolve design coordination issues. The construction team's familiarity with the design early in the process cascaded through the rest of the team. Few problems were identified with the early involvement of everyone in the pre-construction work except for unforeseen factors, such as unknown utilities.

Automated Machine Guidance

In the construction phase, the constructor used AMG for equipment operations. The process focused on leveraging the 3D model as an input, along with some post-processing routines, to extract a terrain that could be leveraged by the AMG software. There are no current minimum requirements for delivering AMG information to constructors. Construction industry practitioners speculate that if a set of standard minimum information requirements were adopted by

BIM Use Cases

- · Author 3D model and design review.
- Estimate quantities.
- · 3D coordination.
- · Automated machine guidance.
- · Record model/digital as-built model.

the owner, the resulting process would create greater efficiencies, which would help drive down prices for equipment operations.

Record Model/Digital As-Built Model

Throughout this project, design and construction teams developed the model to include asset data and leverage template parametric content libraries within the 3D software. After completion of construction, the teams performed an extract, transform, and load process to transition the data from the design model into the asset management system. The operations phase was managed by leveraging GIS data, which is populated from the content within the 3D models.

Benefits and Costs

The following section contains a summary of the identified benefits and costs based upon an interview with team participants.

Benefits

- Time savings from avoided RFIs due to improved clarity of design. There was an estimated reduction of £2,500 for the administration costs of each RFI as well as savings from avoided rework and design changes. The number of RFIs was significantly reduced compared to a traditional contract. There was no overall estimated impact on the schedule critical path, but some time was shifted from construction to the design phase.
- Cost savings from optimization of design options. The design team was able to use the model to assess safety sightlines for selecting the placement of variable driver information signs. The safety audit process was enhanced by using automation for selecting and reviewing the sign placement. While it took some effort and time to automate the safety audit, it eliminated potential rework that typically results in higher costs.
- **Avoided vehicle crashes due to safety simulation with BIM.** BIM provides a higher level of visualization to identify potential safety issues, thus reducing the probability of vehicle crashes. The use of BIM on this project resulted in an increase in safety performance on the operational highway. The team was not able to estimate the financial value of this benefit, which only partially originated from BIM reviews during design.
- Improved safety during construction. There was a significant reduction in the number of onsite staff, which should yield improvements in overall construction safety. However, there were no specific data to support the scale of potential savings.
- Improved worker safety during maintenance inspections. Some inspections are now performed by leveraging photographic information collected from unmanned aerial vehicles. Leveraging this new approach to perform an inspection could limit potential safety concerns related to inspections. However, currently the cost for performing such an inspection is higher. It is a cost tradeoff because the frequency of inspections has increased, which yields improved potential safety, and overall costs per inspection have come down.
- Cost savings from avoided change orders. Typically, projects go over budget due to problems found during construction, which require a cost change order. On this project, however, the use of BIM early in the process helped identify design issues, thereby avoiding cost changes to the contract. The A556 project was completed within the original budget.
- Cost savings from improved project schedule. Typically, projects in the UK experience an approximately 30 percent schedule overrun during the design phase. The use of BIM and the collaborative process enabled the A556 project to finish on time.
- Cost savings from optimization of construction material use due to BIM design. The project team proposed a common family of bridges composed of a standard set of components. The

team worked with potential suppliers and leveraged models to solicit their constructability views, while also performing collaborative workshops that ultimately yielded changed profiles of bridge beams. These detailed reviews significantly reduced concrete volumes used in this project, which yielded estimated savings of £300,000.

- Time savings from reusing standard BIM content libraries (e.g., 3D cells, templates) for similar work in the future. The contractor started a library to use during initial or conceptual stages for common model development. The library does not yet extend into more detailed designs. The digital content library has some indirect benefits, such as accelerating BIM adoption because the private sector does not need to invest time or funding into developing a unique library. The team recommended that if clients want to benefit from libraries, they need to overcome challenges associated with insurance and potential liability. The contractor invested £100,000 to create the model library and projected a fivefold return on this investment.
- Time savings from improved design efficiency, including parametric design and avoided design rework. Parametric design was considered relatively new in 2015. The team had programming scripts for connecting data to external sources. However, starting in 2018, parametric design has become a very important topic in the highway sector in the UK. Parametric design does not just enhance speed but can also improve the quality of the design.
- Time savings in document review and approval due to faster turnaround time by using **cloud-based software.** To undertake the project, the team deployed a cloud-based CDE. The objective was to demonstrate the benefits of collaboration throughout the design and construction of A556 and to demonstrate that difficult linear infrastructure models can be effectively managed by a cloud-based system, to the benefit of all parties (Petri et al. 2017).

Costs

A confidential benefit-cost analysis (BCA) was performed for this project, and it clearly demonstrated the potential for savings during the project delivery phase.

Challenges and Lessons Learned

The following list includes top challenges identified by the team.

- Defining and validating information. Highways England has been working on BIM adoption for some time, yet the company still has to consistently receive the as-built model for each project. While the A556 project was very successful, some other projects have not had the same level of success at receiving quality data from the designers and constructors. There is a need to continue building a robust quality management approach that reviews the data requirements and outlines an approach for validating the information received from each project. This will require active participation between Highways England and service providers to ensure that service providers understand the requirements and the importance of the
- Early information gathering could save money. Using BIM at the earliest project stages could provide significant value. One lost opportunity of the A556 project was that Highways England did not perform a detailed laser scan or photogrammetry survey at the beginning of the project. Had project team members used existing model capture techniques, along with ground-penetrating radar for utility location, they would have saved significant funding in redesign costs, with their estimate projecting a tenfold savings in the cost of the scanning. They did perform some isolated scans.
- Content library for Highways England. A content library to share with designers and constructors with more detailed content elements would be beneficial, although legal and contractual issues regarding the use of the content elements must be resolved first.

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Lessons Learned

The following list includes several lessons learned.

- Collaboration is critical. It is very valuable to have the designers and contractors working together to get the right focus and the right project outcome. The whole team comes together to deliver the results, and the team needs to set single goals, mutual incentives, and collaborative working arrangements. Typically, designers working alone do not have to focus on the deadline, and they may not see the big picture. The creative design process requires iterative cycles; there must be time for creativity as well as a focus on completing the tasks. The collaborative work process can help keep everyone focused on the outcome and provide accountability.
- Parametric design is valuable. The team members felt that the expansion of parametric design concepts—leveraging predefined content libraries—will become a truly significant process disruptor. Design automation approaches will yield high-quality designs and information-rich models, as well as significantly reducing the time needed to develop designs. The contractor is investing in research and development efforts in this area.
- **BIM/3D prototype was the glue.** The model provided a common representation for collaboration.

3.7 BIM Expert Validation Panel

Researchers worked with a BIM expert panel to validate and confirm information collected through the literature review and case study interviews regarding BIM adoption. This expert panel was consulted to help fill in any data gaps for the ROI framework.

Specifically, the panel was asked to

- 1. Supplement data found through literature review and case studies,
- 2. Pull from professional experience,
- 3. Build consensus on possible value ranges, and
- 4. Confirm use of the ROI framework.

The panel consisted of a multidisciplinary group, including bridge and roadway engineers, asset management strategists, and BIM technical support staff from both the building and infrastructure domains.

As shown in Figure 3-3, a series of two virtual workshops were held. During the first workshop, researchers introduced the expert panel to the project objectives and desired outcomes

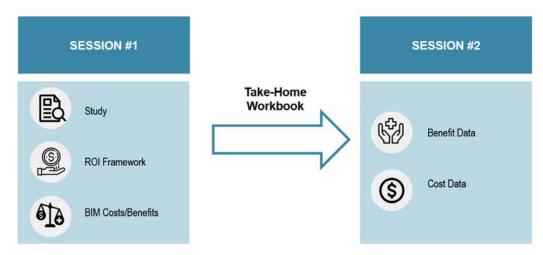


Figure 3-3. Illustration of workshop components.

for their participation, research methodology, and preliminary examination of cost and benefit measures. At the end of the workshop, the researchers provided a data collection booklet that the expert panel could use to assist with filling in the data gaps for specific measures. During the second workshop, the expert panel reconvened to discuss specific input for each of the cost and benefit measures in the workbook.

The information collected during these two virtual workshops was used to fill in data gaps and finalize the cost and benefit data values used for the ROI framework in Chapter 4.



Making the Business Case

4.1 Overview of Business Case Approach

Approach Conceptualization

The objective of Project TFRS-02, "Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management," was to evaluate the business case for BIM for transportation infrastructure by analyzing and quantifying how adopting BIM enterprise-wide could lead to efficiency gains and other benefits throughout the lives of assets, including project design, construction, and asset management. The case was made through ROI analysis, which considers the benefits and costs of BIM adoption.

While the definition of BIM can be broad and ambiguous, this study defined BIM as the adoption of an intelligent, object-based 3D modeling process. From the case studies and literature review, the research team learned that most transportation agencies have not fully integrated BIM processes for project delivery and asset management, but many have achieved certain aspects of BIM adoption. Thus, the ROI approach considered a range of possible "levels" of BIM adoption, discussed later in this chapter under the section on agency maturity.

To define the ROI analysis approach, the research team first conceptualized the process of implementing BIM. This allowed the research team to identify the types of costs and benefits likely associated with implementing BIM, as well as how the initial investment was linked to the eventual outcome. Figure 4-1 illustrates this approach.

As shown in the diagram, examples of BIM implementation activities, or "inputs," included efforts such as investing in software and supporting hardware, developing new standards and processes, and training employees. These inputs helped identify the costs associated with implementing BIM, as well as the "outputs" expected from these activities, such as trained staff able to follow BIM procedures and use modeling software. Outputs then led to "outcomes," which are the benefits that should be compared against costs in an ROI analysis. For instance, one type of outcome expected from BIM was project cost savings from avoided change orders.

This input-outcome process also helped the research team identify the agency context and assumptions necessary to translate inputs into outputs and outcomes. (Assumptions and agency context are described in the boxes below the outputs and outcomes in Figure 4-1.) For example, an agency must purchase sufficient functionality in the modeling software to realize benefits from BIM. In fact, the type of modeling software purchased will determine which specific outcomes (benefits) the agency can realize. This concept was captured by this study through the term "use cases."

A BIM use case is defined as a method of applying BIM during a facility's lifecycle to achieve one or more specific objectives (Messner et al. 2021). The research team identified 14 key use cases that could help an agency realize benefits from implementing BIM (Figure 4-2).

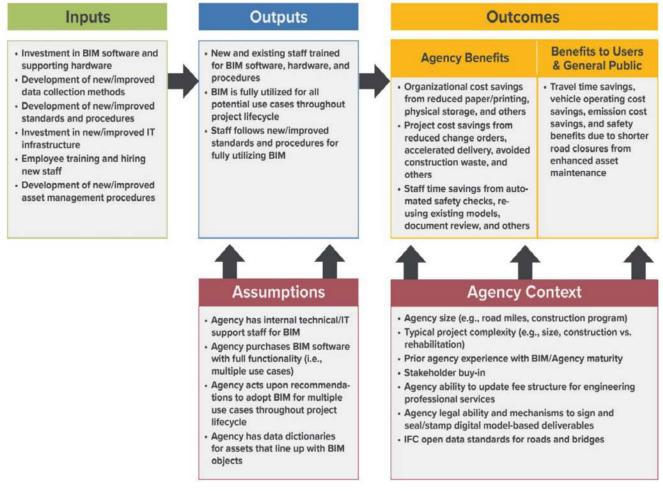


Figure 4-1. Input-output approach for identifying outcomes from adopting BIM.

Once the research team identified a list of all the benefits associated with BIM, each benefit was mapped to one or more use cases. This mapping represents the link between acquiring a particular use case of BIM (through purchasing certain types of modeling software) and the outcome of implementing the use case in practice. For example, purchasing 3D survey modeling software (such as ContextCapture or ReCap Pro) allows an agency to "capture existing conditions" (a core project delivery use case) by developing a 3D object model of the existing conditions for a transportation project. With this technology, the agency can contextualize the project surroundings and has the potential to assess design alternatives to find more cost-effective solutions or avoid potential conflicts (benefit).

Mapping benefits to use cases was critical to the ROI analysis. It allowed the research team to assign one or more specific benefits to an agency, given the knowledge of which use cases would be acquired as part of the Investment Case. The full benefits-to-use cases mapping can be found in Appendix D of this report and in the BIM ROI Tool developed as part of the project (in the "Use Case Matrix" Excel sheet).

Program-Level Approach

The ROI approach for this study considered benefits at a program level rather than taking a project-level approach. There are many reasons why the ROI analysis had to be performed at

Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management

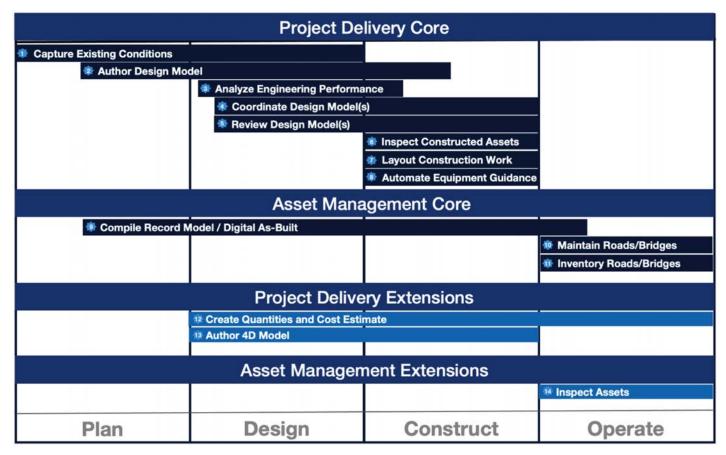


Figure 4-2. BIM use cases for ROI analysis.

the program level. First, given the size of BIM-related investments, these costs would not be fully recovered after applying the new modeling technologies to only one project. Nor was this the intention of the investment—these costs were considered an investment by agencies for the future projects in each program.

Second, not all benefits realized from BIM could be attributed to a specific project; some benefits were accrued by the entire organization. For instance, one of the BIM benefits identified in the study was cost savings from reduced paper, printing, and distribution. By moving to a digital approach, agencies could save money on production and distribution of plan sheets and printing and shipping of bid tabs. Note that agencies that already implement e-construction or only issue electronically signed PDFs for plans would not experience this cost savings when adopting BIM.

Third, there were cumulative project-level benefits that could be realized only when sufficient information had been aggregated into agency databases. These benefits could be attributed to a specific project, but they were realized only after several projects had been completed. For instance, agency staff could save time during design from reusing previous BIM content for future similar work. However, this benefit could be realized only once BIM content had been built up in a 3D-component library.

To achieve the program-level approach, the ROI analysis considered an agency's "typical project." The typical project was intended to capture 85 percent of the type of work the agency does. Identifying the typical project was important for determining how much these projects were expected to benefit from BIM. While a large new construction project was likely to realize

many benefits from BIM, large projects may not be common for the agency. Currently, the typical project type for many DOTs is maintenance work, which—depending on the complexity of the work—may or may not benefit from the use of BIM.

An agency's typical project may be complex or non-complex:

- Complex projects are characterized by the amount of construction activities that introduce the most risk. These projects typically involve multiple phases and complex geometric structures and interchanges. The project scopes vary, but the risks are typically associated with activities to install new or reconstruct infrastructure in an urban environment with many utility corridors and right-of-way impacts. While complex projects may be described by their major scopes of work—such as new pavement, bridge construction, or roadway widening it is probably more useful to define these projects by the level of perceived risk. Complex projects are more likely to benefit from BIM.
- Non-complex projects are characterized by construction activities that introduce the least amount of risk. These projects may include multiple phases and simple activities, such as full-depth pavement replacement, mill and overlay, and safety improvements such as signing and pavement marking. These projects are less likely to benefit from BIM, but they benefit from standard BIM information requirements.

Once the characteristics of a typical project were set, the characteristics were then scaled by the average number of projects each year that would include the use of BIM. While this method did not capture the variety of project types that an agency may implement (such as the occasional megaproject), it was intended to approximate the average ROI for the agency.

Return on Investment Defined

Since there is no industry consensus on what constitutes ROI analysis for transportation programs, for the purpose of this study, the research team had defined ROI analysis as benefitcost analysis (BCA). This approach has been recommended by the research agency for NCHRP Project 08-36/Task 62, "Best Practice Methodology for Calculating Return on Investment for Transportation Programs and Projects" (Cambridge Systematics 2007). This provided a framework for calculating ROI.

From the studies identified in the literature review, the research team found that many BIM studies measure ROI as net benefits divided by total costs. This metric is commonly used for pure financial analyses and intended to calculate a tangible cash return, but it is not consistent with a BCA approach. The equivalent metric for BCA is the benefit-cost ratio (BCR), which is calculated as total benefits divided by total costs. BCA is a more comprehensive approach that includes both financial and non-financial benefits and costs, such as time savings, improved safety, and other societal impacts. As several of the anticipated benefits and costs of BIM are non-financial, a BCA approach is better for capturing ROI of BIM investments.

4.2 Benefit-Cost Analysis Framework

This section describes the key principles of BCA to be considered in ROI analysis. As discussed previously, BCA compares total benefits to total costs and calculates various summary metrics. This approach is illustrated in Figure 4-3.

As shown in the figure, the framework involves identifying and monetizing as many of the benefits and costs related to BIM implementation and use as possible. The future streams of these benefits and costs are discounted by a discount rate over a selected period of analysis to calculate total discounted benefits and total discounted costs. These discounted benefits and

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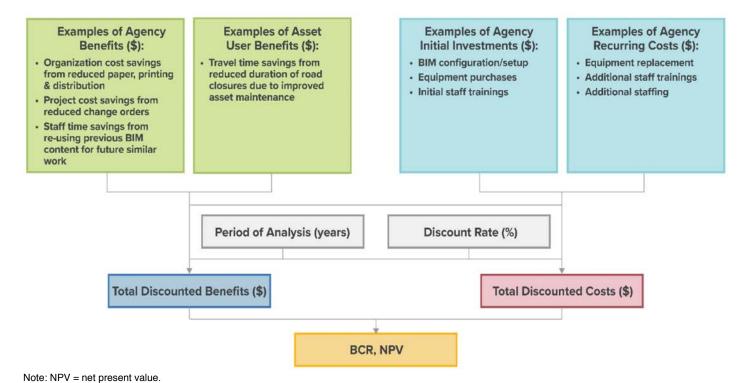


Figure 4-3. Illustration of BCA approach.

costs are used to calculate typical BCA metrics, such as the BCR payback period, and net present value (NPV).

Base Case versus Investment Case

BCA is a method that measures the effects of implementing a particular project, program, or other investment compared to not making the investment. The analysis monetizes as many benefits and costs as possible associated with two states of the world: the "Base Case" (the state of the world without the investment) and the "Investment Case" (the state of the world with the investment). Several Investment Cases can be considered, but they are always compared against the same Base Case.

Defining the appropriate Base Case and Investment Case is the first step in a BCA. The Base Case is typically defined as "business as usual," meaning that no major changes are made from the current state of the world. However, the Base Case must also be realistic. Instead of "doing nothing," the Base Case should still involve regular software and hardware upgrades that would occur without investing in new BIM-related technologies.

For the purposes of this study, the Base Case was defined as "business as usual" with no additional software or hardware investments, other than regularly scheduled upgrades. The Investment Case was defined as "investing in a new BIM technology, training and technical support, and other resources needed to enable BIM methods for project delivery and asset maintenance." These definitions were also consistent with BIM ROI studies identified in the literature review (see Chapter 2), as demonstrated by the studies shown in Table 4-1.

Because BIM is a method of exchanging information and data between many systems and producing 3D models and information to support various use cases, it is important to categorize the types of technologies by specific applications. Software can be purchased with different

Table 4-1. Base Case versus Investment Case for BIM in the literature.

Study	Investment Case	Base Case
Giel and Issa (2013)	Project B (BIM)	Project A (pre-BIM): small, commercial warehouse projects of tilt-up wall construction
Giel and Issa (2013)	Project C (BIM)	Project C (pre-BIM): assisted-living facility projects
Giel and Issa (2013)	Project F (BIM)	Project E (pre-BIM): mid-rise commercial condominium projects
Fanning et al. (2015)	Pecos Street over I-70 Bridge	Fort Lyon Canal Bridge (part of Rocky Ford Bridge project)
Barlish and Sullivan (2012)	Two historical BIM projects, one current BIM project	Two historical non-BIM projects, one current non-BIM project

features and functionalities to support specific tasks, such as authoring and reviewing models and performing clash detection. This variety in functionality indicates that these software packages have codependencies and may be associated with different benefits. As more functionality is attained with the software, there becomes a greater potential for benefits. For instance, while the model authoring software allows the creation of design models, it lacks the functionality to track review comments for QA.

For an agency that already has model authoring software but will be upgrading to a more advanced package or expanding functionality, the Investment Case would include the "incremental costs" of the new software (i.e., the additional costs in the Investment Case compared to the Base Case), as well as all the benefits associated with the expanded modeling software capabilities. The Base Case would be the state of the world with the original BIM capabilities (or lack thereof), including the benefits associated with this software. No new investment costs would be considered for the Base Case because the agency has already purchased the software (sunk costs). However, any ongoing/subscription costs in the Base Case should be considered. The ROI analysis uses the incremental ongoing costs in the Investment Case compared to the Base Case. Multiple Investment Cases can be analyzed, depending on the level of software functionality purchased.

Distribution of Benefits and Costs over Time

BCA considers future streams of benefits and costs. In addition to the initial investments to acquire technology and supporting infrastructure, ongoing costs will be required to maintain the modeling software and BIM practices. For instance, software subscriptions will need to be renewed periodically. Refresher training will be necessary for existing staff, and any new hires will require comprehensive training.

Benefits occur over time. While many of the benefits resulting from improved design and construction are realized within the first few years of acquiring the BIM-related technology, benefits associated with enhanced maintenance will occur many years in the future. Additionally, many benefits will increase (or "ramp up") over time as agencies become more familiarized with the modeling software and as a more comprehensive database of modeling content is built up over time.

For these reasons, estimating the ROI of BIM investment must consider an uneven stream of benefits and costs over time. Figure 4-4 illustrates this concept. Note that this figure is purely

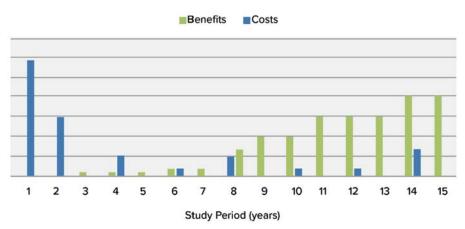


Figure 4-4. Uneven stream of benefits and costs from BIM-related investments.

illustrative and should not be used to indicate the time frame or magnitude of cost recovery for BIM.

As illustrated by Figure 4-4, costs accrue from the beginning of the BIM technology investment, but benefits take time to ramp up and be fully realized. Accordingly, it will take time for agencies to recover their investment costs. Additionally, benefits realized from using BIM for one project will likely be insufficient to make up for these investment costs. Instead, agencies will start to see benefits exceed costs when considering their entire program of projects over time, unless initial BIM investments are for a megaproject.

Discounting

Discounting helps convert the uneven distribution of benefits and costs over time into comparable values. Discounting transforms future streams of benefits and costs into present terms. The need for discounting is based on people's preference for the present over the uncertainty of the future. In other words, discounting reflects the fact that a dollar tomorrow is worth less than a dollar today, even without considering inflation.

Future benefits and costs should be discounted using the social discount rate, which captures the value society places on present versus future consumption. This is a real discount rate that does not include inflation. The discount rate should not be confused with inflation; inflation accounts for how the value of money changes over time, while discounting accounts for the preference of people for consumption today rather than in the future.

Agencies use a range of discount rates. Many state agencies have their own policies for selecting a preferred discount rate. The U.S. DOT follows guidance from the Office of Management and Budget (OMB) to select an appropriate social discount rate. OMB recommends using a 7.0 discount rate to reflect the opportunity cost of capital that would otherwise be invested in private markets. However, OMB also suggests using a 3.0 percent discount rate to provide a sensitivity analysis, where the lower rate represents the scenario in which project funds would otherwise be invested in alternative public uses. The BIM ROI Tool developed during this study has a default discount rate of 4.0, which is a middle value, but tool users should pick the value most appropriate for their analyses. Once a discount rate is selected, the same value should be used consistently for all BCAs in the future for comparability.

During the literature review performed for this study, the research team found that discounting is not commonly included in ROI studies. This is in part because most studies focus on the

benefits of applying BIM strategies during the design and construction phases, which tend to take place over a few years. However, discounting should still be included; it is especially important for BIM benefits in asset management, which occur later in the project lifecycle.

The ROI framework allows the tool user to consider the ramp-up effect common to BIM benefits, which will also be affected by the time value of money. As seen in Figure 4-4, BIM is expected to yield an uneven stream of future costs and benefits, with the bulk of costs occurring at the initial time of investment and benefits increasing over time. Benefits are affected by discounting more than costs, since benefits occur in the future. This timing means that applying discounting will disproportionately affect benefits compared to costs, and will thus result in a longer payback period compared to not applying discounting.

Return on Investment Measures

There are several different metrics that can be used to capture the ROI of BIM implementation: NPV, BCR, and payback period.

- NPV is the difference in the discounted benefits and costs of BIM investment. A positive NPV suggests that the BIM investment is economically justifiable, meaning that the benefits outweigh the costs. It is calculated as the present value of benefits (i.e., the entire stream of benefits discounted to the present) minus the present value of costs (including initial capital costs as well as ongoing maintenance and operating costs discounted to the present).
- BCR is the present discounted value of total benefits divided by the present discounted value of total costs of the BIM investment. A BCR greater than 1.0 indicates that the benefits of the BIM investment outweigh the costs and are worth the investment. A BCR of less than 1.0 indicates that the BIM investment will not generate benefits sufficient to offset the costs. A large positive BCR indicates a better investment than a low positive BCR. This metric can be used to compare different investment options.
- Payback period is the time it takes for the investment to break even—that is, the timespan between investment and when the cumulative benefits first exceed cumulative costs. The BIM ROI Tool shows the payback period in years, which is the difference between the year that the investment first breaks even and the year of investment. A shorter payback period indicates a larger BCR and a more beneficial investment.

As discussed at the beginning of this section, many of the BIM ROI studies identified through the literature review measured ROI as net benefits divided by costs, which is not consistent with BCA metrics. The ROI metrics quantified for this study are consistent with traditional BCA reporting practices.

4.3 Factors Influencing Realization of Benefits

There are several factors that can affect an agency's potential to realize all benefits of BIM, but two are especially important: BIM use cases implemented and agency BIM maturity. These factors are described further in the following sections.

BIM Use Cases Implemented

Software companies typically sell a variety of BIM-related software packages that provide access to particular use cases. For instance, purchasing a software package for cloud-based document management can provide use cases associated with sharing and accessing BIM models. Alternatively, purchasing software specifically for design reviews can provide use cases associated with improved QC, editing, and geometric analysis, in addition to the use cases from sharing and editing BIM models.

Agencies that purchase BIM-related software packages can access more functionality (i.e., enable the adoption of more use cases). The research team mapped each benefit of BIM to one or more use cases. Therefore, agencies that acquire more use cases can realize more benefits. Agencies that purchase BIM-related software with use cases for asset management will be able to unlock the additional benefits that come from using BIM during the entire project lifecycle.

Agency BIM Maturity

This study defines agency maturity as the organization's level of familiarity with BIM. The more "mature" agencies are, the more likely they are to be familiar with potential use cases for BIM and apply BIM throughout the project lifecycle. This can be represented conceptually by a CMM, as discussed in Chapter 2. While several CMMs are available, they are all based on three basic BIM adoption stages. These three stages define minimum BIM requirements and milestones to gauge level of BIM adoption (Succar 2010). These definitions of BIM adoption stages align well with the current state of and desired outcomes for BIM adoption in the United States.

The three stages of BIM adoption are Level 1, Level 2, and Level 3 (illustrated by Figure 4-5).

- Level 1, object-based modeling: might include creating 2D information for contract plans or creating 3D files for contractor use (e.g., AMG).
- Level 2, model-based collaboration: typically involves sharing federated (i.e., combined) models within a single shared online area while also relying on file-based collaboration and library management. Might include creating 3D object models for all disciplines.
- Level 3, network-based integration: fully integrated PIMs shared via real-time CDE and use of standards for interoperable data. Includes information attributes for all 3D objects.

This study defines BIM as the adoption of intelligent object-based 3D modeling. Levels 1–3 represent different variation in the adoption of BIM; Level 1 indicates an agency that has acquired fewer use cases of BIM than Level 2 or Level 3.

However, it is the increment between the Base Case and Investment Case, rather than the value at each level, that is important for BIM. Levels 1–3 can be represented by different Investment Cases for BIM adoption. The Base Case represents the level of BIM adoption if new investment

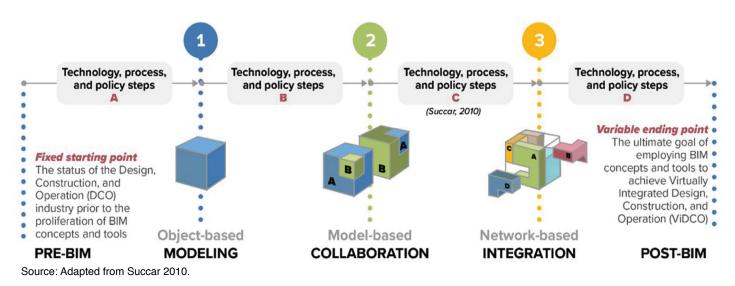
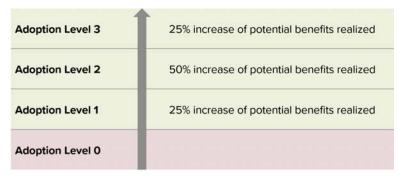


Figure 4-5. Levels of BIM adoption.



Note: Each increase in potential benefits shown in the figure is calculated as the change from the previous adoption level to the current level, rather than the total benefits accumulated from Level 0.

Figure 4-6. Benefits realized by levels of BIM adoption.

in BIM is not made. The Base Case could be Pre-BIM (Level 0), Level 1, or Level 2. Going from a Base Case of Pre-BIM (Level 0) to an Investment Case of Level 1, for example, would generate fewer benefits than going from a Base Case of Pre-BIM (Level 0) to an Investment Case of Level 3. In fact, the returns from achieving different levels of BIM adoption are not expected to be linear; that is, going from Level 0 to Level 1 is expected to generate fewer benefits than going from Level 1 to Level 2. Figure 4-6 summarizes this effect, which is also coded into the BIM ROI Tool. (Note that the value of percent changes between levels is an assumption made in the BIM ROI Tool to capture the concept of nonlinear returns.)

4.4 Identified Benefits and Costs of BIM

Based on the literature review, case studies, and expert panel, 24 benefits and 15 costs were associated with investing in BIM-related technologies. This section describes all unique benefits and costs; however, not all benefits can be monetized due to current data limitations. All the costs identified are costs to the agency. Most of the benefits also accrue to the agency, but some benefits would also accrue to users of the transportation asset (e.g., roadway users), and a small portion would go to the public.

BIM Benefits

The research team identified four categories of benefits associated with BIM:

- In-house agency cost savings: financial cost savings to the agency at an institutional level that are not attributable to a particular project. Benefits ramp up over time as more projects are designed using BIM methods.
- **Project cost savings:** financial cost savings attributable to a specific project from using BIMrelated technologies on that project.
- Staff time savings: efficiency gains due to implementing BIM. By saving time on a particular task, staff time can be reallocated to another task.
- User benefits: all benefits realized by asset users, plus a small portion of benefits to the general public.

As indicated in the definitions, both agency cost savings and project cost savings are avoided financial costs. However, as avoided costs, financial cost savings do not represent revenue generation for the agency. Benefits monetized in this study represent added value, not necessarily increased revenues. It should not be assumed that BIM-related investments will generate net financial savings. Instead, the combination of avoided financial costs plus improved efficiencies and workforce utilization can result in a positive net gain from investing in BIM, which is reflected through financial cost savings and efficiency gains.

Not all benefits of BIM can be monetized. First, some benefits of BIM are intangible improvements. For instance, improved communication due to detailed BIM design is a benefit. If improved communication leads to staff time efficiencies, then it can be monetized, but communication without time efficiencies can be difficult to monetize. Therefore, the ROI does not reflect all possible benefits of BIM. Additionally, as more agencies and industries adopt BIM, agencies that choose not to adopt BIM may be left behind, causing additional intangible costs.

Second, data limitations prevent the monetization of some benefits. User benefits, for instance, are not monetized in the BIM ROI Tool because these benefits can vary significantly from project to project. One example of user benefits is travel time savings to roadway users from reduced construction road closures for projects that use BIM techniques to improve schedule management. By reducing the days of construction, an agency is also able to reduce the days of road closures and congestion for vehicles. However, estimating such a benefit would require an understanding of the traffic levels during construction, the delay caused by construction, the diversion routes, and the hours of road closures that could be avoided, which vary vastly from project to project.

The BIM ROI Tool includes calculations to monetize 20 benefits; however, several of these benefits require agency data in order to be included in the analysis. Table 4-2 through Table 4-5 list the benefits identified by four categories: in-house agency cost savings, project cost savings, staff time savings, and user benefits.

BIM Costs

The research team identified 15 BIM-related costs, grouped into two categories:

- **Initial costs:** one-time, upfront costs associated with purchasing BIM technology. This includes costs such as the initial setup and configuration of BIM-related software for the DOT, as well as initial comprehensive trainings for staff.
- Ongoing costs: regular, semi-regular, or temporary costs incurred over time to maintain BIM-related investments. These include costs such as ongoing software subscriptions, recurring software and hardware upgrades as needed, and ongoing staff trainings.

Table 4-6 lists the identified costs associated with adopting BIM.

4.5 Monetizing Benefits

This section provides an overview of the calculations made in the BIM ROI Tool to estimate the benefits of BIM. Calculations are illustrated using structure and logic (S&L) diagrams. S&L diagrams are a visual illustration of a set of calculations used to estimate a particular result or final output. The diagrams consist of boxes connected with arrows. Each box represents an input variable or parameter; intermediate output (calculated based on the input variables, parameters, and other intermediate outputs); or the final output. The arrows between boxes are operations (e.g., add, multiply, divide). In addition to helping to explain how calculations are made in the tool, S&L diagrams also identify the data needs for the calculations.

There are a total of six S&L diagrams included in this section, grouped into one of the three benefit categories monetized for the BIM ROI Tool. Rather than having one diagram for each of the 20 monetized benefits, some diagrams are generalized to represent calculations for several

Table 4-2. In-house agency cost savings from adopting BIM.

Code	Benefit Name	Benefit Definition
BA 1	Cost savings from reduced paper, printing, and distribution	This benefit refers to reduced spending on the production and distribution of plan sheets plus printing and shipping of bid tabs that results from moving to a digital approach. Agencies that have already implemented "e-construction" or only issue electronically signed and sealed PDFs of the plans will not experience these cost savings.
BA 2	Cost savings from reduced physical storage needs and office space/elimination of leased building space	This benefit is the cost savings from reduced use of office space and leased building space for storage of paper plans and other physical files due to digital conversion. Agencies that have already implemented "e-construction" or only issue electronically signed and sealed PDFs of the plans will not experience these cost savings.
BA 3	Avoided vehicle crashes due to safety simulation with BIM	This benefit results from avoiding potential vehicle crashes due to improved safety simulations during project design. Specifically, this benefit is monetized by the avoided operational costs to the agency (e.g., cleanup and property repair costs, such as guardrail replacements) that would have resulted from vehicle crashes.
BA 4	Improved worker safety during construction inspections	This benefit represents the value of reduced worker accidents during construction inspections resulting from increased use of automation by contractors. Specifically, workers may be less exposed to heavy equipment when contractors use AMG, and they may spend less time onsite performing inspections by using 3D model viewer apps on mobile devices.
BA 5	Improved worker safety during maintenance inspections	This benefit represents the value of reduced worker accidents during asset maintenance inspections resulting from increased use of automation when capturing existing conditions. Specifically, workers may be less exposed to live traffic because they may be using remote sensors to capture information that can be compared to a 3D as-built model of the asset.
BA 6	Cost savings on inspections due to the use of drones	This benefit is the cost savings on inspections due to the use of drones. For instance, using drones during bridge inspections has been shown to reduce the need for traffic control, which avoids the costs associated with traffic control.

Table 4-3. Project cost savings from adopting BIM.

Code	Benefit Name	Benefit Definition
BP 1	Cost savings from avoided change orders	This benefit is the cost savings from avoided change orders due to improved collaboration between disciplines to identify conflicts and constructability issues.
BP 2	Cost savings from improved schedule management	This benefit is the cost savings that result from completing a project early or on time due to the use of BIM for managing the schedule. For instance, the use of 4D model simulations to identify sequences of activities that may interfere with each other. This risk management tool enables the team to make plan modifications to conduct the work without affecting the timeline.
BP 3	Lower construction bid prices due to improved communication of design intent	This benefit captures the reduction in costs of construction contracts due to reduced risk from the use of BIM. Specifically, contractors bidding on construction contracts may reduce bid amounts by removing the risk contingency given the access to 3D models that better communicate the design intent.
BP 4	Cost savings from creating visualizations with BIM	This benefit represents the cost savings of creating a visualization video with the use of modern 3D modeling software (compared to completing a project visualization without 3D design models of the project). This might include visualizations for public information, safety simulations, or other uses.
BP 5	Cost savings from optimization of construction material or design options due to BIM design	This benefit is the cost savings from optimization of construction material use or design options due to having a detailed project 3D model. This refers to the optimization of material use rather than reduction of material overruns. Construction materials or design options can be optimized through BIM visualization and design tools.

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Table 4-4. Staff time savings from adopting BIM.

Code	Benefit Name	Benefit Definition
BS 1	Time savings from re-using previous BIM content for future similar work	This benefit represents the time saved in developing a project design by re-using previous BIM content (3D-component libraries in CAD). This benefit grows over time as a content library of 3D templates is developed.
BS 2	Time savings from avoiding tracking down information for scoping project	This benefit is the total time saved on scoping a project. Specifically, this represents time saved in tracking down information due to having access to an enterprise database that has been populated from BIM products as a reference, such as digital as-built or asset inventory record models.
BS 3	Time savings from improved design efficiency, including parametric design and avoided design rework	This benefit is the time saved when creating a project design due to improved work efficiency, including parametric design and avoided design rework. This would require the use of modern modeling software with parametric design and dynamic updates functionality.
BS 4	Time savings in document review and approval due to faster turnaround time by using cloud- based software	This benefit is the time saved when reviewing and approving documents due to faster turnaround time with cloud-based software. This benefit will not be realized for agencies already using real-time review workflows with cloud-based software to review PDF plan sheets (e.g., Bluebeam). Benefits may also be realized by taking an intermediate step to go from paper to electronic workflows using PDF plans. While not a BIM environment, the implementation of a real-time collaborative review process using electronic plans (PDF form) and cloud-based software to track comments can result in some benefits similar to the full implementation of BIM.
BS 5	Time savings from avoided RFIs due to improved clarity of design	This benefit is the time saved by having fewer RFIs, and therefore spending less time responding, due to improved clarity of design from BIM models.
BS 6	Staff time saved from improved schedule management/improved workforce utilization	This benefit is the staff time saved due to improved schedule management. Improved schedule management enables teams to reallocate staff tasks from one activity to another (i.e., improved workforce utilization).
BS 7	Time savings during construction inspections due to use of 3D digital design data	This benefit is the time savings during construction inspections from utilizing 3D digital design data and GPS equipment or mobile model viewers (instead of traditional methods, such as using plan sets, cross-sections, or level and tape methods).
BS 8	Time savings on completing design quantities	This benefit is the time savings on completing design quantities due to automation with BIM. This refers to the BIM software functionality to automate reports for all pay item quantities, instead of using manual methods with spreadsheet calculations.
BS 9	Avoided time spent tracking down information needed for routine maintenance or repair work	This benefit is the avoided time spent tracking down information needed for routine maintenance or repair work due to having all information saved in a centralized location.

Table 4-5. User benefits from adopting BIM.

Code	Benefit Name	Benefit Definition
BU 1	Travel time savings for roadway users due to reduced construction road closures (from improved schedule management)	Reduced road closures translate to fewer days of detours for vehicles.
BU 2	Vehicle operating cost savings for roadway users due to reduced construction road closures (from improved schedule management)	Reduced road closures translate to fewer vehicle miles traveled.
BU 3	Emissions cost savings for roadway users due to reduced construction road closures (from improved schedule management)	Reduced road closures translate to fewer vehicle miles traveled, and thus fewer emissions.
BU 4	Safety benefits for roadway users due to reduced construction road closures (from improved schedule management)	Reduced road closures translate to fewer vehicle miles traveled, and thus fewer vehicle collisions.

Table 4-6. Costs from adopting BIM.

Code	Cost	
Initial Costs		
CI 1	Initial cost of BIM asset management software or system configuration and customization (e.g., professional services to set up system solution)	
CI 2	Initial BIM hardware investments or upgrades required (e.g., computer workstations, tablets, GPS rovers, drones, robotic stations)	
CI 3	Cost of initial comprehensive staff training	
CI 4	Opportunity cost of staff time for initial comprehensive training	
Ongoing Costs		
CO 1	Incremental costs of BIM-related software subscription	
CO 2	Incremental spending on IT resources or infrastructure from BIM (e.g., cloud storage capacity/data storage, ProjectWise capacity, internet speed/capacity)	
CO 3	Semi-regular hardware replacement costs (e.g., GPS rovers, drones, robotic stations)	
CO 4	Cost of external refresher staff trainings	
CO 5	Opportunity cost of staff time for external refresher trainings	
CO 6	Opportunity cost of staff time for internal refresher trainings	
CO 7	Opportunity cost of creating new training materials	
CO 8	Average cost increase of professional services contracts due to requiring BIM for design	
CO 9	Cost of hiring additional staff needed for BIM program	
CO 10	Cost of acquiring digital as-built once project is completed	
CO 11	Cost to maintain database of digital as-builts	

benefits. As indicated by the diagram legends, the rectangular boxes with the darkest shading represent data used to quantify benefits of BIM, while rectangular boxes with lighter shading represent model parameters or other economic data used in the tool. Rounded boxes with the lightest shading are intermediate outputs calculated, and darker rounded boxes are the final output (i.e., BIM benefits).

Calculations for In-House Agency Cost Savings

All six agency cost-savings benefits shown in Table 4-2 can be represented by either

- Direct reduction in annual organizational costs due to BIM; or
- Reduction in quantity of inputs required for organizational operations due to BIM, which translates to reduced costs.

The S&L diagrams in this section represent these two categories of agency cost savings.

The S&L diagram in Figure 4-7 shows the calculation of agency cost-saving benefits from a direct reduction in costs. An example of this type of agency cost-savings benefit (represented by the "X" in Figure 4-7) is reduced spending on the production and distribution of plan sheets as well as printing and shipping of bid tabs, a result of moving to a digital approach. This benefit is calculated by estimating the average annual spending on paper, printing, and distribution prior to adopting BIM, as well as the percent reduction in this spending due to digital conversion. Multiplying these two variables yields the average annual cost savings, which is then discounted using the social discount rate over the period of analysis. This results in total discounted agency cost savings from reduced spending on paper, printing, and distribution.

Figure 4-8 includes an S&L diagram representing in-house agency cost savings from a reduction in quantity of inputs. An example of this type of benefit is the reduction in average worker injuries during construction inspections due to increased use of automation. This limits Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management

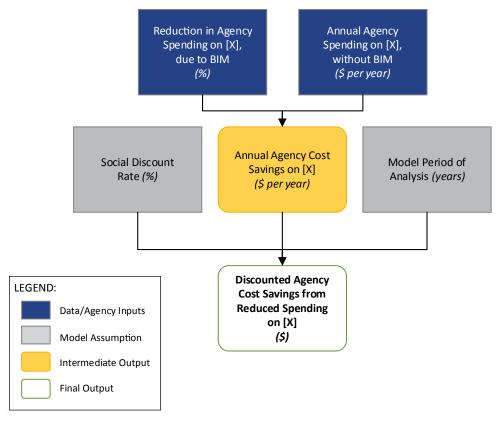


Figure 4-7. Agency cost savings—reduced cost.

worker exposure to heavy equipment and may reduce the amount of onsite inspection time versus 3D model viewings. To estimate this benefit, the average annual number of worker injuries across all projects without automation is multiplied by a percent reduction in injuries due to the use of automation. This yields the avoided annual number of worker injuries, which is monetized using average values per injury, by level of severity, as provided in the U.S. DOT BCA guidance. This annual avoided cost is discounted over the period of analysis.

Project Cost Savings

Like agency cost savings, project cost savings are calculated as either a direct reduction in per-project costs due to BIM or a reduction in input quantities required per project due to BIM. Since project cost savings are an improvement per project, the benefit is scaled up by the number of projects per year to calculate annual cost savings. The S&L diagram in Figure 4-9 illustrates the calculation of a project cost-savings benefit brought about by a direct reduction in cost.

One example of a project cost-savings benefit fitting this calculation structure is reduced spending on construction materials or design options due to BIM design. This benefit is calculated by estimating average spending on construction materials as a percentage of total contract value, then multiplying by the average contract value for the agency's typical project to get average spending on construction materials per project. This number is then multiplied by the percent reduction in spending on construction materials due to the optimization of materials from the use of BIM during design. Per-project savings are then scaled by the average number of projects per year that use BIM to calculate annual cost savings, and then discounted back over the model period of analysis to get discounted total project cost savings.

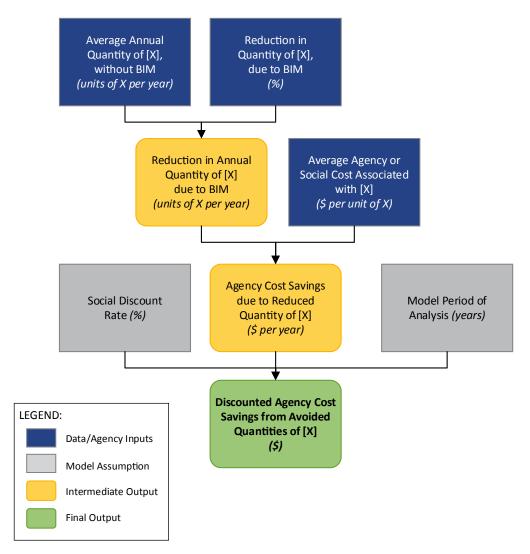


Figure 4-8. Agency cost savings—reduced quantity.

The S&L diagram in Figure 4-10 illustrates the calculation of a project cost-savings benefit brought about by a reduction in quantities per project. An example of this benefit is project cost savings from improved schedule management. This is the benefit that results from completing a project early or avoiding overruns due to the use of BIM for managing the schedule. To calculate this benefit, the average duration of the agency's typical project should be estimated. This is multiplied by the percent improvement in project schedule due to BIM to get the number of avoided days of delay. This is monetized using a generalized conditions cost to approximate the average value of a day saved in the project schedule. These cost savings are discounted over the model period of analysis to get total discounted project cost savings from improved schedule management.

Staff Time Savings

Staff time-savings benefits (as shown in Table 4-4) can be represented by either

- Reduction in staff time spent on project-related activities due to BIM; or
- Reduction in staff time spent each year on other agency-related duties due to BIM.

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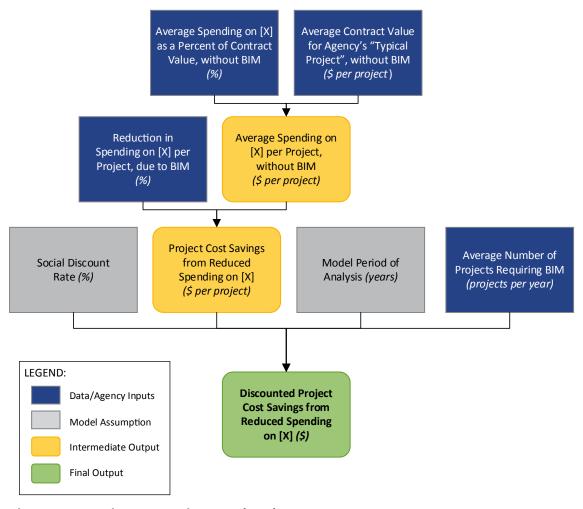


Figure 4-9. Project cost savings—reduced cost.

The S&L diagram in Figure 4-11 illustrates calculations for the first type of staff time-savings benefits.

One example of this project-related staff time-savings benefit is time saved on completing design quantities due to automation. In this example, using BIM to automate reports for all pay item quantities (rather than using manual methods with spreadsheet calculations) allows staff to save time on this project task. To monetize this benefit, the average time spent on manual methods is multiplied by a percent reduction in staff time on this activity due to automation. Hours saved are then monetized using average hourly staff rates for the relevant staff involved in the task. The total value of staff time saved is estimated on a per-project basis and is scaled to annual cost savings based on the average number of projects each year requiring BIM. These savings are discounted over the model period of analysis.

The S&L diagram in Figure 4-12 illustrates calculations for staff time-savings benefits at the organizational level rather than staff time related to a specific project.

An example of organizational staff time-savings is reduced time spent tracking down information needed for routine maintenance and repair work because all information is saved in a centralized location. Populating asset inventory databases creates centralized data storage processes, facilitating access by all staff. This example includes staff time savings during operations for

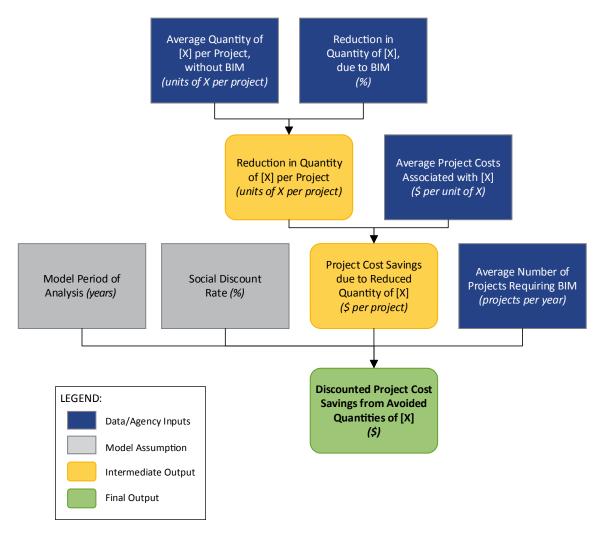


Figure 4-10. Project cost savings—reduced quantities.

all projects maintained by the agency. These calculations are very similar to those in Figure 4-11, but time is saved for the agency per year rather than per project. To calculate this benefit, the average time spent each year tracking down relevant asset information without BIM is multiplied by the percent improvement (in time spent) given the centralized data location. These hours saved are monetized using staff hourly wages. These annual savings are accrued over the model period of analysis and discounted back to present value terms using the social discount rate.

4.6 Conclusions and Observations

The ROI framework described in this chapter was implemented into the Excel-based BIM ROI Tool. This tool calculates the benefits and costs of investing in BIM-related technologies assuming a 10-year period of analysis and a social discount rate of 4.0 percent, though both parameters can be adjusted by the agency. The tool calculates and displays the various ROI metrics discussed in this report, including the BCR and NPV of the investment.

The analysis is necessarily performed at the program level rather than at the project level. There are many reasons for this approach, including the fact that the investment costs are not meant to be recovered by one project, but rather over time after the process is applied to a program **76** Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management

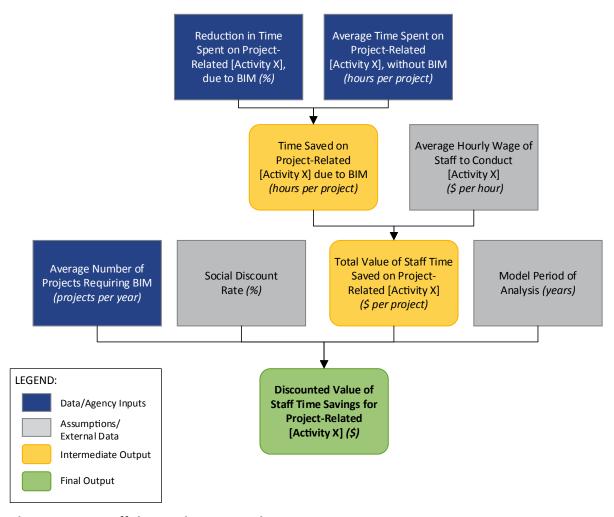


Figure 4-11. Staff time savings per project.

of projects. Also, not all the benefits of BIM can be attributed to a specific project. The agency benefits listed in Table 4-2 accrue to the organization rather than to one project. Finally, there are several cumulative project-level benefits that can only be realized once enough time has passed and enough data have been collected. For instance, agency staff can save time on designing a new project by reusing previous BIM content, but first a 3D component library must be built over time. Due to this program-level approach and data limitations, described later in this report, the BIM ROI Tool cannot be used to evaluate the case study projects individually. Instead, the tool should be used to evaluate the extent to which an agency's program of projects can benefit from the use of BIM.

Based on the literature review, case studies, and expert panel, this study identified 24 benefits associated with implementing BIM for transportation projects. Four of these benefits could not be quantified because they were context specific and the data would be difficult to obtain. These are the four user benefits described in Table 4-5. For instance, roadway users are expected to receive travel time savings from reduced construction road closures for projects that use BIM techniques to improve schedule management. In other words, by reducing the days of construction, the agency is also able to reduce the days of road closures and therefore reduce congestion for vehicles. However, this would require an understanding of the traffic levels during construction, the delay caused, the diversion routes, and the hours of road closures that could be avoided, which vary largely from project to project.

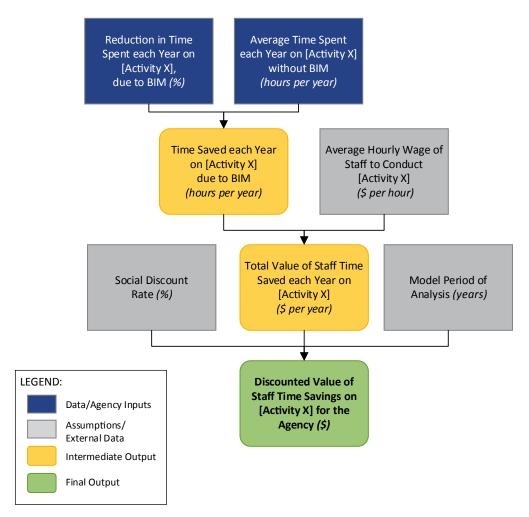


Figure 4-12. Staff time savings—organizational.

Calculations for the remaining 20 benefits were built into the BIM ROI Tool; however, 14 of these benefits were missing data for one or more variables and thus required agency input. The remaining 6 benefits were monetized in the BIM ROI Tool. Similarly, there were 15 costs of BIM identified by this study. Of these 15 costs, 8 costs were missing data for one or more variables and thus required agency input. The remaining 7 costs were monetized in the tool.

Based on the 6 monetized benefits in the tool, cost savings from avoided change orders (BP 1 in Table 4-3) are the largest benefit. This also aligns with qualitative findings from the case studies—all five of the case studies identified avoided costs associated with change orders as a significant benefit of BIM. The next largest benefits are both agency cost savings: from the use of drones during inspections—thus avoiding costs associated with traffic control (BA 6 in Table 4-2)—and also from avoided worker injuries during maintenance inspections due to increased automation, remote sensors, and reduced exposure of workers to live traffic (BA 5 in Table 4-2). The remaining 3 monetized benefits are all associated with improved staff efficiencies. Out of the 20 quantifiable benefits identified, 9 are staff time savings. This indicates that while there may be more benefits associated with staff efficiencies, the highest value comes from project cost savings and agency cost savings. Thus, agencies may decide to focus on tracking benefits associated with project and agency cost savings, while tracking staff efficiencies from BIM may not be worth the effort.

Considering the 6 monetized benefits and 7 monetized costs and making various assumptions about the agency context (e.g., the number of use cases, typical project size and duration, and software costs), this ROI study calculated an ROI from BIM greater than 1.0, indicating a net positive investment. However, there are several qualifications to this result.

First, not all the identified benefits and costs are monetized and included in this ROI result due to data limitations. For instance, the literature review found that many ROI studies tend to focus on the returns of BIM for buildings rather than for transportation infrastructure. The case studies were helpful in enumerating the benefits of BIM qualitatively. For instance, all five of the case studies had identified avoided costs associated with change orders as a significant benefit of BIM. However, these agencies did not track much of the data needed to monetize benefits. Additionally, only one of these agencies (DEN) has started using BIM for asset management, so these benefits were particularly difficult to capture. Collecting cost data from the case studies was also difficult since the project teams interviewed were not in charge of the agency's financial decisions (i.e., investing in software, hardware, or other equipment) and therefore were unaware of these costs. The expert panel was helpful in providing orders of magnitude estimates of the benefits; many BIM practitioners do not collect the data but do have a sense of the relative significance of the benefits. Additionally, some participants did provide data on costs and benefits after the panel session.

Agency context is also critical for determining the benefits and costs of BIM; therefore, it is not feasible to provide one solution to the ROI of BIM for any given agency. Instead, the BIM ROI Tool requires the agency to enter various inputs to specify the agency context. As discussed in this chapter, realizing benefits from BIM depends largely on the number of BIM use cases acquired and pursued by the agency. Acquiring more use cases (through the purchase of various modeling software programs) allows the agency to realize more benefits. Thus, the agency must specify in the BIM ROI Tool that BIM use cases will be acquired in the Investment Case.

Similarly, agencies need to specify what types of investments they plan to make as part of their BIM adoption process (such as investing in new hardware, BIM trainings, and equipment). Because many of the benefits are calculated as a percent reduction in project costs, agencies must also specify the size of their typical project.

Another important aspect of the agency context is specifying the level of BIM adoption in the Base Case compared to the Investment Case (Table 4-1). This allows the BIM ROI Tool to calculate the incremental change in benefits between the state of the world with the BIM investment and "business as usual" for an agency. For instance, if the agency plans to go from Level 0 (pre-BIM) to Level 1 (object-based modeling), the benefits will be lower than if the agency goes from Level 0 (pre-BIM) to Level 2 (model-based collaboration). While the tool does require several inputs by the agency, there are also many suggested values provided to help inform an agency's estimates.

Given these data limitations and the requirements for inputs on the agency context, the BIM ROI Tool provides two options to the user. First, the agency can perform a default analysis, which allows the user to perform a quick ROI analysis based on the data collected for the 6 benefits and 7 costs. The agency will still need to enter information on the agency context under the "User Inputs" sheet.

The second option is to perform a detailed analysis, which captures all 20 benefits and 15 costs identified by the study. This option requires the agency to provide data or estimates to help monetize the 14 benefits and 8 costs with missing data. These values can be based on agency estimates at first, and then these values can be adjusted over time, as the agency collects the data indicated by the tool, to more precise measures. The agency must still enter information on the

agency context on the "User Inputs" sheet. (More details on these options and instructions on how to use the BIM ROI Tool are provided in Appendix B of this report.)

One finding from this study is that many transportation agencies agree conceptually that there are many benefits from BIM and that these benefits likely exceed the costs of investment. However, agencies are often not collecting the type of data needed to measure and monetize the benefits from this investment. One reason is likely that there is no standardized set of metrics established to inform agencies on what type of data should be collected.

Thus, one of the key outcomes from this study should be to establish such a set of standard metrics. The BIM ROI Tool includes a sheet called "Benefits Data," which lists all the variables and units needed to measure each benefit. The research team strongly recommends that agencies use this sheet of variables to inform their data collection process going forward. After several agencies have collected these data, the team suggests performing further research to compile, aggregate, and review these data to add to the knowledge base of BIM benefits.

One of the goals of this study was to answer four key questions regarding the ROI of BIM. These questions are presented in the following sections, along with responses based on the findings from this study.

Can the Benefits of BIM Be Quantified?

The research team identified 20 quantifiable benefits of BIM. However, due to data limitations, 6 of these benefits were fully monetized in the tool, while the remaining 14 benefits include some, but not all, of the required data for monetization. However, calculations for all 20 benefits are coded into the BIM ROI Tool. If agencies provide estimates for the remaining data items, the tool will automatically incorporate the remaining benefits into the ROI calculation.

Are the Benefits of BIM Substantial Enough to Justify the Investment Required by Implementation?

Based on the 6 benefits and 7 costs monetized in the BIM ROI Tool, and given several assumptions about agency context, the benefits of BIM do justify the investment. However, there are several caveats to this answer. As described earlier, this result does not account for 14 benefits and 8 costs of BIM identified by this study. These benefits and costs cannot be fully monetized in the tool at this time due to data limitations. Additionally, agency context is critical for determining the benefits and costs of BIM, thus it should be tailored to each agency. This includes specifying which BIM use cases are acquired by the agency, what types of investment costs will be incurred (hardware, trainings, equipment, etc.), what is the agency's typical project size, and what is the agency's maturity level of BIM in the Base Case versus Investment Case (refer to Figure 4-5). However, based on qualitative feedback received during the interviews with transportation agencies and BIM experts during this study, there is a strong belief that the benefits of BIM do outweigh the costs.

What Is the Cost of Doing Nothing?

While the ROI of investing in BIM varies by agency, the long-term cost of making no investment into BIM-related technologies is likely to be significant. Software costs are one of the few costs identified in the study. An agency that chooses not to integrate BIM does not necessarily avoid the costs of upgrading systems. Software is frequently updated, and legacy versions are sunsetted. As a result, an agency may have to purchase new software simply to continue what it has already been doing. An agency adopting only a basic package does not receive the full benefits of BIM. This would be like purchasing a smartphone but using it only to make phone calls. The marginal costs of additional packages are minor compared to the benefits of BIM integration.

Based on conversations with agencies and BIM experts during this study, BIM is the future for the industry. While there are limited data to quantify the ROI from this investment, the feedback received overwhelmingly confirms that using BIM techniques can help save money and time. If an agency chooses not to integrate BIM, the missed benefits of BIM (minus the marginal costs of additional packages) are the costs of inaction.

How Can Stakeholders Realize the Maximum Benefit of BIM?

Based on the findings from this study, there are multiple factors that determine the level of benefits that can be realized from BIM. First, the more BIM use cases acquired by the agency, the more opportunities there are to realize benefits from BIM. This means that investing in software and technologies that allow more opportunities for applying BIM methods provides more avenues for realizing benefits. In particular, agencies that apply BIM techniques throughout the project lifecycle (from delivery through asset management) have more opportunities to realize benefits.

Another factor that determines the scale of benefits is the level of agency BIM maturity (i.e., the level of BIM adoption). As described in Figure 4-6, the adoption of BIM can be grouped into different levels, ranging from pre-BIM (Level 0), to the use of 2D and 3D independent files (Level 1), to model-based collaboration (Level 2), to a fully integrated model sharing real-time information in a CDE (Level 3). Depending on the agency's level of BIM adoption in the Base Case and the Investment Case, the benefits realized will vary. For instance, going from Level 0 to Level 1 is likely to provide fewer benefits than going from Level 1 to Level 2.

Finally, this study found that the level of benefits can also be constrained by the type of projects to which BIM processes are applied. BIM tends to be most beneficial for large and complex projects. For instance, using BIM techniques for a straightforward re-paving project may offer fewer benefits; but for a megaproject, BIM will likely provide more opportunities to save costs and time. While project complexity is not factored into the BIM ROI Tool calculations, a larger contract value does increase the size of the benefits realized.



CHAPTER 5

BIM for Asset Data Management

5.1 Summary

In Part 1 of ISO 19650, BIM is defined as the "use of a shared digital representation of a built asset to facilitate design, construction, and operation processes to form a reliable basis for decisions" (ISO 2018a). BIM has shown significant benefits across many industry sectors. The adoption of BIM for highway and bridge assets will allow for workflow efficiency gains, detailed construction costs, and reduction of construction errors in a time when the transportation sector needs to effectively address the improvement and management of deficient infrastructure. The adoption of BIM requires the development of an intentional transition strategy to alter the methods for producing and organizing information related to two broad phases of a project: delivery and operations. It also requires organizations to evaluate their approach to handling assets, which frequently includes identifying the need to move from a siloed, primarily phase-based perspective to a lifecycle perspective.

This chapter provides a structure to help highway agencies develop their BIM asset data management strategy. Following the introduction, this chapter presents a four-part approach to develop the BIM strategy; define the asset information data requirements; leverage BIM during the delivery phase for improved delivery performance, along with the production of asset information for operations; and use an AIM to support operations.

The broad adoption of BIM throughout a transportation agency is a journey and will require significant planning. This guide was developed to initiate and direct this planning, while also pointing to some of the most valuable external resources for detailed implementation.

5.2 Introduction

To achieve the benefits of leveraging asset data from BIM throughout asset management and future infrastructure projects, an agency must focus on developing a structured lifecycle information management approach. This introduction provides the foundation for this approach.

Information Management Process

The development of clear BIM asset data requirements necessitates a structured information management process. In 2018 and 2020, ISO released a series of new standards (ISO 19650, Parts 1, 2, and 3) that document a framework and structured process for adopting BIM strategies to define asset information requirements (AIR) for an organization. These asset information needs can be interpreted into specific project information requirements (PIR) from team members, enabling an owner to receive valuable asset data at the conclusion of the project delivery phase.

The information management process, as it relates to the built highway and road infrastructure, has two broad phases, as defined within asset information management standards (ISO 2018a). These phases of the asset information management lifecycle include 1) development of asset information in the project delivery phase, and 2) the use and updating of asset information in the operational phase. One challenge faced by transportation agencies is how to implement requirements on the activities within the delivery phase to obtain valuable information that can be used during the operational phase of the assets (roads, bridges, signs, etc.). To do this, an intentional process must be performed—first to define the overall goal of leveraging asset data to support lifecycle asset O&M, then to identify and define the information that can be developed or procured during the delivery phase (design and construction) to support the overall operational process.

To align with the two primary phases of delivery and operation (or asset management), there are two categories of models: 1) the PIM, developed by project team members (e.g., designers, constructors, and inspectors, either in-house or contracted parties); and 2) the AIM, maintained by the transportation agency. It is important to note that the term "model" frequently refers to a federated model (composed of multiple, integrated data sources), and the model is an information model, not necessarily requiring 3D information for all its components. To successfully develop these information models, the information requirements need to be clearly defined, both at a project level and at an asset management level.

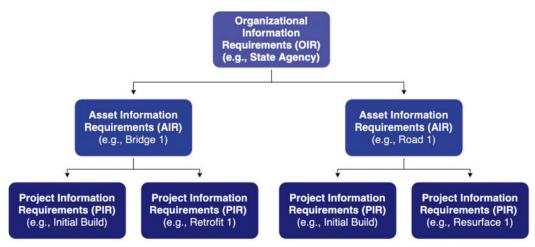
There are multiple approaches to documenting these requirements, including 1) the development of well-defined information exchanges, 2) the creation of detailed asset data requirements, and 3) requiring that elements within a 3D modeling application be modeled to a specific LOD and level of information (LOI). LOD generally relates to the reliability and detail of graphical content of models, while LOI relates to the non-graphical content of models.

Within the information management lifecycle, there are important information exchange points or events when information is shared. The information exchange points or events include the start of a project delivery phase, where information is shared from the operational phase of the AIM, as well as from the new project to represent the existing conditions (especially important for renovation or repair projects). At the end of the project delivery phase (or throughout the delivery), information is shared from the PIM to the AIM. These fundamental information exchanges—from AIM to PIM, and from PIM to AIM—must be clearly defined and closely managed.

In the context of a highway project, the information exchanges can be documented as clear BIM requirements. An example of requirements can be found in projects such as the NYSDOT Kew Gardens Project (described in the case studies chapter). Within this project, existing condition information was captured and shared with the design team. Then the project team continuously built upon the existing information by creating a design model. This design model content was required to be used as the foundation for construction model content. At the conclusion of the delivery, the contractor was required to provide as-built model content to NYSDOT, including updated underground utilities. The as-built model data will be used to populate the AIM for use during the operational phase to support asset management and asset inventories. It is important to note that an AIM is not one single model, but a collection of individual models that are harvested into their authoritative asset inventories by asset class.

Recommendations for Planning for BIM for Asset Management

Initially and clearly defining the information that will benefit the agency within the asset operations and inventory processes is critical to the success of leveraging BIM data and models created during the design and construction phases in support of asset management. Information



Note: This chart is aligned with ISO 19650, Part 3. However, in the standard, hierarchy is not represented under this structure, and there is an exchange information requirement (EIR) defined as a subset of PIR and AIR.

Figure 5-1. Representation of information requirement hierarchy.

needs can be viewed as a hierarchy of information (as seen in Figure 5-1), moving from overall agency information needs to specific information per asset (e.g., bridges, roads, and other assets) and information that can be gained from the delivery (design and construction) phase.

To develop the AIR, there are a series of steps that an agency can perform (defined in Section 2 of this chapter). In general, the agency will need to prioritize the specific information needs for assets documented as the AIR (e.g., bridge condition information, accurate utility location information) and confirm that clear PIR are defined to ensure that the necessary information can be collected from various project team members (e.g., designers, constructors, and inspectors). The actual information is collected in a series of information exchanges, which are defined as exchange information requirements (EIRs). Once the series of exchange requirements is defined, the requirements can be added to the project agreements to ensure that team members deliver the information as required.

5.3 Section 1: BIM for Asset Data Management Strategic Plan

To be successful in developing a comprehensive strategy for managing lifecycle asset data across multiple projects, it is important to develop a strategic plan for collecting, storing, retrieving, and using the data. A transportation infrastructure owner should develop an asset data management plan to clearly define the important asset information that will be managed throughout the lifecycle, along with the various use cases for leveraging this information. This section defines the elements that are foundational to developing the asset data management strategy. The strategy can be developed by 1) creating a BIM and asset data steering committee to guide the process; 2) developing the asset data management strategy; and 3) assessing and updating the existing portfolio of BIM and asset data throughout the organization.

Create a BIM and Asset Data Steering Committee

A BIM and Asset Data Steering Committee should be assembled to include individuals who have background knowledge and experience with BIM and its processes and should represent a diverse group of members from across the organization (Messner et al. 2019). As with any organizational change, the Steering Committee should be a multidisciplinary group that includes all stakeholders who will feel the impact of the changes, as well as those with deep knowledge of the organization's asset data and data storage capacities. Their role is to develop the strategic plans, make key decisions, and guide the implementation of the plan. The Steering Committee may report to a separate executive group, depending upon the structure of the agency or the level of executive involvement in the Steering Committee. If the agency does not have previous BIM experience, it may be advantageous to seek assistance from third-party BIM implementers.

The Steering Committee should include the following types of representatives:

- BIM champion. A technically skilled and motivated person to guide the development and implementation of the asset data strategy, or BIM champion, should be included. The champion could be from areas such as asset management, design, or construction, depending on the strengths and experience of the person and departments within the agency. A champion should have the ability to direct funds and staffing as necessary to support the BIM efforts. The importance of a dedicated BIM champion cannot be overemphasized. The champion will need to be devoted, have the authority to make key decisions, and sometimes face challenges when people resist change within the delivery process.
- Executive representation. The Steering Committee should have appropriate representation from an executive level to ensure that it has access to the necessary resources to plan and implement the recommendations that are developed. Examples of possible job titles for individuals in this role within a transportation agency include deputy or assistant deputy director, chief or assistant engineer/director, division administrator/engineer, director of project development, director of operations, and director of information technology, or people who directly report to them.
- Middle management representation. Mid-level managers should be involved in the core
 plan development to ensure appropriate process adoption throughout various departments.
 Typical job titles for individuals in this role within a transportation agency include state design
 engineer, state right-of-way director, state planning director, state construction/materials
 engineer, state structures engineer, state maintenance engineer, and state traffic engineer, or
 people who report directly to them.
- Technical representation. Individuals with technical expertise in various workflows and BIM
 tools will benefit the Steering Committee since their involvement can help foster acceptance
 of the new processes and provide insight into the challenges involved in modifying processes.
 Typical job titles for individuals in this role within a transportation agency include standards
 and methods engineer, CADD services manager, automation engineer, construction management systems manager, GIS manager, and asset management systems manager, or people who
 report directly to them.

When assembling the BIM Steering Committee, consideration should be given to involving personnel with specific responsibilities and capabilities, including

- One or more individuals who can champion the planning throughout the organization;
- Decision-makers who have authority to grant access to resources required by the team (e.g., time, funding, personnel, and infrastructure);
- Individuals who might be directly affected by the adoption or change;
- Motivated individuals who can contribute to the process and support improving the process through change;
- Implementers of the BIM process; and
- Individuals who will be able to monitor progress and manage the process change (Messner et al. 2019).

In addition to the Steering Committee, there can be disciplinary or topic-focused subcommittees or subgroups that work on individual technical initiatives to execute directives provided through the strategic planning process.

Assess and Update BIM and Asset Data Management **Technical Portfolio**

Transportation infrastructure owners typically have multiple databases as well as digital or paper documents that contain information about existing assets. Once a BIM and asset data management strategy is developed, it will be important to review the portfolio of existing asset data information platforms available and develop strategies for managing these platforms. There are several relatively simple core concepts for governing these data sources, but achieving these objectives may require detailed planning. Part 1 of the ISO 19650 information management standards (ISO 2018a) defines a CDE as an "agreed source of information for any given project or asset, for collecting, managing, and disseminating each information container through a managed process." In more common language, the CDE is a defined, common location for an organization to store all information related to projects and assets within a structure that allows for one source of truth for the information required for a task. The CDE may be composed of multiple interconnected data sources, but there should be a clear definition for the location within the CDE that contains the single source of truth for each type of asset information. Ideally, there would be procedures in place to ensure data consistency and quality throughout the CDE.

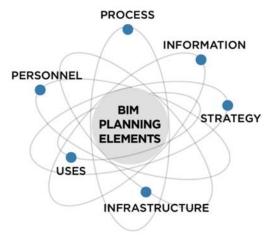
The CDE at a project level encompasses the information needed to manage the project using PIM data. The CDE is typically implemented via a collaborative project management system that enables file sharing and communication about design and construction information (design models, specifications, RFIs, submittals, and change requests). This collection of design, construction, and initial AIMs makes up the PIM. The agency manages the assets by referencing a series of other information sources that make up the AIM.

Every highway agency will have a significant amount of data from previous and existing projects and asset databases that may not be consistent with the developed strategy. An evaluation of the data environment and existing data sources will need to be conducted. When practical, it is necessary to develop strategies for collecting and updating information throughout the existing data environment to work toward a cohesive, comprehensive, and secure CDE. The existing data environment; the as-constructed, as-found existing asset inventory; and existing data sources make up the AIM within the authoritative asset management system. Ideally, the various data sources are related and make up a comprehensive CDE for the asset information.

Determine a BIM and Asset Data Management Strategy

The Steering Committee will focus on the development of a BIM and asset data management strategy. The development of this strategy can be performed through a series of steps. There are several resources to help guide this process, such as structured process documents like the information management standards developed with ISO 19650, along with more practice-oriented guidelines such as BIM Planning Guide for Facility Owners. The documents have common elements that are important to successfully developing a strategy for an asset owner:

- 1. Assessment: Identify the current status of the organization's information management processes related to asset information management.
- 2. **Alignment:** Define the desired future state (at a point in time) for the organization's asset information management.



Source: Messner et al. 2019.

Figure 5-2. BIM planning elements.

3. **Advancement:** Develop an implementation plan to transition the organization from the current state to a future state with improved asset information management.

This process requires time and a commitment to analyzing the organization's current practices and information management approaches. Information and data management processes within the organization are frequently structured around legacy processes and practices, which may not be the best approach when transitioning to digitalization with an increasing LOI.

When developing the strategy, it is important to consider a number of factors. These factors were defined within *BIM Planning Guide for Facility Owners* as 1) strategy, 2) information, 3) process, 4) personnel, 5) uses, and 6) infrastructure (Figure 5-2). A CMM can be used to evaluate the agency's maturity in these areas.

This report will not delve into the details of this process since it has been defined within *BIM Planning Guide for Facility Owners*, but a maturity model that was originally published in the planning guide has been modified to focus on transportation agencies and is included in Appendix E. The Steering Committee should review the process defined within this guide to gain insights into the planning process and leverage the resources provided to create a strategy.

5.4 Section 2: Information Exchange Requirements for BIM Asset Data

This section defines the steps involved for an agency to develop asset data requirements for core asset data and models. The core need to clearly define owner asset data requirements has been highlighted in multiple initiatives, including the emphasis on "beginning with the end in mind" (with the "end" being operations) highlighted in *BIM Project Execution Planning Guide* (Messner et al. 2021) and the initial step in the ISO 19650 information process of assessment of needs by the owner. While this process is included in the strategic planning process in Section 1 at a high level, it is important to consider the detailed steps involved in developing these exchange requirements.

The following seven steps can be followed to develop these AIR, which can be translated into individual requirements as part of an agreement.

1. **Identify lifecycle asset management use cases.** Within the strategic planning process (Section 1), agencies should identify the BIM use cases that align with their core objectives and

goals for implementing BIM. While BIM Planning Guide for Facility Owners does not include specific details regarding BIM uses for highways and roads, Figure 5-3 includes a specific set of BIM uses, organized within two categories of essential and enhanced, that agencies should consider implementing. The details of these BIM uses are defined in Section 3 for plan, design, and construct phases and Section 4 for the operate phase. These use cases are divided into four categories: project delivery core, asset management core, project delivery extensions, and asset management extensions.

- 2. Identify core data models needed to support use cases (e.g., roadway geometry model, bridge model, road network model).
- 3. Define BIM data entities (e.g., shoulders, lanes, medians). Figure 5-4 shows an example of the various potential building blocks for a data model. For example, the roadway geometry data model should include the shoulders, lanes, medians, vertical alignment, horizontal alignment, and routes as objects within the data model, including their geometry.
- 4. Identify data properties that can be collected from the delivery phase. The agency can define specific data properties for each primary object category. The Minnesota Department of Transportation's as-built deliverables website is an example of the clear definition of asset data submissions required from a project. This website provides a series of spreadsheet templates for various road and bridge project asset categories, including bridge, drainage, and facility (Figure 5-5).
- 5. Assign responsible party for data collection. All information should be collected from one source of truth. For some information (e.g., the design information), the responsible party will be the design engineer, and more specifically, the model information that the engineer develops. For other information, such as utility locations, the surveyor may be the responsible party. These responsible parties should be clearly documented.

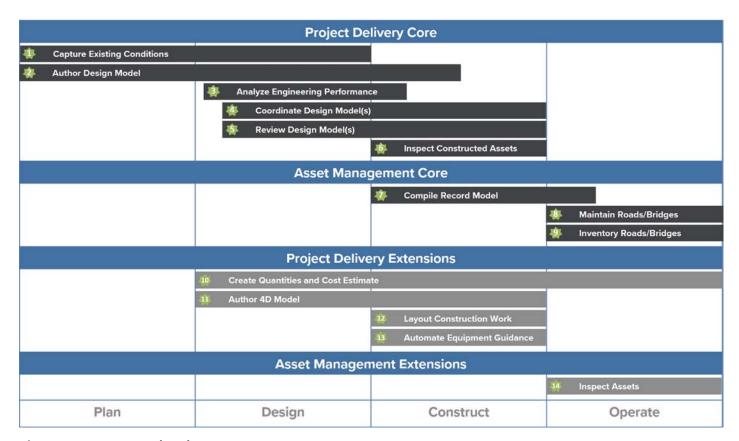
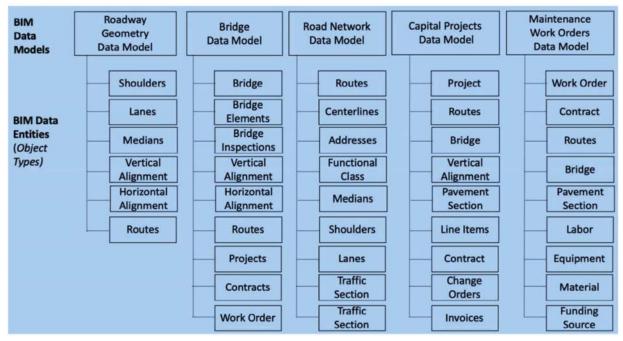


Figure 5-3. BIM uses by phase.



Source: Bhargava et al. 2021.

Figure 5-4. Data entities (or object types) as building blocks for data model.

Drainage Asset Class

Drainage As-built Survey Data Templates

<u>Pipes Template (Excel)</u>, <u>Structures Template (Excel)</u>, and <u>Ponds-Basins Template (Excel)</u> files standardize deliverables for below Index.

Drainage Feature Collect Index

Modified existing culverts, storm drain and structures use TAMS-Hydinfra IDs.

File	Feature Class	Feature	Coordinates Collect	Elevations Collect
Drainage Pipes As-built Survey Data	Pipes	Culvert	At each center of pipe end	At each center of pipe end invert
		Storm sewer drain and slotted drain	At center of casting	At each recessed pipe end invert
		Drain tile in infiltration and filtration areas	At each center of pipe end	At each center of pipe end invert

Source: http://www.dot.state.mn.us/gisspec/index.html.

Figure 5-5. Sample drainage asset class sheet from Minnesota Department of Transportation.

6. Determine ideal data exchange format to enable easy consumption of data. For asset data exchanges, the data should be structured so that they can be easily translated into the core asset management systems (or using ISO terminology, the AIM). This may include a requirement that information be documented in templated data tables, or it could involve defining a standard data schema, such as Construction-Operations Building information exchange (COBie).

There are also ongoing efforts to clearly define openBIM information exchanges that will make this process easier. One initiative that is advancing in the international community, with support from DOTs in the United States, is the BIM for Bridges and Structures Transportation Pooled Fund. This project aims to identify specific information objects, attributes, and relationships for a series of information exchange standards that can or should occur within the design and construction phases of a bridge project. The information exchanges will be very detailed, along with software to transact the information using the IFC data schema managed by buildingSMART International. This schema has been adopted by AASHTO as the data schema for openBIM data exchange. Several other efforts are underway through buildingSMART International Infrastructure Room projects. When complete, this will allow for agencies to simply specify a desired exchange instead of having to create unique information requirements for each exchange. (More information and the current status of this initiative can be found within the buildingSMART International Infrastructure Room at https:// www.buildingsmart.org/standards/rooms/infrastructure/.) Agencies can leverage these open information exchanges once documented. It would be valuable for BIM champions to make sure they are aware of the resources available in these standards projects.

7. Create data exchange requirements. Finalize the exchange requirements in a format that can be clearly referenced within design and construction contracts or leveraged for internal use when required. The requirements should leverage openBIM standards as much as possible.

5.5 Section 3: BIM in the Delivery Phase

The delivery phase is composed of the planning, design, and construction of the asset. BIM can be used throughout the delivery phase to improve overall project performance, including reducing overall delivery costs, improving schedule reliability, and helping to ensure a high-quality design and constructed asset. There are many ways that BIM can be used to support the delivery process. A core subset of these BIM uses is presented in Figure 5-3, and a brief definition is provided in the following sections.

BIM in the Planning Process

The core BIM uses performed within the planning process can be used to develop an existing conditions model to represent current conditions and the initial phases of authoring the early scoping and design schemas. The following are concise definitions of these planning uses:

- Capture Existing Conditions: using 3D information-capture approaches and BIM authoring software to develop a 3D model of the existing conditions for a site, roads/bridges on a site, or a specific area within a road or bridge (Messner et al. 2021).
- Author Design Model: using BIM authoring software to develop a model with 3D and additional attribute information for a road/bridge design, leveraging a library of parametric design elements (Messner et al. 2021).

When viewing the specific data management tasks associated with these BIM uses, the agency should prepare to support the development of the planning model through the following steps:

- 1. Organize existing AIMs and data provided from asset management databases.
- 2. Identify existing or newly classified assets within project work area and associated work type.
 - If work is programmed, information can be updated in the authoritative system with project information as pending status.

- 3. Collect preliminary data from authoritative asset inventory databases or management systems and attach to PIMs as required by the project information exchange requirements.
- 4. Contextualize the project area using conceptual visualization products to help get input from stakeholders and collaborate with external agencies.
- 5. Provide these conceptual visualization models and preliminary data resources to designers as a point of beginning. It may be helpful to involve the design team during the contextualization of the project area.

BIM in the Design Process

The core BIM uses performed within the design process include the development of a design model along with analysis for performance, coordination, and review. The following are concise definitions of these design uses:

- Author Design Model: using BIM authoring software to develop a model with 3D and additional attribute information for a road/bridge design, leveraging a library of parametric design elements (Messner et al. 2021).
- Analyze Engineering Performance: a process in which intelligent modeling software uses the BIM model to determine the most effective engineering method based on design specifications (Messner et al. 2021).
- Coordinate Design Models: using 3D coordination software to compile a federated model of design models for performing automated 3D collision detection to identify potential coordination issues and a visual analysis to identify potential spatial design issues (Messner et al. 2021).
- **Review Design Models:** reviewing a building information model with project stakeholders to gain their feedback and to validate the design, construction, or operational aspects of a project (Messner et al. 2021).

In addition to these essential uses, there are potential enhanced uses that are focused on cost and schedule management. One such use is Create Quantities and Cost Estimate, a process in which BIM can be used to assist in the generation of accurate QTOs and cost estimates throughout the lifecycle of a project (Messner et al. 2021).

Key asset data tasks for setting up a process to develop BIM in design include:

- 1. Uploading any model content created in the design phase to the CDE to share with the design team;
- 2. Generating 3D models with distinct elements for classified assets;
- 3. Populating classified assets with data specified in data exchange requirements; and
- 4. Providing models and data deliverables from the design process to the contractor.

BIM in the Construction Process

The core BIM uses performed within the construction process include the development of a record construction model, the use of the design model released for construction and inspection of constructed assets, authoring 4D models, laying out construction work, and use in automated machine equipment. The following are concise definitions for these construction uses:

- **Inspect Constructed Assets:** using 3D models to verify location, elevation, and quantities of installed assets against contract requirements.
- Compile Record Model/Digital As-Built Model: a process for obtaining information about the elements, surrounding conditions, and assets of a road or bridge (adapted from Messner et al. 2021). This includes the review and acceptance of digital as-built models, including asset objects and appropriate asset information and status. For example, part of the information requirements may include an asset property to indicate if the asset was newly installed, replaced, repaired, or removed/decommissioned.

Also, it is important to recognize that asset objects do not always require a 3D model. It is anticipated that items like striping, for example, are asset objects whose data is important to collect at the end of installation. This information can then be harvested by the authoritative database or system. Thus, compiling a record model or digital as-built of the built environment can be done for all types of projects when the owner agency has established clear requirements guided by data governance policies.

In addition to these essential uses, there are potential enhanced uses focused on the automation of laying out work in the field and guiding equipment, including the following:

- Author 4D Model: a process in which a 4D model (3D model with the added dimension of time) is utilized to effectively plan staged work or to show the construction sequence of various activities (Messner et al. 2021). This BIM use is primarily a construction risk management tool for complex projects or for the benefit of contractors as part of their means and methods. Nevertheless, it is an option for certain types of projects.
- **Layout Construction Work:** using model information to lay out road/bridge assemblies or automate control of automated equipment on a construction project (adapted from Messner et al. 2021).
- Automate Equipment Guidance: using information from a model to guide or control excavation for road and bridge construction equipment on the jobsite.

A core aspect of many of these use cases is the need to create highly detailed models with accurate geometric data, which have been defined within the BIM Forum LOD specification as LOD 400 elements. These detailed asset models will either use the design model as the base reference or, in some instances, transition the design model components into a more detailed construction model representation. This process also includes the compilation of the final record model, documenting an accurate representation with varying potential levels of geospatial detail, and the final constructed product. Specific items that are important within the construction process include

- 1. Creating or transitioning the design models to an appropriate LOD to support construction;
- 2. Using design models, newly developed construction models, and data deliverables for construction use cases;
- 3. Collecting data as required by the EIRs;
- 4. Updating location and attributes of 3D elements in the model as appropriate to capture as-built locations and actual constructed element information; and
- 5. Providing the final BIM and data deliverables to the owner.

5.6 Section 4: BIM for Operations Phase

Once the digital as-built model, including the asset information exchange, has been handed off by the construction team, the information from the PIM relevant to the operations phase is used to populate or update the AIM, which is continuously maintained during the operations phase. The following are concise definitions of these BIM uses during operations:

- Maintain Roads/Bridges: using information from AIMs to monitor status and schedule maintenance activities for a road or bridge (adapted from Messner et al. 2021). It is assumed that this use will be enabled by defining information delivery requirements for all areas that contribute to the development of the AIM. It is important to recognize that the AIM is not static, but rather a model that is constantly being upgraded by the information being collected during O&M activities.
- Inventory Roads/Bridges: using information extracted from AIMs to document and track conditions and quantities assets. It is expected that the digital as-built will augment the information housed in authoritative databases or systems.

In addition to these essential uses, there are potential enhanced uses that are focused on the periodic inspection of assets. For example, Inspect Assets involves using the AIM to inform the inspection of bridges and roads during the operational phase of the assets.

Several core items to consider in this phase include

- 1. Use PIMs and data deliverables to populate Asset Management databases;
- 2. Merge PIMs with AIM;
- 3. Collect data and update AIMs as required by the data exchange requirements;
- 4. Generate reports necessary for O&M; and
- 5. Generate the PIMs from AIMs as necessary to begin a new project.

5.7 Conclusions and Observations

The development of a comprehensive asset management plan using BIM across the scope of assets managed by a transportation agency will require detailed planning over multiple years. It will also require a mindset throughout the agency that places a high value on lifecycle information management. This guide aims to outline a high-level approach to this asset management plan development. There are many resources available to support the development with different solutions.

Some lessons learned from previous initiatives and case studies include

- Seek out empowered BIM champions.
- Start with pilot implementations and grow initiatives after prototyping.
- Begin with the end in mind, that is, understand which data have high value and focus on them from the beginning.
- Focus on targeted improvements, and continue to expand.
- Leverage lessons and resources from others whenever possible, including the ongoing standards work at buildingSMART International, U.S. National BIM Standard activities, and requirements from other agencies.

There are ongoing efforts to support the development and adoption of national and international standards for BIM implementation that will continue to make adoption easier and more consistent. For example, the IFC Bridge and IFC Road projects within buildingSMART International are focused on defining consistent, open information exchanges for bridge and road assets. Agencies can leverage these information exchanges to define information needs and support software vendors in implementing the tools needed to develop the exchanges. The NIBS BIM Council is also leading efforts to develop consistent and detailed processes for defining BIM planning and requirements through national standards. In addition, there are efforts to develop standard, common object-type libraries and minimum information requirements for objects within the library to support common information exchanges. There are many additional initiatives, supported by FHWA, AASHTO, and national standards organizations, to develop more comprehensive and valuable resources for BIM adoption.



CHAPTER 6

Conclusions and Suggested Research

6.1 Research Conclusions

This research focused on defining structured approaches to developing a business case for BIM adoption to support transportation infrastructure projects in the United States. Through analyzing and quantifying enterprise-wide benefits and costs, a transportation agency can identify the value of adding BIM implementation strategies to gain efficiencies and foster comprehensive, data-driven lifecycle management of transportation assets. The information for this research was gathered using domestic and international examples, with the findings targeted toward U.S. transportation agencies and DOT stakeholders.

Several consistent conclusions drawn from multiple data sources include the following:

- 1. BIM provides a significant opportunity for highway agencies to improve the lifecycle management of assets through the creation and use of digital data.
- 2. International and domestic standards initiatives can provide a structure for planning the asset information needs to support a structured lifecycle information management approach.
- 3. While ROI case studies have been reported, the project- and organization-specific context means broad application of results from these individual studies is not always appropriate. Instead, this research can assist organizations in developing a customizable framework for calculating a project's ROI.
- 4. Agencies should develop a high-level asset data management strategy to support the adoption or expansion of BIM to support the entire asset lifecycle.
- 5. Communicating the BIM plan and operationalizing the plan by defining clear practices is critical to successful adoption.

Why do state DOTs continue to struggle to implement BIM as a standard practice? The answer lies in the complexity and perceived cost of moving an organization forward. In a world of dwindling public funds, it is difficult to invest in all initiatives while also maintaining a large and deteriorating transportation infrastructure. Thus, getting the executive support to invest in BIM deployment is unlikely without a robust business case that demonstrates its value. Throughout the literature, case studies, and expert panel discussions, it is clear that in many organizations there is a strong business case for adopting BIM to support the efficient and effective delivery of projects, as well as the larger, more long-term effort to use BIM information in support of O&M. There is a strong and timely need for a solid framework for determining a repeatable approach to calculating the ROI for adopting BIM for Infrastructure and strategies for a strong business case.

This study identified 24 benefits associated with implementing BIM for transportation projects. Based on the six monetized benefits of the BIM ROI Tool developed during this study, cost savings from avoided change orders is the largest benefit. This finding aligns with qualitative

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findings from the case studies. Transportation agencies agree conceptually that there are many benefits of BIM, and that these benefits likely exceed the costs of investment. All five of the case studies identified avoided costs associated with change orders as a significant benefit of BIM.

BIM adoption requires investment from an organization. Some of the top investment categories include training and building competencies, software and professional services for systems setup, and hardware or equipment.

It is important to recognize the value and need for champions to clearly develop the business case, but also clearly communicate the business case to organizational leadership and stakeholders. The multi-media kit supports this communication and includes an overall roadmap, along with videos and responses to frequently asked questions.

6.2 Future Research

The research team identified several items that would benefit from investments in future research and development activities. These can be separated into the categories of standards, structured guidance, legal and contractual, and education and training.

There is a significant need to support the development of standards related to BIM to ensure consistency across projects and throughout organizations. There are international standards (ISO) that we can leverage within the United States, but there remains a need to continue building upon these standards. For example, openBIM data standards are necessary to support the interoperability of data on a project. At this time, there are ongoing activities to develop open data schema standards to support infrastructure projects, such as the IFC defined within ISO 16739, but these standards are not yet complete or adopted.

Standardization initiatives include clearly documenting the information needed for each information exchange between participants within the delivery and operations processes. For these exchanges, it is important to know the objects, attributes, and relationships of the information elements in an open, standard data schema. Additional options, such as creating a common LOD/LOI approach, may also support designers and constructors when creating, using, or validating information contained within a model.

In addition to data standards, process standards and guidelines can be applied to BIM adoption. These include standardizing processes to ensure consistency, such as the adoption of information management standards documented in the ISO 19650 standard.

One limitation of documenting and evaluating the impact of BIM on delivering and operating assets is a lack of clear benchmarking data to support the business case. Throughout this study, many organizations and project teams shared that they did not have consistently collected, readily available information regarding the costs or impacts of implementing BIM or on aspects of their current practice.

There is also an opportunity to develop a guide to define the approaches to adopting BIM specifically for transportation agencies, which could expand upon the framework and asset data management planning contained within this report. This guide could clearly expand upon the CMM and recommend common practices for planning and implementing BIM strategies.

There is also a need for solutions to legal and contractual challenges. These include common contract language to support BIM adoption, mechanisms for signing and sealing digital models to enable transitioning to the model as the legal contract document, and policy to address risk management.

Development of the BCA framework in this study provides a structure to initiate the collection of this information within transportation agencies. A more formalized benchmarking initiative could support additional research into the costs and benefits of specific BIM use cases in the future, leveraging this comment evaluation framework.

Finally, the industry must create and provide avenues to support the education and training of all affected employees of transportation agencies and stakeholders. This could include common education programs, software training, and potential BIM certifications, if they provide value to the industry.

6.3 Final Remarks

While there are many remaining topics related to BIM adoption in the highway sector that need to be advanced, there are currently significant opportunities to leverage BIM to improve the delivery and operations of transportation infrastructure. These opportunities will continue to improve as more standard processes and data exchange schemas are developed, and as agency employees and stakeholders continue to develop their BIM skills. BIM can provide the foundation to support the continued digitalization of information related to transportation infrastructure. This transformation may ultimately contribute to providing and operating infrastructure that is more resilient and safer, while reducing the cost and time required to support the infrastructure.

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APPENDIX A

Multi-Media Toolkit

The purpose of the Multi-Media Toolkit is to support the publicity and dissemination of the study's findings. The toolkit's numerous packages and tools highlight the benefits of BIM as supported by the study. The Multi-Media Toolkit can be found on the National Academies Press website (nap.nationalacademies.org) by searching for *CRP Special Release 4: Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management.*

Package	Tool	Description
Frequently Asked Questions	Handout	This handout covers key terminology and common points of confusion that have been discovered through case study research as well as via discussion with a panel of experts.
BIM Graphics	Infographic	Infographic that explains the connection between a project information model and an asset information model. Accessible via Adobe Reader and Bluebeam.
	Levels of BIM Adoption	Depicts different processes associated with levels of BIM adoption.
	Benefits Realized by Adoption/Maturity Level	Depicts the increase in potential benefits realized with a greater level of BIM adoption.
	BIM Uses by Phase	Depicts BIM Core and BIM Extensions through the phases of a project.
	BIM Costs & Benefits	Depicts changes in costs and benefits throughout phases of BIM.
	BIM Costs	Depicts common initial and ongoing costs associated with BIM.
	BIM Benefits	Depicts high-level common benefits of BIM.
	Uneven Cost & Benefit Streams	Depicts the reduction in costs and increase in benefits over time.
	BIM Realized Benefit per Adoption Stages	Depicts the relative realized benefit based on the adoption stages.
	BIM Implementation Workflow	Depicts the steps that go into BIM implementation.
	BIM ROI Workflow	Depicts the workflow associated with the ROI tool to calculate the total costs and benefits of BIM for a specific project.
Presentations	BIM Presentation for Technical Staff	Presentation to help technical staff to understand the value in BIM and how it can be applied in their day-to-day in order to provide cost savings throughout the infrastructure

(continued on next page)

A-2 Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management

Package	Tool	Description
		design, construction, and asset management process.
	BIM Presentation for Managers	Presentation to help managers to assess the benefits and costs of BIM and how best to overcome common barriers to adoption in their departments. Participants will leave with the tools to make a case for leading BIM adoption in their departments.
	BIM Presentation for Executives	Presentation to help executives identify the benefits and costs, understand the value of BIM, and leave with tools for supporting their agency in the adoption of BIM.
Webinar	ROI Tool Tutorial	Webinar presentation that teaches how to use the ROI tool.
Video Interviews	TRB Panel Interview	Video interview with Morgan Kessler (FHWA), Bill Pratt (CTDOT), Becky Hjelm (UDOT) about the impetus and significance of the study.
	Research Team Interview	Video interview with Alexa Mitchell (HDR), Chris Williges (HDR), and John Messner (Penn State) about the study findings and lessons learned for BIM moving forward.



APPFNDIX B

ROI Workbook and User Guide

ROI Workbook

The BIM ROI Tool is intended to help transportation agencies understand the business case for investing in BIM. Because the results vary greatly depending on the agency context and how the agency plans to use BIM, there is no one-size-fits-all ROI result. Instead, agencies should use the BIM ROI Tool to quantify the benefits and costs of BIM given their own circumstances. Agencies should be prepared to collect and enter cost and benefit data as directed by the tool. Data may need to be obtained from various areas within the organization.

The BIM ROI Tool is provided as a separate Microsoft Excel workbook, which can be downloaded from the link available on the National Academies Press website (nap.nationalacademies.org) by searching for CRP Special Release 4: Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management.

ROI Workbook User Guide

Introduction

The purpose of this User Guide is to provide step-by-step instructions for how to use the BIM ROI Tool and to explain the contents of the workbook. For additional details on the methodology used to calculate the ROI of BIM investments, see Chapter 4.

After this introduction, the User Guide provides a summary of the contents of the BIM ROI Tool, including some detailed sheets that most users can ignore. Next, the User Guide provides instructions for how to use the three functions of the tool:

- 1. Run a quick "Default Analysis" based on rule-of-thumb data and limited agency inputs.
- 2. Run a "Detailed Analysis" tailored to the agency context and requiring more information.
- 3. Use "Investigate Impacts" as an interactive way to review findings from this study.

Workbook Contents

There are 41 worksheets in the tool. However, the agency needs to view only the first 10 sheets to use the tool. The tabs of these 10 "user sheets" are either yellow or red to indicate that they require user inputs or provide results. Throughout the Excel workbook, workbook tabs are color coded as follows:

Yellow: These worksheets require user inputs. Sheets with lighter yellow tabs are required only for the Detailed Analysis, while sheets with darker yellow tabs are required for both the Detailed Analysis and Default Analysis. There are six yellow sheets in the tool:

- START
- USER INPUTS

B-2 Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management

- STAFF DATA
- BENEFITS DATA
- COST DATA
- PARAMETERS

Red: These worksheets show results of the ROI analysis, impact metrics associated with each benefit, and a list of sources used for the data in the tool. There are four red sheets in the tool:

- ROI RESULTS DEFAULT
- ROI RESULTS DETAILED
- INVESTIGATE
- REFERENCES

Blue: These include 20 benefit calculation worksheets plus one sheet that calculates overall ROI metrics. There are four shades of blue indicating four types of calculation sheets:

- Agency benefit calculations (sheets BA1 through BA6)
- Project benefit calculations (sheets BP1 through BP5)
- Staff time benefit calculations (sheets BS1 through BS9)
- ROI results

Orange: These are cost calculation worksheets. There are two orange sheets in the tool:

- INITIAL COSTS
- ONGOING COSTS

Purple: These are additional data worksheets used in the tool. There are five purple sheets in the tool:

- SOFTWARE COSTS
- CASE STUDY RESULTS
- USE CASE MATRIX
- OTHER DATA
- PRICE INDICES

Black: There is one black worksheet (LISTS LOOKUPS), which shows information used in the tool to create dropdown menus or other lists for reference.

Gray: There are two gray worksheets that serve as separators between calculation and data sheets.

Instructions

Agencies can perform three functions with the tool:

Default Analysis allows the user to perform a quick ROI analysis based on rule-of-thumb data included in the tool and some user inputs. This option incorporates only benefits and costs with the best data found through literature review, expert panel, and case studies. However, results will not be tailored to the context of a given agency.

Detailed Analysis allows the user to perform a detailed ROI analysis specific to the agency's context and includes all quantifiable benefits and costs identified by this study. This function requires the user to enter agency-specific data on several sheets. The data inputs are more detailed and take more time to enter than the simple inputs needed in the default analysis.

Investigate Impacts allows the user to review findings from the study. This function is like an automated literature review. No calculations are made, but the user can select from a drop-down list of benefits to view the benefit definition, impact metrics found through the study, and examples of case studies that experienced a given benefit.

The user selects one of these functions on the START sheet, which is shown in Figure B-1. The rest of this chapter explains how to use each of these three functions. The last section explains how to update certain data in the tool periodically.

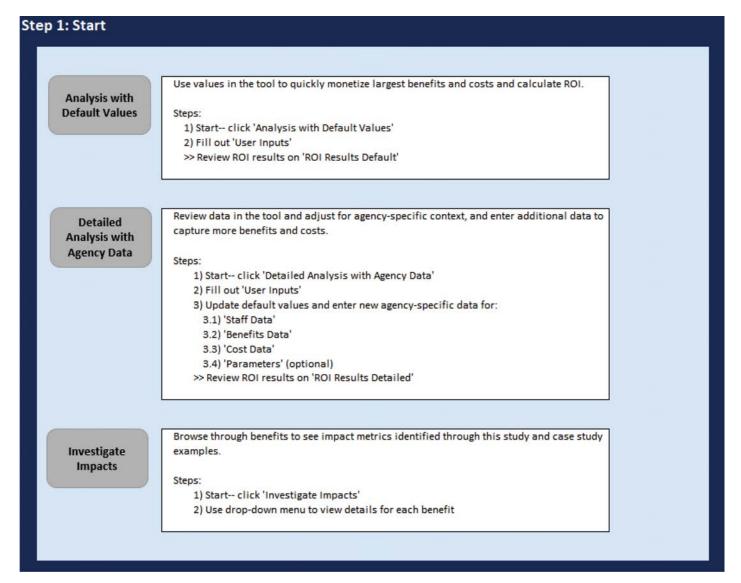


Figure B-1. START sheet.

Default Analysis

There are three steps to perform the Default Analysis, as described in the following sections.

Start

For either type of analysis, the user must begin on the START sheet and click the "Analysis with Default Values" button (shown in Figure B-2) to run the Default Analysis. It is important that the user clicks this button to calculate and view the correct results in the rest of the tool.

User Inputs

Clicking "Analysis with Default Values" will automatically direct the user to the USER INPUTS sheet. As indicated by the instructions on the top of the sheet, the user must fill out all cells in green on the sheet. There are four sections that the user must review and fill out, described as **B-4** Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management

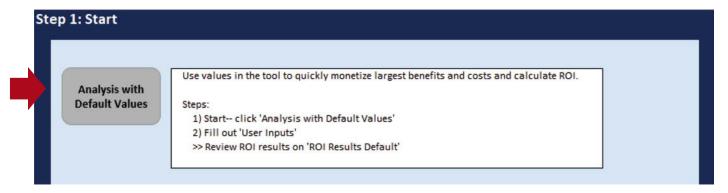


Figure B-2. START sheet—select Default Analysis.

follows. Each section includes various definitions and instructions, plus green cells requiring data from the user.

- **A. Investment Case versus Base Case:** asks the user questions about the level of BIM adoption in the Base Case and the Investment Case. It also asks about the agency's typical projects. Definitions are provided to assist the user.
- **B.** Incremental Software Costs in Investment Case: requires the agency to estimate the additional annual spending on software due to the conversion to BIM in the Investment Case. Note this is not the total software costs, it is only the incremental cost compared to software spending in the Base Case. The user can click the hyperlink to review a table of sample BIM-related software subscription costs; however, these costs vary given what software the agency is purchasing, package discounts, and other factors.
- **C. Use Cases of BIM in Investment Case:** asks the user yes/no questions to identify how the agency will be using BIM in the Investment Case. The user should answer "yes" only if this is a new use of BIM-related technologies that the agency did not implement prior to the BIM adoption in the Investment Case.
- **D. Other Costs in Investment Case:** asks yes/no questions about additional costs that the agency will incur in the Investment Case, such as investment in additional hardware, IT infrastructure, and/or new BIM-related trainings.

After completing all four sections, the user should scroll to the top right of the sheet and click the right navigation arrow. This will take the user to the ROI RESULTS DEFAULT sheet.

To clear all previous data entered in the tool, click "Clear All User Inputs" in the top right of the screen (Figure B-3). **Once this button is clicked, data cannot be restored.** Therefore, it is recommended that the user save a copy of the tool before clicking the "Clear All User Inputs" button.

ROI Results Default

This sheet shows summary metrics from the ROI analysis, including the BCR, total discounted benefits, total discounted costs, NPV, and the payback period. When evaluating results, note that



Figure B-3. Clear All User Inputs button.

a BCR greater than 1.0 indicates that the investment is "net beneficial." The benefits of the investment are expected to outweigh the costs.

The sheet also shows the relative value of all six benefits and seven costs monetized under the Default Analysis. A partial screenshot is provided in Figure B-4.

When finished reviewing results, click "Return to Start" to access the START sheet.

Detailed Analysis

There are seven steps to perform the Detailed Analysis, as described in the following sections.

Start

For either type of analysis, the user must first begin on the START sheet. Click the "Detailed Analysis with Agency Data" button to run the Detailed Analysis (Figure B-5). It is important that the user clicks this button to calculate and view the correct results in the rest of the tool.

User Inputs

Clicking "Detailed Analysis with Agency Data" will automatically direct the user to the USER INPUTS sheet. The agency must fill out the same information as with the Default Analysis. (See instructions for Default Analysis.)

After completing all user inputs, scroll to the top right of the sheet and click the right navigation arrow. This will take the user to the STAFF DATA sheet.

Staff Data

On the STAFF DATA sheet, the user must fill out data on agency staff wages, as well as the number of staff expected to attend BIM-related trainings. Instructions are provided at the top of the worksheet. Throughout the tool, the user should only enter values in green cells. This sheet includes various "suggested values" that the user can reference, but agency-specific data should be provided.

After entering all staff data, the user should scroll to the top right of the sheet and click the right navigation arrow. This will take the user to the BENEFITS DATA sheet.

Benefits Data

This sheet includes a table of all the benefits of BIM identified by this study. The table is divided into four categories based on the benefit categories:

- In-House Agency Benefits: financial cost savings to the agency at an institutional level, not attributable to a single project, and due to implementing BIM methods. For instance, this includes cost savings from repeated data collection and reduced paper and printing requirements.
- Project Cost Savings: financial cost savings attributable to a specific project from using BIM-related technologies on that project. For example, this could include avoided costs associated with change orders.
- Staff Time Savings: efficiency gains due to implementing BIM that are attributable to a specific project or to the agency in general.
- User Benefits: benefits realized by asset users. For instance, travel time savings to vehicles due to reduced construction road closures because of improved schedule management (attributable to BIM). While user benefits are included in this table, they are not monetized in the ROI tool and therefore do not require data from the agency.

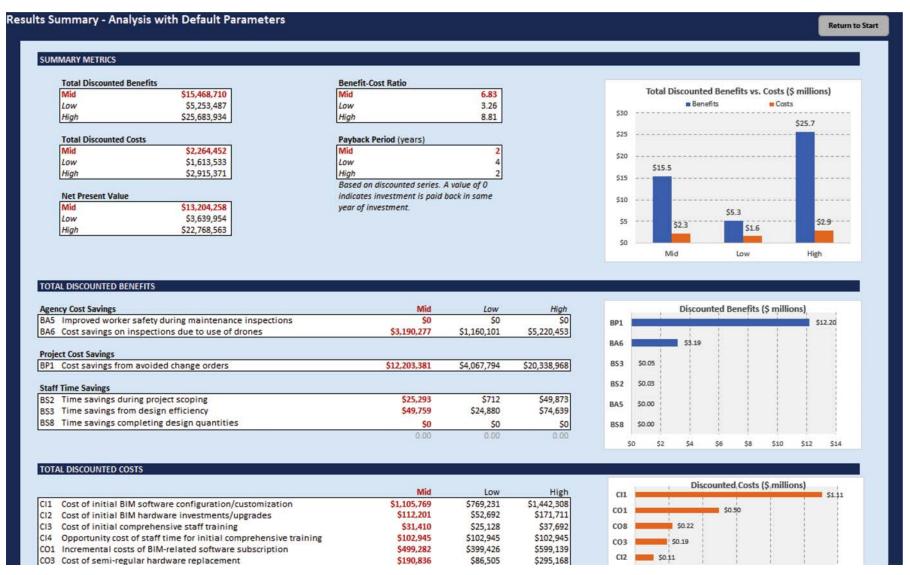


Figure B-4. ROI results default sheet.

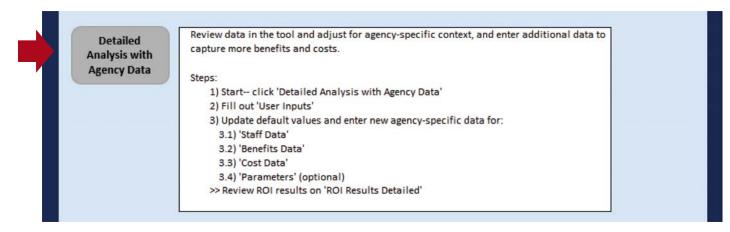


Figure B-5. START sheet—select Detailed Analysis.

For each benefit category, the table includes the benefit code, name, definition, variables used to monetize the benefit, and units of these variables. Columns N through P (in blue) provide suggested values collected through the literature review, expert panel, and case studies. A range of values are provided including a mid-estimate, followed by a low and high range.

Instructions for filling out the benefit data are located at the top of the worksheet. The user should scroll through each benefit, review the suggested value for reference, and enter agencyspecific data in the green cells. If one or more of the benefits do not apply to the agency, the user should enter zeros in the relevant green cells.

After entering all benefit data, the user should scroll to the top right of the sheet and click the right navigation arrow. This will take the user to the COST DATA sheet.

Cost Data

This sheet includes a table of all the costs of BIM as identified in this study. The table is divided into two categories to indicate the type of cost:

Initial/one-time costs: one-time agency costs associated with purchasing BIM technologies, such as the initial setup/configuration of modeling software.

Ongoing costs: regular and semi-regular agency costs incurred over time to maintain BIMrelated investments. This includes things such as ongoing software subscriptions or periodic hardware upgrades.

For each cost category, the table includes the cost code, name, variables used to monetize the cost, and units of these variables. Columns M through O (in blue) provide suggested values as identified through the literature review, expert panel, and case studies. A range of values is provided including the mid-estimate, followed by a low and high range.

Instructions for filling out the cost data are located at the top of the worksheet. As instructed, the user should scroll through each cost, review the suggested value for reference, and enter agency-specific data in the green cells. If one or more of the costs do not apply to the agency, the user should enter zeros in the relevant green cells.

After entering all cost data, the user should scroll to the top right of the sheet and click the right navigation arrow. This will take the user to the PARAMETERS sheet.

Parameters

This sheet includes various modeling parameters and assumptions. For instance, this sheet defines the years of analysis included in the model, the discount rate, and various ramp-up periods **B-8** Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management

for realizing certain benefits or costs. The agency does not need to make changes on this sheet, but the user may review and make updates as desired.

After reviewing and updating parameter values as needed, scroll to the top right of the sheet, and click the right navigation arrow. This will take the user to the ROI RESULTS DETAILED sheet.

ROI Results Detailed

This sheet shows summary metrics from the ROI analysis, including the BCR, total discounted benefits, total discounted costs, NPV, and the payback period, which are common metrics used for economic analyses to determine project viability. The sheet also shows the relative value of all 20 benefits and 15 costs monetized under Detailed Analysis. This sheet looks like the results sheet shown for the Default Analysis (Figure B-4).

When finished reviewing results, the user should click "Return to Start" to access the START sheet.

Investigate Impacts

There are two steps to Investigate Impacts, as described in the following sections.

Start

From the START sheet, click on the "Investigate Impacts" button (Figure B-6). This will automatically direct the user to the INVESTIGATE sheet.

Investigate

The INVESTIGATE sheet allows the user to explore the various benefits identified from this study. Click the green cell to select from a drop-down list of benefits. Selecting a benefit will automatically update the text on the sheet.

Once a benefit is selected, the user will be provided with the following information:

Benefit Full Name: provides the full name of the benefit selected.

Benefit Description: provides a description of the benefit selected.

Impact Metrics: lists the impact metric associated with the benefit selected (if values were found for this benefit). Where available, the percent reduction in agency costs associated with the selected benefit is shown with a mid-value as well as a low to high range.

Reference(s): lists the source(s) used to estimate the range of values provided under Impact Metrics

Case Study Findings: provides examples of the selected benefit from the case studies, if applicable.

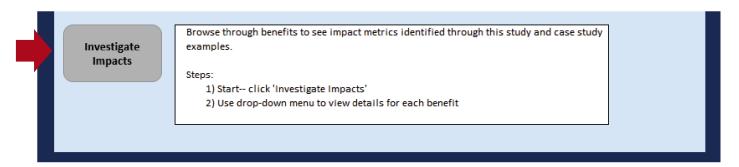


Figure B-6. START sheet—select Investigate Impacts.

When the user is finished investigating benefit impacts, the user should click "Return to Start" to access the START sheet.

Periodic Tool Updates

There are two sheets in the tool that should be updated annually by an agency. This process is described as follows.

Price Indices

PRICE INDICES is a purple sheet located toward the back of the workbook. While the user does not need to review this sheet to perform the ROI analysis, the sheet should be updated annually. To update the sheet, follow these steps:

- 1) Go to the Bureau of Economic Analysis (BEA) website: https://www.bea.gov/.
- 2) Click on Tools: Interactive Data > National Data: GDP & Personal Income > Begin using
- 3) Select National Income and Product Accounts (NIPA) tables > Table 1.1.9 Implicit Price Deflators for GDP.
- 4) Click "modify":

Series: annual.

First year: 2020.

Last Year: [[current year]].

- 5) Click "download."
- 6) Open the downloaded file.
- 7) Navigate to the PRICE INDICES sheet.
- 8) Copy and paste the values for [[current year]] from the downloaded file into PRICE INDICES in the next available column.

Parameters

Most values on PARAMETERS can be updated at the agency's discretion. However, there is one dollar value that should be updated annually: "Value of U Injury (Severity Unknown)." This value comes from the U.S. DOT Benefit Cost Analysis Guidance for Discretionary Grant Programs, which is typically updated annually. Each time a new version of the BCA Guidance is released, the injury value should be updated. Enter the new value in the green cell in E27.

If the dollar year specified in BCA Guidance does not match the dollar year used in the tool (located on STAFF DATA, cell D11), the user will need to inflate the value in the tool based on the GDP deflators on PRICE INDICES. To inflate, use the following formula:

$$Value_{year\,A}*\frac{GDP\ Deflator_{year\,B}}{GDP\ Deflator_{year\,A}} = Value_{year\,B}$$





Glossary

In an effort to provide consistency of terms and definitions for the BIM for Infrastructure domain, this glossary was built upon the glossaries developed for and published by the Utah Department of Transportation and the Pennsylvania Department of Transportation.

BIM Terms

4D BIM: A 3D model linked to time or scheduling information. Model objects and elements with this information attached can be used for construction scheduling analysis and management. 4D BIM can also be used to create animations of project construction processes.

Appointment: Agreed instruction for the provision of information concerning works, goods, or services (ISO 19650, Part 1). *See also* Appointment, Use Cases

Asset: General concept for completed facility, building, or infrastructure.

Asset Information Model (AIM): A model that contains information to support the management, operation, design, and construction of the asset. *See also* 4D BIM

Asset Information Requirements (AIR): Information requirements in relation to an asset (ISO 19650, Part 1).

Asset Management: The process of managing the financial aspects of assets, including buildings; properties and infrastructure; and issues such as initial value, depreciated value, and future commitments.

BIM Execution Plan (BEP): A plan to manage the use of BIM, especially collaboration and information delivery, to accomplish the project goals.

BIM Manager: The individual, normally identified in a BEP, responsible for overseeing the use of BIM on the project. *See also* BIM Execution Plan

BIM Maturity: The levels of complexity and collaboration that Building Information Modeling can take.

BIM Use: A unique project task or procedure that benefits from the application and integration of Building Information Modeling into that process (e.g., design authoring, 3D coordination).

BS 1192: Collaborative production of AEC information. Code of practice.

Building Information Management: The organization and control of the business process by utilizing the information in the digital prototype to affect the sharing of information over the entire lifecycle of an asset (NIBS 2015).

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Building Information Model: The digital representation of physical and functional characteristics of a facility. As such, it is a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its lifecycle from inception onwards (NIBS 2015).

Building Information Modeling (BIM): A service that collects, stores, manages, and shares information through a managed process.

Collaboration: Multiple parties working in a way that is focused on a common outcome rather than individual goals.

Common Data Environment (CDE): See Building Information Modeling

Computer-Aided Design and Drafting (CADD): A category of computer software that is used to develop designs for a variety of disciplines. CADD software typically uses an object-oriented approach to apply mathematical rules that automate the process of drafting roadway designs. 3D digital design data is a common output of the application of CADD software. *See also* Building Information Modeling

CPI: Construction Project Information

CPIc: Construction Project Information Committee

CPIx: Construction Project Information Xchange

Coordination: The process of ensuring the correct spatial separation of elements within a model or on site.

Discipline Model: A model or linked models related to a single discipline. The superstructure model, substructure model, and detailing models are linked together into a federated Structural Discipline Model. *See also* Federated Model

Facility Management (FM): The process of managing and maintaining the efficient operation of facilities, including buildings, properties, and infrastructure. The term also applies to the discipline concerned with this process.

Federated Model: A model that is compiled by integrating different discipline models together into one model through either linking and/or importing. *See also* Discipline Model

Industry Foundation Classes (IFC): A nonproprietary data schema and format to describe, exchange, and share the physical and functional information for the assets within a facility. IFC is the ISO standard for BIM and is being extended to roadway and bridge asset classes.

Level of Detail: Often confused with LOD, level of detail describes only the amount of geometric detail in a model element, not the amount of engineering intent. Highly detailed model elements may be placed in a model as placeholders with no engineering intent. Though detail often increases in parallel with development, observing the detail of a model element is not an effective way to determine its development or the appropriate uses. *See also* Level of Development

Level of Development (LOD): A qualitative designation that communicates the degree of engineering intent behind a 3D model element (or group of model elements) and defines the authorized uses for which the model element is sufficiently developed. Normally the LOD will increase through the design development process as defined in the Model Progression Specification. *See also* Level of Information; Model Progression Specification

Level of Information (LOI): A description of the quality of the non-graphical information attached to the model elements. *See also* Level of Development

Model Element: An entity within a model that represents a physical object or an abstract concept (e.g., alignment, north arrow). *See also* Level of Development; Model Progression Specification

Model Progression Specification (MPS): A specification that defines how the LOD for individual model elements increases over the project milestones. The MPS will assign a specific, minimum LOD to each model element for each milestone. The LOD typically increases from milestone to milestone.

Model Uses or Use Cases: A method of applying BIM during a facility's lifecycle to achieve one or more specific objectives (Messner et al. 2021).

Project Information Model (PIM): See 4D BIM

Project Information Requirements (PIR): Information requirements in relation to the delivery of an asset (ISO 19650, Part 1).

Data-Related Terms

Attribute: Non-graphical data that is part of a model element definition.

Graphical Data: Data conveyed using shape and arrangement and/or location in space. *See also* Non-graphical Data; Spatial Data

Metadata: Data used for the description and management of documents and other containers of information. Metadata are usually structured data embedded within the file. However, metadata could include an external document that describes pertinent information to others on the assumptions and basis for the 3D models, such as the geospatial metadata (grid/ground coordinate system definitions), intended uses of the 3D models, approximations, and simplifications (e.g., removing minor curvature from analysis models). An MPS is important metadata that accompanies a federated model. *See also* Model Progression Specification

Model: A representation of a system that allows for investigation of the properties of the system (EN ISO 29481-1:2016).

Non-graphical Data: Data that describe attributes and properties of a model element that do not relate to its physical dimensions or location. *See also* Attribute; Graphical Data; Property

Parametric: An approach to creating a model where the physical dimensions are constrained by mathematical rules such that the model can be manipulated by changing individual property definitions.

Property: Non-graphical information that describes a model element. For example, the modulus of elasticity is a property of a girder. *See also* Attribute

Schema: A formalized model for structuring information. *See also* Industry Foundation Classes

Spatial Data: Data that are associated with a spatial reference system, such as State Plane coordinates. Spatial data may be raster (e.g., aerial photography) or vector (e.g., point, line, or polygon). *See also* Graphical Data

Data Management Terms

Construction-Operations Building Information Exchange (COBie): An IFC reference standard supporting the direct software information exchange and a spreadsheet that can be used to capture COBie data for both small renovation and capital projects (https://www.wbdg.org/bim/cobie).

Data Exchange: The process of taking data structured under a source schema to transform and restructure into a target schema, so that the target data are an accurate representation of the

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source data within specified requirements and minimal loss of content. *See also* Construction-Operations Building Information Exchange; Information Exchange

Exchange Information Requirement (EIR): Information requirement in relation to an appointment (ISO 19650, Part 1).

Geographic Information System (GIS): A software application that is designed to display, manage, analyze, create, connect, and manipulate spatial data. GIS software includes many Geoprocessing Tools that manipulate Geodatabases, as well as Graphical and Non-Graphical datasets in order to perform complex analyses. For example, PennDOT OneMap is a hosted GIS application. See also Spatial Data

Information Exchange: Packages of information passed from one party to another in a BIM process, or the act of passing such information, possibly as a contractual deliverable. Parties involved agree upon and understand what information content and format will be exchanged. *See also* Construction-Operations Building Information Exchange

Information Requirements: Specifications for what, when, how, and for whom information is to be produced. Information requirements could be documented in a PennDOT publication, in a project Scope of Work, or in a BEP. *See also* 4D BIM; Construction-Operations Building Information Exchange

Organizational Information Requirements: Information requirements in relation to organizational objectives (ISO 19650, Part 1).

Project Information Model (PIM): Information model relating to the delivery phase (ISO 19650, Part 1).

Project Information Requirements (PIR): Information requirements in relation to the delivery of an asset (ISO 19650, Part 1).

Use Cases

3D Coordination: The process in which information models are used to determine field conflicts via clash detection software or visual inspection. 3D coordination is accomplished by comparing proposed 3D geometry from discipline models aggregated into a federated model. 3D elements for all objects are required to perform 3D coordination.

Analyze Engineering Performance: A process in which intelligent modeling software uses the BIM model to determine the most effective engineering method based on design specifications (Messner et al. 2021).

Appointment: Agreed instruction for the provision of information concerning works, goods, or services (ISO 19650, Part 1).

As-Built Record: See 4D BIM

Asset: General concept of a completed facility, building, or infrastructure.

Asset Information Model: The process of creating an inventory of the assets removed, modified, and constructed to hand over to the maintenance, operations, and asset management departments' business systems. The asset information is defined within the organizational AIR. *See also* 4D BIM; Information Requirements

Asset Inventory: See 4D BIM

Asset Management: See 4D BIM

Author 4D Model: A process in which a 4D model (3D model with the added dimension of time) is utilized to effectively plan the phased occupancy in a renovation, retrofit, or addition, or to show the construction sequence and space requirements on a building site (Messner et al. 2021).

Author Design Model: Using BIM authoring software to develop a model with 3D and additional attribute information for a road/bridge design, leveraging a library of parametric design elements (Messner et al. 2021).

Automate Equipment Guidance: Using information from a model to guide or control excavation for road and bridge construction equipment.

Automated Machine Guidance (AMG): The use of real-time positioning equipment with 3D digital data to guide or control the blade on construction equipment, resulting in real-time construction layout without the need for physical markers such as stakes or hubs.

Capture Existing Conditions: Using 3D information-capture approaches and BIM authoring software to develop a 3D model of the existing conditions for a site, roads/bridges on a site, or a specific area within a road or bridge (Messner et al. 2021).

Compile Record Model/Digital As-Built Model: A process for obtaining information about the elements, surrounding conditions, and assets of a road or bridge (adapted from Messner et al. 2021).

Construction Inspection: The process in which the owner's representative monitors and documents construction QA and measures and verifies pay item quantities for completed work.

Contract Documents: A collection of clearly identifiable documents that describe the requirements and terms for a construction project. The contract documents typically include plans, specifications, and working drawings. The specification defines "plans and working drawings," as well as how to coordinate contract documents in the case of a conflict. Models and/or CAD documents may be included in the definition of "plans and working drawings" or defined as specific contractual entities in the specifications or special provisions.

Coordinate Design Models: Using 3D coordination software to compile a federated model of design models for performing automated 3D collision detection to identify potential coordination issues, and performing a visual analysis to identify potential spatial design issues (Messner et al. 2021).

Create Quantities and Cost Estimate: A process in which BIM can be used to assist in the generation of accurate quantity take-offs and cost estimates throughout the lifecycle of a project (Messner et al. 2021).

Design Review: The process in which an information model is used to review and provide feedback related to multiple design aspects. These aspects include evaluation of design alternatives and environmental constraints, review and validation of geometric design criteria, and completeness or quality of overall design.

Inspect Assets: Using the model to inform the inspection of bridges and roads during the operational phase of the assets.

Inspect Constructed Assets: Using 3D models to verify location, elevation, and quantities of installed assets against contract requirements.

Inventory Roads/Bridges: Using information extracted from a model to document and track conditions and quantities of assets.

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Layout Construction Work: Using model information to lay out road/bridge assemblies or automate control of automated equipment on a construction project (adapted from Messner et al. 2021).

Maintain Road/Bridges: Using information of road or bridges models to monitor status and schedule maintenance activities for a road or bridge (adapted from Messner et al. 2021).

Pay Item Quantities: A schedule of work items for which the contractor will be paid and an estimated number for each item. *See also* Quantity Take-Off

Permitting: The process of coordinating with other agencies to secure permits to conduct the construction activities. Many permitting agencies are not prepared for digital delivery and require 2D plans.

Quantity Take-Off (QTO): The process of estimating the pay item quantities. The designer performs QTO to determine the engineer's estimate. QTO is also part of the contractor-estimating process to bid the job.

Review Design Models: Reviewing a building information model with project stakeholders to gain their feedback and to validate the design, construction, or operational aspects of a project (Messner et al. 2021).

Right-of-Way: Conducting a deed search for the right-of-way property boundaries and easements, determining the need for new right-of-way acquisition or vacation, and executing the surveying and platting to document these changes, as well as the acquisition/vacation process.

Scoping: Capturing digital information about the asset inventory, condition and other performance information (e.g., traffic, safety) and evaluating alternatives to determine the scope and estimated cost of the project. For bridge projects, this includes conducting a "type, size, and location" study that includes preliminary structural design.

Visualization: The process of creating visual representations of the project to communicate with technical and non-technical stakeholders throughout the project lifecycle.



Mapping of Use Cases to Benefits

Table D-1 includes the mapping of each use case to one or more monetized benefits. This matrix is used in the ROI tool to attribute benefits based on the use cases selected by the agency. The matrix is located in the Excel workbook in the "Use Case Matrix" sheet. The codes used for the benefits and use cases can be found in Table D-2 and Table D-3, respectively, following the use case mapping table.

Table D-1. Use case mapping matrix.

	Project Delivery Core					Project Delivery Extensions		Asset Mgmt. Core		Asset Mgmt. Extensions				
	CEC	ADM	AEP	СДМ	RDM	ICA	LCW	AEG	CQCE	A4DM	CRM	MA	INV A	INSP A
In-Hou	In-House Agency Benefits													
BA 1		1		1	1	1					1			
BA 2		1									1			
BA 3			1											
BA 4						1	1	1		1				
BA 5														1
BA 6	1					1								1
Projec	t Cost Sa	vings												
BP 1	1	1		1	1				1					
BP 2							1	1		1				
BP 3		1		1	1				1					
BP 4		1												
BP 5		1												
Staff 1	Γime Savi	ngs												
BS 1		1									1			
BS 2											1		1	
BS 3		1												
BS 4				1	1									
BS 5		1		1	1									
BS 6							1	1		1				
BS 7						1								
BS 8									1					
BS 9											1	1		

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Table D-2. Benefit codes.

Benefit Code	Benefit Name
BA 1	Cost savings from reduced paper, printing, and distribution
BA 2	Cost savings from reduced physical storage needs and office space/elimination of leased building space
BA 3	Avoided vehicle crashes due to safety simulation with BIM
BA 4	Improved worker safety during construction inspections
BA 5	Improved worker safety during maintenance inspections
BA 6	Cost savings on inspections due to the use of drones
BP 1	Cost savings from avoided change orders
BP 2	Cost savings from improved schedule management
BP 3	Lower construction bid prices due to improved communication of design intent
BP 4	Cost savings from creating visualizations with BIM
BP 5	Cost savings from optimization of construction material or design options due to BIM design
BS 1	Time savings from re-using previous BIM content for future similar work
BS 2	Time savings from avoiding tracking down information for scoping project
BS 3	Time savings from improved design efficiency, including parametric design and avoided design rework
BS 4	Time savings in document review and approval due to faster turnaround time by using cloud-based software
BS 5	Time savings from avoided RFIs due to improved clarity of design
BS 6	Staff time saved from improved schedule management/improved workforce utilization
BS 7	Time savings during construction inspections due to use of 3D digital design data
BS 8	Time savings on completing design quantities
BS 9	Avoided time spent tracking down information needed for routine maintenance or repair work

Table D-3. Use case codes.

Use Case Code	Use Case Name	
CEC	Capture Existing Conditions	
ADM	Author Design Model	
AEP	Analyze Engineering Performance	
CDM	Coordinate Design Models	
RDM	Review Design Models	
ICA	Inspect Constructed Assets	
LCW	Layout Construction Work	
AEG	Automate Equipment Guidance	
CQCE	Create Quantities and Cost Estimate	
A4DM	Author 4D Model	
CRM	Compile Record Model	
MA	Maintain Roads/Bridges	
INV A	Inventory Roads/Bridges	
INSP A	Inspect Assets	



BIM Maturity Matrix for Transportation Agencies

The following maturity matrix is a modified version of the Owner's BIM Maturity Matrix contained within the *BIM Planning Guide for Facility Owners* (Messner et al. 2021). This matrix was developed to identify the current level of BIM maturity within a transportation agency and allow the Steering Committee to assess opportunities to advance the integration of BIM into the agency. A Microsoft Excel spreadsheet is provided as an accompaniment to Appendix E. Please download the spreadsheet from the link available on the National Academies Press website (nap.nationalacademies.org) by searching for *CRP Special Release 4: Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management.*

The spreadsheet contains a total of 11 worksheets. The first workbook (Figure E-1) provides the instructions for completing the second workbook (Figure E-2). The third workbook, labeled "Summary," summarizes the overall Organizational BIM Assessment Profile results (Figure E-3). The rest of the tabs show the results of the individual BIM Planning Elements. Figure E-4 shows an example of the "Strategy" BIM Planning Element. There is also a "Detailed Summary" (Figure E-5) and a summary of calculations, labeled "Summary Calc" (Figure E-6).

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Organizational BIM Assessment Matrix Transportation Agency Edition Version 1.0, June 4, 2021 Instructions This Organizational BIM Assessment Matrix is designed to help guide an organizational through a process to evaluate the current maturity level to support BIM within an organizational, along with identifying a future target. 1) Identify the planning timeframe for your targeted future evaluation. This could be one or two years for developing shorter term goals, or 5 to 10 years when developing a long term roadmap. 2) Go to the 'Assessment Matrix' worksheet tab at the bottom of this MS Excel page. Within the matrix, 3) Enter a value in each of the 'current' and 'future'. Once entered, the cells will change colors.

4) After completed each of the items, go to the 'Summary' tab to see a summary of all categories. You can also view a summary of each individual category with the 6 category tabs below.

Copyright: This matrix was developed as a minor variation to the Organizational BIM Assessment Matrix contained within the BIM Planning Guide for Facility Owners. This version is shared under a Creative Commons License consistent with the initial version published by Penn State, and available at bim.psu.edu. For more information regarding the use of this matrix, please see the BIM Planning Guide for Facility Owners.

Figure E-1. Transportation agency BIM maturity matrix (instructions).

Planning Element	Description			Level of	Maturity			Current Level	Target Level	Total Possible
Strategy	the Mission, Vision, Goals, and Objectives, along with management support, BIM Champions, and BIM Planning Committee.	0 Non-Existent	1 Initial	2 Managed	3 Defined	4 Quantitatively Managed	5 Optimizing	0	0	25
Organizational Mission and Goals	A mission is the fundamental purpose for existence of an organization. Goals are specific aims which the organization wishes to accomplish.	No organizational mission or goals	Basic organizational mission established	Established basic organizational goals	Organization mission which addressed purpose, services, values (at a minimum)	Goals are specific, measurable, attainable, relevant, and timely	Mission and goals are regularly revisited, maintained and updated (as necessary)	0	0	5
BIM Vision and Objectives	A vision is a picture of what an organization is striving to become Objectives are specific tasks or steps that when accomplished move the organization toward their goals	No BIM vision or objectives defined	Basic BIM vision is established	Established Basic BIM Objectives	BIM Vision addresses mission, strategy, and culture	BIM objectives are specific, measurable, attainable, relevant, and timely	Vision and objectives are regularly revisited, maintained and updated (as necessary)	0	0	5
Management Support	To what level does management support the BIM Planning Process	No management support	Limited support for feasibility study	Full Support for BIM Implementation with some resource commitment	Full support for BIM Implementation with appropriate resource commitment	Limited support for continuing efforts with a limited budget	Full support of continuing efforts	0	0	5
BIM Champion	A BIM Champion is a person who is technically skilled and motivated to guide an organization to improve their processes by pushing adoption, managing resistance to change and ensuring implementation of BIM	No BIM Champion	BIM Champion identified but limited time committed to BIM initiative	BIM Champion with adequate time commitment	Multiple BIM Champions with each working Group		Executive-level BIM Champion working closely with working group champion	0	0	5
BIM Planning Committee	The BIM Planning Committee is responsible for developing the BIM strategy of the organization	No BIM Planning Committee established	Small Ad-hoc Committee with only those interested in BIM	BIM Committee is formalized but not inclusive of all operating units	Multi-disciplinary BIM Planning Committee established with members from all operative units	Planning Committee includes members for all levels of the organization including executives	BIM Planning decisions are integrated with organizational Strategic Planning	0	0	5
BIM Uses	The specific methods of implementing BIM	0 Non-Existent	1 Initial	2 Managed	3 Defined	4 Quantitatively Managed	5 Optimizing	0	0	10
Project Uses	The specific methods of implementing BIM on projects	No BIM Uses for Projects identified	Minimal owner requirements for BIM	Minimal BIM Uses required	Extensive use of BIM with limited sharing between parties	Extensive use of BIM with sharing between parties within project phase	Open sharing of BIM data across all parties and project phases	0	0	5
Agency Uses	The specific methods of implementing BIM within the transportation agency	No BIM Uses for Operations identified	Record (As-Built) BIM model received by operations	Record BIM data imported or referenced for operational uses	BIM data manually maintained for operational uses	BIM data is directly integrated with operational systems	BIM data maintained with operational systems in Real-time	0	0	5
Process	The means by which the BIM Uses are accomplished	0 Non-Existent	1 Initial	2 Managed	3 Defined	4 Quantitatively Managed	5 Optimizing	0	0	10
Project Processes	The documentation of External Project BIM Processes	No external project BIM processes documented	High-level BIM process documented for each party	Integrated high-level BIM process documented	Detailed BIM process documented for primary BIM Uses	Detailed BIM process documented for all BIM Uses	Detailed BIM process documented and regularly maintained and updated	0	0	5
Agency Processes	The documentation of Internal Agency BIM Processes	No internal organizational BIM processes documented	High-Level BIM process documented for each operating unit	Integrated high-level organizational process documented	Detailed BIM process documented for primary organizational Uses	Detailed BIM process documented for all BIM Uses	Detailed BIM Process documented and regularly maintained and updated	0	0	5

Figure E-2. Transportation agency BIM maturity matrix. (continued on next page)

Planning Element	Description			Level of	Maturity			Current Level	Target Level	Total Possible
Information	Information Needs refer to Model Level of Development and Facility Data requirements	0 Non-Existent	1 Initial	2 Managed	3 Defined	4 Quantitatively Managed	5 Optimizing	0	0	15
Model Element Breakdown (MEB)	Model Element Breakdown Structures are identifiers assigned to each physical or functional element in the breakdown of the facility model.	No consistent Organizational Model Element Breakdown	Agency Model Element Breakdown defined but not uniform within entire organization	Agency Model Element Breakdown is uniform within the organization	Agency Model Element Breakdown aligned with industry standards	Agency Model Element Breakdown updated along with industry standards	Agency modifications to industry standard model element breakdown are balloted for inclusion in industry standards	0	0	5
Level of Development (LOD)	The Level of Development (LOD) describes the level of completeness to which a Model Element is developed	No consistent Level of Development	LOD defined but not standardized within entire organization	LOD standardized within the organization	Organizational LOD standards aligned with industry standards	Model View Definitions & Information Delivery Manuals are used to define LOD	Organizational modification to MVDs and IDMs are balloted for inclusion in industry standards	0	0	5
Facility Data	Asset Data is non-graphical information that can be attached to objects within the Model that defines various characteristics of the object	No consistent asset data requirement	Asset data defined but not internally standardized	Asset data defined and standardized within the organization	Organizational asset data attributes aligned with industry standards	Asset data attributes aligned with open standards	Asset data attributes updated with open standards	0	0	5
Infrastructure	Technological and physical systems needed for the operation of BIM with the organization.	0 Non-Existent	1 Initial	2 Managed	3 Defined	4 Quantitatively Managed	5 Optimizing	0	0	15
Software	The modeling programs and other operating information used by a computer to implement BIM	No BIM Software	Software capable of accepting BIM data	Basic BIM Software Systems	Advanced BIM software systems	All software systems available to all personnel	Program established for continuous updating of BIM software systems	0	0	5
Hardware	Physical interconnections and devices required to store and execute (or run) BIM software	No Hardware capable of running BIM software	Some hardware capable of running basic BIM software	All hardware capable of running basic BIM software	Some advanced hardware systems within the organization	All organization hardware is capable of running advanced BIM Software	Program established for continuous updating of BIM hardware systems	0	0	5
Physical Spaces	Functional areas within the agency offices used to collaborate on BIM projects within the agency	No dedicated BIM space	Single workstation for viewing BIM data	Small workspace for collaborating with a screen large enough for multiple viewers	BIM room for collaborating with large screen viewing capability	Multiple collaborative workspaces within regular work area	Program established for continuous updating of BIM spaces	0	0	5
Personnel	Human resources of an organization	0 Non-Existent	1 Initial	2 Managed	3 Defined	4 Quantitatively Managed	5 Optimizing	0	0	25
Roles and Responsibilities	Roles are the primary function assumed by a person within the organization and Responsibilities are the tasks or obligations that one is required to do as part of that role.	No roles and responsibilities documented	BIM is the responsibility of the BIM Champion	BIM is the responsibility of the interdisciplinary BIM group	BIM responsibility lies with each operating unit	BIM responsibility lies with each person	BIM responsibilities are regularly reviewed to ensure they are properly distributed	0	0	5
Organizational Hierarchy	An arrangement of personnel into functional groups within the organization	Organizational Hierarchy does not address BIM	BIM Champion outside of typical organizational hierarchy	Small BIM Implementation Team outside the typical organization hierarchy	Large interdisciplinary BIM Group created	BIM Champion defined within each operating unit	BIM Implementation Team supports BIM Use within operating units	0	0	5
Education	Education is to formally instruct about a subject	No Education Program	Ad hoc education as needed	Formal presentations on what is BIM and the Benefits it has for the organization	Regularly conducted employee education sessions	On-demand education program established for the organization	Education is seamlessly improved through lessons learned within the organization	0	0	5
Training	Training is to teach so as to make fit, qualified, or proficient in a specific task or process	No Training Program	Training program run by vendors - only for necessary personnel	Internal training program for all personnel that may interact with BIM	Regularly conducted and routine training programs	On-demand training program established for the organization	Training is seamlessly improved through lessons learned within the organization	0	0	5
Change Readiness	The willingness and stated preparedness of an organization to integrate BIM	No Change Readiness Awareness	Established need for BIM	Upper management buy- in	Operating unit buy-in	All individuals buy-in	Willingness to change is part of the culture of the agency	0	0	5
Totals	This is the total for all the categories. Note this organization's BIM Implementation.	s does reflect maturity in a	all sections. While the org	ganization could score hig	h, there could be some ke	ey areas not implemented	that could hinder the	0	0	100

Figure E-2. (Continued).

Organizational BIM Assessment Profile							
BIM Planning Element	Current Level	Target Level	Total Possible				
Strategy	0	0	25				
BIM Uses	0	0	10				
Process	0	0	10				
Information	0	0	15				
Infrastructure	0	0	15				
Personnel	0	0	25				
Totals	0	0	100				



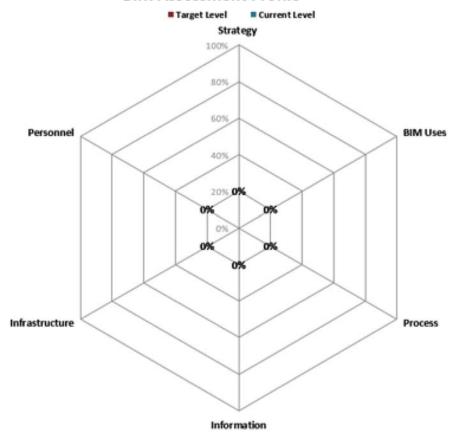


Figure E-3. Summary of Organizational BIM Assessment Profile.

E-6 Lifecycle BIM for Infrastructure: A Business Case for Project Delivery and Asset Management

Strategy								
BIM Planning Element	Current Level	Target Level	Total Possible					
Organizational Mission and Goals	0	0	5					
BIM Vision and Objectives	0	0	5					
Management Support	0	0	5					
BIM Champion	0	0	5					
BIM Planning Committee	0	0	5					
Total	0	0	25					

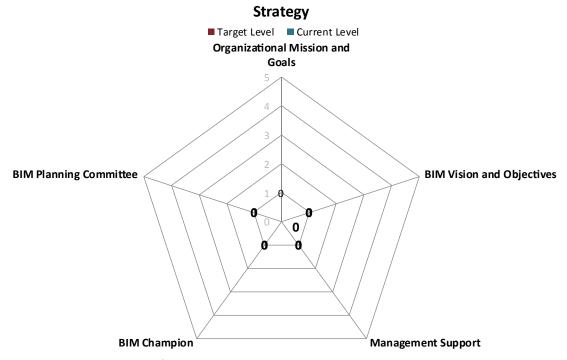


Figure E-4. Example of individual BIM planning element summary.

BIM Planning Element	Current Level	Target Level	Total Possible
Strategy	0	0	25
Organizational Mission and Goals	0	0	5
BIM Vision and Objectives	0	0	5
Management Support	0	0	5
BIM Champion	0	0	5
BIM Planning Committee	0	0	5
BIM Uses	0	0	10
Project Uses	0	0	5
Operational Uses	0	0	5
Process	0	0	10
Project Processes	0	0	5
Organizational Processes	0	0	5
Information	0	0	15
Model Element Breakdown (MEB)	0	0	5
Level of Development (LOD)	0	0	5
Facility Data	0	0	5
Infrastructure	0	0	15
Software	0	0	5
Hardware	0	0	5
Physical Spaces	0	0	5
Personnel	0	0	25
Roles and Responsibilities	0	0	5
Organizational Hierarchy	0	0	5
Education	0	0	5
Training	0	0	5
Change Readiness	0	0	5
Totals	0	0	100

Figure E-5. Detailed summary.

BIM Planning Element	Current Level	Target Level	Total Possible
Strategy	0%	0%	25
BIM Uses	0%	0%	10
Process	0%	0%	10
Information	0%	0%	15
Infrastructure	0%	0%	15
Personnel	0%	0%	25

Figure E-6. Summary of calculations.



Abbreviations and acronyms used without definitions in TRB publications:

A4A Airlines for America

AAAE American Association of Airport Executives
AASHO American Association of State Highway Officials

AASHTO American Association of State Highway and Transportation Officials

ACI–NA Airports Council International–North America

ACRP Airport Cooperative Research Program ADA Americans with Disabilities Act

APTA American Public Transportation Association
ASCE American Society of Civil Engineers
ASME American Society of Mechanical Engineers
ASTM American Society for Testing and Materials

ATA American Trucking Associations

CTAA Community Transportation Association of America CTBSSP Commercial Truck and Bus Safety Synthesis Program

DHS Department of Homeland Security

DOE Department of Energy

EPA Environmental Protection Agency FAA Federal Aviation Administration

FAST Fixing America's Surface Transportation Act (2015)

FHWA Federal Highway Administration

FMCSA Federal Motor Carrier Safety Administration

FRA Federal Railroad Administration
FTA Federal Transit Administration
GHSA Governors Highway Safety Association

HMCRP Hazardous Materials Cooperative Research Program
 IEEE Institute of Electrical and Electronics Engineers
 ISTEA Intermodal Surface Transportation Efficiency Act of 1991

ITE Institute of Transportation Engineers

MAP-21 Moving Ahead for Progress in the 21st Century Act (2012)

NASA National Aeronautics and Space Administration
NASAO National Association of State Aviation Officials
NCFRP National Cooperative Freight Research Program
NCHRP National Cooperative Highway Research Program
NHTSA National Highway Traffic Safety Administration

NTSB National Transportation Safety Board

PHMSA Pipeline and Hazardous Materials Safety Administration RITA Research and Innovative Technology Administration

SAE Society of Automotive Engineers

SAFETEA-LU Safe, Accountable, Flexible, Efficient Transportation Equity Act:

A Legacy for Users (2005)

TCRP Transit Cooperative Research Program

TEA-21 Transportation Equity Act for the 21st Century (1998)

TRB Transportation Research Board
TSA Transportation Security Administration
U.S. DOT United States Department of Transportation

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