Building Information Modeling for Airports

DETAILS

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ACRP
SYNTHESIS 70

AIRPORT
COOPERATIVE
RESEARCH
PROGRAM

Building Information Modeling for Airports

Sponsored by
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A Synthesis of Airport Practice

TRB TRANSPORTATION RESEARCH BOARD
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AIRPORT COOPERATIVE RESEARCH PROGRAM

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Building Information Modeling for Airports

A Synthesis of Airport Practice

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

The need for ACRP was identified in TRB *Special Report 272: Airport Research Needs: Cooperative Solutions* in 2003, based on a study sponsored by the Federal Aviation Administration (FAA).

ACRP carries out applied research on problems that are shared by airport operating agencies and not being adequately addressed by existing federal research programs. ACRP is modeled after the successful National Cooperative Highway Research Program (NCHRP) and Transit Cooperative Research Program (TCRP). ACRP undertakes research and other technical activities in various airport subject areas, including design, construction, legal, maintenance, operations, safety, policy, planning, human resources, and administration. ACRP provides a forum where airport operators can cooperatively address common operational problems.

ACRP was authorized in December 2003 as part of the Vision 100—Century of Aviation Reauthorization Act. The primary participants in the ACRP are (1) an independent governing board, the ACRP Oversight Committee (AOC), appointed by the Secretary of the U.S. Department of Transportation with representation from airport operating agencies, other stakeholders, and relevant industry organizations such as the Airports Council International-North America (ACI-NA), the American Association of Airport Executives (AAAE), the National Association of State Aviation Officials (NASAO), Airlines for America (A4A), and the Airport Consultants Council (ACC) as vital links to the airport community; (2) TRB as program manager and secretariat for the governing board; and (3) the FAA as program sponsor. In October 2005, the FAA executed a contract with the National Academy of Sciences formally initiating the program.

ACRP benefits from the cooperation and participation of airport professionals, air carriers, shippers, state and local government officials, equipment and service suppliers, other airport users, and research organizations. Each of these participants has different interests and responsibilities, and each is an integral part of this cooperative research effort.

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Once selected, each ACRP project is assigned to an expert panel appointed by TRB. Panels include experienced practitioners and research specialists; heavy emphasis is placed on including airport professionals, the intended users of the research products. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, ACRP project panels serve voluntarily without compensation.

Primary emphasis is placed on disseminating ACRP results to the intended users of the research: airport operating agencies, service providers, and academic institutions. ACRP produces a series of research reports for use by airport operators, local agencies, the FAA, and other interested parties; industry associations may arrange for workshops, training aids, field visits, webinars, and other activities to ensure that results are implemented by airport industry practitioners.

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Cover figure: Image symbolizing that BIM for airports can be integrated into all asset life-cycle phases. *Source*: Benson Photography.

FOREWORD

Airport administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to the airport industry. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire airport community, the Airport Cooperative Research Program authorized the Transportation Research Board to undertake a continuing project. This project, ACRP Project 11-03, "Synthesis of Information Related to Airport Practices," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an ACRP report series, *Synthesis of Airport Practice*.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Gail R. Staba
Senior Program Officer
Transportation Research Board

Building information modeling (BIM) is a digital representation of a facility's physical and functional characteristics. It can be shared by planners, designers, constructors, operators, and maintainers to provide reliable information for decision making throughout the facility's life cycle. BIM offers tools that allow airport decision makers to understand all components of a facility, their location, and their attributes, both graphically and systematically, to minimize the total cost of owning and operating an airport facility.

The objective of this synthesis is to deliver information about the general, current *state of the art and practice* in BIM applications in industry and to provide a snapshot of existing experience related to the emergence of BIM in North American airports. The goal is to provide information about BIM and assist airports in understanding available opportunities, benefits, and value related to engaging in BIM. Information used in this study was acquired through a review of the literature and interviews with airport operators and industry experts. In addition to the report, a link to a PowerPoint presentation is provided for use by readers in presenting powerful uses of BIM at airports and information contained in the report.

Dominique M. Pittenger, University of Oklahoma and Arbor Services, and Tamera L. McCuen, University of Oklahoma, Norman, Oklahoma, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

ACRONYMS AND GLOSSARY

Acronyms

AEC	architecture, engineering, and construction professionals
AIA	American Institute of Architects
BBC	Balfour Beatty Construction
BIM	building information model/modeling
CMMS	computerized maintenance management system
FM	facility management
GIS	geographic information systems
KPI	key performance indicator
LOD	level of development
NBIMS	National BIM Standard
O&M	operations and maintenance
RFI	request for information
RFP	request for proposals
ROI	return on investment

Airport Codes

ANC	Ted Stevens Anchorage International Airport
BOS	Boston Logan International Airport
DEN	Denver International Airport
LAWA	Los Angeles World Airports
SFO	San Francisco Airport Commission

Glossary

BIM: a digital representation of physical and functional characteristics of a facility; multidimensional, intelligent facility information (NBIMS 2015).

BIM adoption: begins when an organization makes the decision to use BIM.

BIM adoption status: status of an organization's decision to use BIM; includes five stages (Jung and Lee 2015):

- Stage 1—Interested in adopting BIM, but not yet adopted

- Stage 2—Beginning the process of adopting BIM
- Stage 3—Integrating BIM adoption with existing operations, discovering barriers to adoption
- Stage 4—Completing BIM adoption—overcoming barriers to adoption
- Stage 5—Completed adoption—realizing benefits of BIM adoption.

BIM activity profile: status of an organization's BIM activity level based on its BIM experience, expertise, adoption, and implementation intensity over the project life cycle (McGraw-Hill 2014; Jung and Lee 2015).

BIM engagement: status of an organization's BIM use based on an organization's experience, expertise, and implementation; ranges from low to very high (McGraw-Hill 2014).

BIM implementation: integration of BIM into an organization's business processes (Kreider and Messner 2013).

BIM implementation maturity: status of an organization's integration of BIM based on use/types of BIM activities that facilitate implementation across the facility life cycle; includes four levels: beginning, basic, intermediate, and advanced (Khosrowshahi and Arayici 2012).

BIM implementation plan: a clear organizational strategy that includes the purpose and use of BIM, which is developed during adoption to guide the subsequent implementation process (Penn State 2013).

BIM process: the process of utilizing BIM tools and approaches to improve "traditional" business processes and bring value to projects (Penn State 2010).

BIM purpose: the specific objective to be achieved when applying BIM during a facility's life (Penn State 2010).

BIM resource: the systems, tools, and knowledge required in addition to BIM tools to support and complete the BIM process (Penn State 2010).

BIM tools: support BIM processes at the project and organization levels and are generally categorized as authoring tools or audit and analysis tools (Penn State 2010).

BIM use: a method of applying building information modeling during a facility's life cycle to achieve one or more specific objectives (Kreider and Messner 2013).

Facility life cycle: all phases of a facility, from earliest conception to demolition; generally includes planning, design, construction, operations and maintenance, and renewal.

Level of development (LOD): describes the minimum dimensional, spatial, quantitative, qualitative, and other data included in a model element to support the authorized uses associated with such LOD (AGC, AIA, and NBIMS 2015).

Organization-level BIM: BIM is used by an organization throughout the entire facility life cycle; generally associated with an intermediate to advanced BIM implementation.

Project-level BIM: BIM is reserved for project application only; generally associated with a beginning to basic BIM implementation.

CONTENTS

VII ACRONYMS AND GLOSSARY

1 SUMMARY

3 CHAPTER ONE INTRODUCTION
Building Information Modeling Description, 3
Synthesis Study Methodology and Results Summary, 5
Audience, 8
Report Organization, 8
Costs and Benefits of Building Information Modeling (business case), 8
Background, 8
Airport Experience—Survey Results and Case Examples, 10

14 CHAPTER TWO BUILDING INFORMATION MODELING PURPOSE, PROCESSES, AND TOOLS
Background, 14
Airport Experience—Survey Results and Case Examples, 19

23 CHAPTER THREE ADOPTION AND IMPLEMENTATION
Background, 23
Airport Experience—Survey Results and Case Examples, 26

31 CHAPTER FOUR TECHNICAL ISSUES—CONTRACTS, RESOURCES, AND REQUIREMENTS
Background, 31
Airport Experience—Survey Results and Case Examples, 34

38 CHAPTER FIVE FACILITY LIFE-CYCLE MANAGEMENT
Background, 38
Airport Experience—Survey Results and Case Examples, 41

43 CHAPTER SIX CONCLUSIONS
Summary, 43
Trends and Issues, 43
Knowledge Gaps and Future Research, 44

45 REFERENCES

47 BIBLIOGRAPHY

48 APPENDIX A SURVEY QUESTIONNAIRE AND CONSOLIDATED RESPONSES

65 APPENDIX B MASSPORT BIM ROADMAP

66 APPENDIX C MASSPORT BIM DECISION MATRIX

67 APPENDIX D LAWA PROJECT REQUIREMENT (PR-20)

87 APPENDIX E BIM FOR AIRPORTS: A POWERPOINT PRESENTATION (WEB-ONLY)

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

BUILDING INFORMATION MODELING FOR AIRPORTS

SUMMARY

Building information modeling (BIM) is a digital representation of a facility's physical and functional characteristics. It can be shared by planners, designers, constructors, operators, and maintainers to provide reliable information for decision making throughout the facility's life cycle. BIM offers tools that allow airport decision makers to understand all components of a facility, their location, and their attributes, both graphically and systematically, to minimize the total cost of owning and operating an airport facility.

The objective of this synthesis is to deliver information about the general, current *state of the art and practice* in BIM applications in industry and to provide a snapshot of existing experience related to the emergence of BIM in North American airports. The goal is to provide information about BIM and assist airports in understanding available opportunities, benefits, and value related to engaging in BIM.

Currently, little guidance is available for airport operators on how to implement BIM from project conception through planning, design, construction, commissioning, operation, maintenance, and demolition. Although several airports have utilized some BIM tools and processes in their development programs, there is a shortage of documentation on benefit metrics and lessons learned.

The synthesis study methodology included a comprehensive literature search and survey (i.e., questionnaire and case example interviews), designed to capture current airport BIM practices and experiences. Purposive sampling was used to target a group of airports in North America, as well as other airport architecture, engineering, and construction (AEC) professionals, with known BIM use or use of BIM-related technologies. Fourteen of the solicited 19 airports provided survey responses. Adding in AECs, a total of 18 organizations participated in the survey. Although only potential BIM adopters were targeted, all levels of BIM engagement are demonstrated in the results, from no engagement to full engagement, as presented in this report.

Trends, knowledge gaps, and future research needs were identified by comparing state-of-the-art BIM in various industries as determined in literature with state-of-the-practice BIM in respondent airports as revealed in the survey instruments. Specifically, BIM activity profiles were developed for each of the respondents to provide context for results and to reveal trends.

The study reveals that most of the respondent airports targeted in this study are in the early phases of BIM adoption—*discovering barriers* and *overcoming barriers* to implementation related to integration issues, such as organizational readiness, standards development, contract language creation, and system interconnections. However, a few airports are at the forefront of implementing and deploying BIM, such as Denver, Los Angeles, and Boston Logan.

The results showed that BIM benefits are not generally realized in the short term. The importance of quantifying BIM benefit for cost savings and committing to long-term

implementation was noted. Although the BIM activity levels for the airports currently range from low to very high, *airports are realizing (basic) project-level BIM benefits, such as cost savings generated from early detection of issues.* However, most have not yet fully integrated BIM throughout their organizations and are, therefore, not realizing organization-level (full facility life cycle) benefits, which is where the greatest benefit of BIM is realized.

This study identified a number of knowledge gaps related to business processes and BIM. There is little guidance for airports in the areas of

- Implementing a comprehensive BIM-enabled facility management strategy,
- Developing meaningful key performance indicators for BIM,
- Calculating return on investment for BIM, and
- Creating the contract language and documents to facilitate a full BIM implementation.

Results indicate a shift in airport BIM activity from project-level (beginning to basic) implementation to organization-level (intermediate to advanced) implementation. All airports report the expectation of increasing BIM use in the future that will facilitate the airports' expansion or advancement of their current use of BIM throughout all facility life-cycle phases. This will lead to greater BIM implementation maturity (experience, project implementation, and BIM use across the life cycle) and, in turn, will translate to greater benefits.

CHAPTER ONE

INTRODUCTION

The National BIM Standard (NBIMS) defines building information modeling (BIM) as *multi-dimensional, intelligent facility information* (NBIMS 2015). In 2012, a general survey of owners, architects, engineers, constructors, and owners revealed the BIM adoption rate to be 71%, compared with 28% in 2007, a 75% growth surge in five years (McGraw-Hill 2012). BIM is increasingly being applied by organizations, including airports, to facilitate the process of planning, design, procurement, construction, operation, and maintenance of facilities (FAA 2015a; NBIMS 2015). Because BIM adoption is relatively new, a non-sector-specific *BIM Planning Guide for Facility Owners was released* in 2013 to assist organizations (Penn State 2013).

The objective of this synthesis is to deliver information about the current state of the art in BIM applications in industry and to provide insight related to the emergence of BIM in North American airports. This chapter provides a general description of BIM, a summary of literature about BIM in airports, an overview of the study's methodology and survey results, a BIM activity profile for survey participants, a description of the intended synthesis audience, and an outline of the synthesis topics.

BUILDING INFORMATION MODELING DESCRIPTION

What Is BIM?

> *One common misconception is that BIM is just a 3D model. True BIM requires intelligent data to be input by the various disciplines working within the project and thus elevate the BIM model to its full potential.*
> – Gatwick Airport 2014

NBIMS version 3 (2015) defines BIM as an acronym that is used to describe three separate but linked functions. The first function is described by *building information modeling*, which is a business process for generating and leveraging building data to design, construct, and operate a building during its life cycle. The second function is described by *building information model.* According to NBIMS (2015), a building information model is a digital representation of a building's physical and functional characteristics that serves as a shared knowledge resource for information about a facility. The third definition—for which the acronym BIM is rarely used—is *building information management*, which combines the first two functions to organize and control the business process of building information modeling by utilizing the information in the building information model to enhance the sharing of information over the entire life cycle of an asset.

BIM in the Facility Life Cycle

Facility owners use BIM as a decision-making tool to support the creation and management of assets across a facility's life cycle (GSA 2016). During the feasibility, planning, and development phase, BIM provides owners with information about the current state of the facility and generates information for analysis. During design and construction, BIM primarily supports information capture, communication, coordination, and construction. During the operations phase, BIM supports the performance monitoring of a facility and its systems. For an owner, full life-cycle BIM use requires an *enterprise BIM* approach, which involves implementation at the organization level. *Project-level BIM* is implemented on a project-by-project basis only. Both approaches are supported with technology and methods that include multiple stakeholders, processes, and tasks. Although enterprise BIM focuses on streamlining business operations, establishing a consistent working environment, and increasing work effort devoted to value-added tasks (i.e., decreasing effort for non-value-added tasks) across an organization's operations, project-level BIM is limited to improving the processes of facility design and construction through reduced initial cost or shortened construction time (Smith and Tardif 2009). Enterprise BIM also supports asset management, the "strategic approach to the optimal capital and operational spending on assets to ensure control of cost and risk, asset life, performance, and stakeholder satisfaction" (Shoolestani et al. 2015). Figure 1 provides an example (schematic) of BIM use throughout the facility life cycle.

A link to web-only Appendix E, a PowerPoint Presentation outlining powerful uses of BIM at airports and other information contained in the report, is provided on the TRB web page for ACRP Synthesis 70.

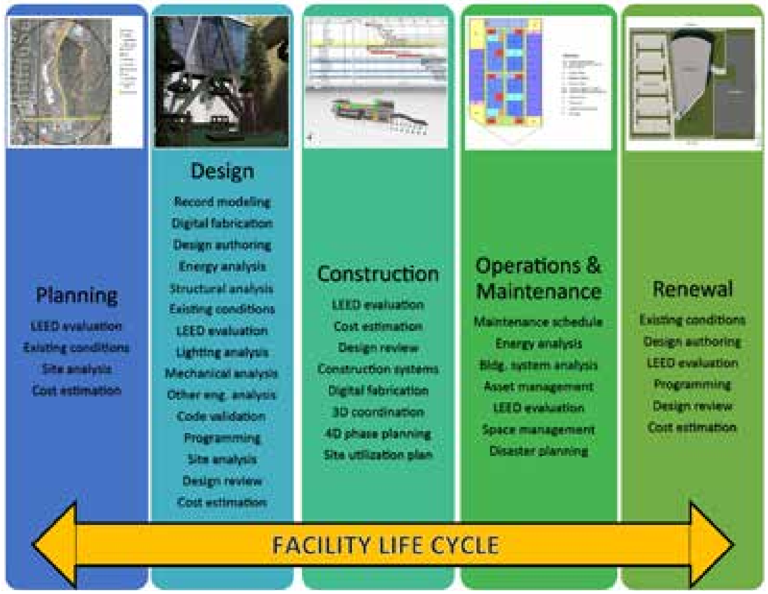


FIGURE 1 Example (schematic of BIM) over a facility life cycle (McCuen and Pittenger 2015).

> *For real property owners and managers, BIM holds great promise beyond improving productivity in the design and construction process. Ultimately, this technology has the potential to enable the seamless transfer of knowledge from facility planning through design, construction, facility management, and operation, and recapitalization or disposal. While all parties involved in design and construction stand to gain from the adoption of BIM,* it is the owners who will potentially benefit the most, *through the use of the facility model and its embedded knowledge throughout the 30 to 50 year facility life cycle.*
>
> – GSA (2016)

BIM Users/Stakeholders in an Organization

BIM users in an organization are classified by discipline and by the facility's life-cycle phase for which they input or consume BIM information (Smith and Tardif 2009). A facility's life cycle begins at the feasibility, planning, and development phase, and typical stakeholders may include the owner, planner, architect, and constructor. The second phase—design and construction—may include the owner, designers, engineers, cost estimators, consultants, general contractors, subcontractors, fabricators, suppliers, manufacturers, facility managers, and code officials. Operations and maintenance is the third phase of a facility's life cycle and may include the owner, facility managers, maintenance personnel, occupants, space manager, security manager, network manager, and first responders. Renewal is the final phase and may include the owner, recyclers, and archivists. A more comprehensive list of stakeholders and their associated uses of BIM can be found on page 23 of NBIMS version 1, part 1 (2007).

History of BIM at Airports (Published Literature)

BIM use has been documented at Frankfurt Airport in Germany (approximately 65 million enplanements/year). It implemented BIM in 2003 and developed a centralized database to support its operations and facilities management and enable "engineering, finance, operations, maintenance, security and emergency response teams to visualize mission critical facility information through interactive facility maps, to find relevant data more quickly, and to minimize operations downtime" (Shoolestani et al. 2015).

London Heathrow Airport (approximately 73 million enplanements/year) reported using BIM since 2004. A case study was conducted on its BIM use during a 2008 airport terminal project. It reported a high rate of savings directly related to its approach (buildingSMART UK 2010).

In 2010, Gatwick Airport in London (approximately 38 million enplanements/year) implemented BIM to support its billion-dollar capital improvement program after a transition to private ownership occurred. It aims to integrate BIM with its existing processes and implement BIM in all life-cycle phases. Although it is has not completed full BIM implementation, it reports that BIM "has transformed project delivery and asset management" at the airport (Neath et al. 2014).

Effectively managing facility information from design through demolition for all of the FAA's buildings and systems is a fundamental element of operating and maintaining the NAS. An integral part of the NextGen transformation is to efficiently manage the FAA's Building and System information. BIM allows for such efficient information management.

– FAA (2015a, b)

The United Kingdom will start requiring BIM for all its public projects in 2016. The Cabinet Office has stated that it has not gotten full value from public sector construction; and it has failed to exploit the potential for public procurement of construction and infrastructure projects to drive growth. The government expects BIM to reduce inaccurate, incomplete and ambiguous information and mitigate unnecessary additional capital delivery costs amounting to 20–25%. The new BIM requirement is expected to impact BIM in the private sector also.

– Gatwick Airport (2014)

The Denver International Airport (approximately 53 million enplanements/year) began to implement BIM in 2010 with its Hotel and Transit center project (Ball 2015). It has since institutionalized BIM and has extended its use to all life-cycle phases of its assets. It expects that its long-term strategy will produce economic returns (Ball 2015).

In 2011, FAA initiated its BIM Implementation Roadmap pursuant to its Naval Air Station Brunswick BIM Pilot Project, which was used to demonstrate the benefits of a full BIM implementation (FAA 2015a). FAA has since decided to institutionalize BIM and has been developing its *BIM Implementation Plan*, along with its *BIM Standards, Guidelines and Infrastructure* documents (FAA 2015a, b). FAA is currently in its pilot projects and solution development phase. The plan is to incrementally integrate BIM functionality related to facility life cycle into FAA operations: BIM will be implemented in the design and construction phases, then progress to providing access to information to support Facilities Management and Geographic Information Systems capabilities (FAA 2015b).

Little has been published about the status of BIM in airports because it is an emerging technology that is only recently being implemented in airports in North America. Therefore, this study will seek to broadly synthesize existing literature and practice.

SYNTHESIS STUDY METHODOLOGY AND RESULTS SUMMARY

This synthesis study methodology included a comprehensive literature search and survey of airport professionals (i.e., questionnaire and case example interviews) to provide a "snapshot of existing experience" related to BIM in airports in North America. Trends, knowledge gaps, and future research needs were identified by comparing state-of-the-art BIM in various industries as determined in literature with state-of-the-practice BIM in respondent airports as revealed in the survey instruments. The findings are presented in this report.

Literature Search

Myth: BIM is reserved for large organizations who can afford the investment and for large projects with complex geometries. Fact: All size organizations are realizing benefits on all size/shape of projects. The level of investment and commitment is scalable.

– AGC 2008

Relevant BIM-related literature found in the *Transportation Research Information Documentation* database and other information services and libraries was reviewed. The effort provided general information related to opportunities, benefits, and value of BIM, as well as identified current and common BIM implementation and usage practices.

Airport Survey—Questionnaire and Case Examples

Based on the literature review topics, a concise questionnaire was created according to standard principles (Oppenheim 1992) and was designed to capture current airport BIM practices and experiences. Purposive sampling was used to target a group of airports, as well as other airport AEC professionals, with known BIM use or use of BIM-related technologies. The questionnaire, shown in Appendix A, was administered online to U.S. and Canadian airports and organizations. Because of the diverse nature of BIM application and administration, participant profiles and responses vary. Resultant data were reduced and analyzed. Aggregate responses are also contained in Appendix A. To ascertain trends among respondent types, the data from the two survey groups (airport and AEC) are reported separately, where applicable, throughout the report.

A summary of the results is presented in this section to provide a brief description of the survey participants along with respective levels of BIM activity and progressive BIM use. Detailed results will be presented in subsequent chapters. In total, 18 organizations responded to the questionnaire (Table 1, Figure 2), representing small, medium, and large hub airports (airport authorities) and other stakeholders (designers and contractors with airport project experience). Fourteen of the respondents reported using BIM. For the purposes of this report, responses from internal airport owner and operator personnel will be denoted "Airport" and responses from external stakeholders that offer BIM services for airport projects (designer/contractors) will be denoted "AEC."

TABLE 1
QUESTIONNAIRE RESPONSES REGARDING BIM USE—ALL PARTICIPANTS

Response to: *Does your organization use BIM?*	Percent	Count	
		Airport	AEC
Yes	77.8	10	4
No	22.2	4	0
Total Respondents		14	4

FIGURE 2 Geographic distribution of respondents.

BIM Adoption Status. Figure 3 shows the distribution of survey responses related to current BIM adoption status (as defined by McGraw-Hill 2009). Two airports and three AECs have fully adopted BIM and are currently realizing the associated benefits. One airport and one AEC are currently completing BIM adoption (overcoming barriers to adoption), whereas two others are integrating BIM adoption with existing operations (discovering barriers to adoption).

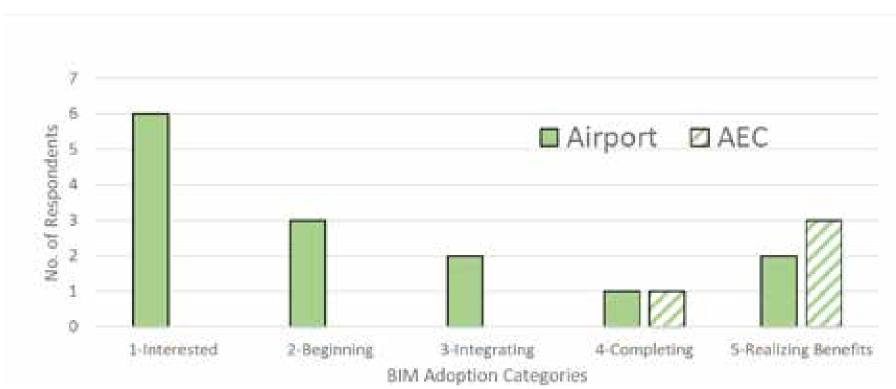


FIGURE 3 BIM adoption status in 2015—All respondents (McCuen and Pittenger 2015).

Three of the airports surveyed are beginning to adopt BIM, whereas six airports have not yet adopted BIM but are interested in BIM (considering/preparing for it). Therefore, survey results throughout the rest of this report are based on 12 respondents: the eight airports and four AECs that report BIM use (represented in Categories 2 through 5 in Figure 2).

Barriers to BIM Adoption. Some common barriers attributed to BIM adoption, industrywide and cited in this study, are related to (Penn State 2010; Khosrowshahi and Arayici 2012) the following:

- Lack of organizational readiness to change
- Lack of expertise
- Greater system complexity
- Lack of system interoperability
- Lack of industry standards.

All of these issues are inherent to the paradigm shift related to the emerging technology-intensive approach of BIM.

BIM Activity Profiles. An organization's BIM activity level can be evaluated based on its BIM experience, expertise, adoption, and implementation intensity over the project life cycle (McGraw-Hill 2014; Jung and Lee 2015). Using self-assessment criteria, the level of BIM activity for the 12 respondents that are currently adopting or have adopted BIM has been determined and is summarized in Figure 4.

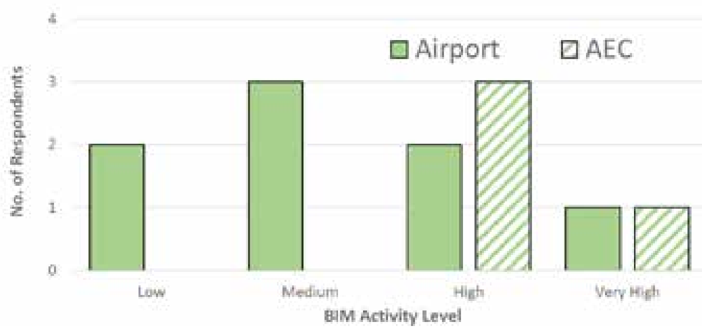


FIGURE 4 Respondent profile based on BIM activity level (McCuen and Pittenger 2015).

Progression of BIM Implementation at Airports. The survey results indicate an airport-expected progression of BIM activity and implementation. Based on use of BIM and types of use that facilitate implementation, *BIM implementation maturity* can be evaluated (Khosrowshahi and Arayici 2012). Figure 5 shows the status of current and future (expected) implementation maturity of the eight respondent airports based on their reported current and future expected BIM use.

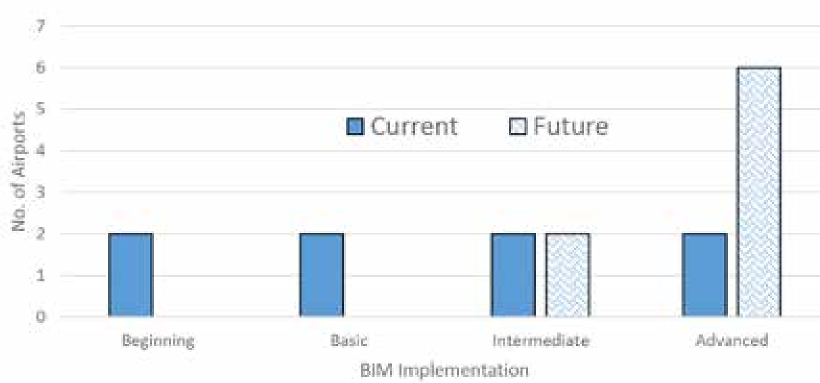


FIGURE 5 Current and future (expected) BIM use implementation by airport respondents (McCuen and Pittenger 2015).

The results indicate a shift from project-level (beginning to basic) implementation to an organization-level (intermediate to advanced) implementation. These results are fairly consistent with the self-assessment results in the previous section, highlighting the link between BIM use and BIM activity level across the life cycle. Increasing BIM benefits are associated with increasing implementation (McGraw-Hill 2009). Therefore, it is expected that the "Realizing Benefits" segment noted in Figure 2 should increase for these airports as they increasingly integrate BIM into their processes.

> *BIM is a disruptive and transformative process.*
>
> – Denver International Airport

Based on the questionnaire results, case examples were created with five airports and two AECs, guided by standard protocol (Yin 1994). The case examples serve to highlight airport BIM experience consistent with the report topics. The open-ended interview with the case example participants was conducted by telephone. The case example participants and general topics summary of content located throughout this report are as follows:

- Denver International Airport: *Realizing Benefits of Full BIM Implementation*
- San Francisco Airport Commission: *Undertaking a New Full BIM Implementation*
- Los Angeles World Airports: *Realizing Benefits of Project-Level BIM*
- Ted Stevens Anchorage International Airport: *Realizing Benefits of Organization-Level BIM*
- Massachusetts Port Authority: *Roadmapping BIM Implementation*
- Iron Horse Architects: *BIM for Airports—A Designer's Perspective*
- Balfour Beatty Construction: *BIM for Airports—A Contractor's Perspective*.

AUDIENCE

The goal of this effort is to provide a "snapshot of existing experience" that will inform airports about BIM and assist airports in understanding available opportunities, benefits, and value related to engaging in BIM. The intended audience is airport decision makers who are considering or are currently engaged in the implementation of BIM. However, owing to the organizationwide-application nature of BIM and the diversity of BIM experience represented in the survey results, the synthesis may inform a broader range of airport stakeholders that have involvement in any part of the asset life cycle.

REPORT ORGANIZATION

This report presents state of the art and state of the practice related to BIM in North America based on available literature and tailored to the specified audience. The following topics were established for the subsequent chapters, to include effective practices and lessons learned:

- Costs and Benefits of BIM (Business Case)
- BIM Purpose, Processes, and Tools
- Adoption and Implementation
- Technical Issues: Contracts, System, Resources, and Maintenance
- Facility Life-Cycle Management.

All have a similar format: each chapter begins with a general background section to provide the context for the survey results and case examples section, which highlights the airport experience. The conclusions section includes trends, knowledge gaps, and future research needs that were identified in the study.

COSTS AND BENEFITS OF BUILDING INFORMATION MODELING (BUSINESS CASE)

An organization's BIM effort often begins with consideration of the business case. Calculating BIM-associated costs is generally straightforward, as costs are often discrete and trackable. This is not the case with BIM-associated benefits, the value of which are often accrued across the entire organization through increased efficiency of operations and enhanced facility (asset) performance. Currently, there is no guidance on how to quantify BIM benefits. However, both the calculated and perceived return on investment (ROI) associated with BIM is believed to be significant. This chapter provides general information related to the initial and recurring costs of BIM, the benefits of BIM, and the metrics and key performance indicators used in evaluating BIM ROI. It also provides the airport experience related to the business case for BIM.

BACKGROUND

Costs of BIM

Costs associated with BIM occur initially with adoption and recur during its implementation and use. Initial costs generally include the following:

1. Personnel training,
2. Lost productivity during the learning curve,
3. Hardware costs, and
4. Software costs (Eastman et al. 2011).

Evaluating the overall costs and benefits of a BIM approach is not straightforward. There is no standard methodology and no consistency in measuring benefits gained. Nonetheless, case studies—and even anecdotal evidence—indicate that there are benefits to be gained.

– buildingSMART UK (2010)

Much of the initial costs will recur as an organization maintains/updates software and expands its use of BIM. Over time, the initial costs of adoption and implementation are amortized as internal BIM processes are standardized, and the organization will begin to realize benefits from its BIM implementation.

Benefits of BIM

In 2007, the obstacle that was most cited by industry for delaying BIM adoption was lack of objective documentation of attributable benefits (McGraw-Hill 2012). A recent survey of industry participants revealed that organizations have since begun to collect and analyze data to track benefits (McGraw-Hill 2014). The following list includes common project-level and organizationwide benefits identified:

- Reduced cost
- Better cost control/predictability
- Increased profitability
- Increased productivity (e.g., reducing redundant work)
- Fewer requests for information (RFIs), errors and omissions, and rework (project-level)
- Reduced cycle times for project workflows and approvals
- Fewer unplanned project changes
- Less disruption in project process
- Improved visualization
- Linking of vital information such as vendors for specific materials, location of details, and quantities required for estimation and tendering
- Collaboration among project/facility teams using a single source of information
- Shortened construction duration
- Facilitation of analysis of design and compliance
- Single repository for building system information
- Improved safety
- Increased competitiveness and enhanced image
- Increased operations/maintenance efficiency (organization level)
- Reduced operations/maintenance personnel costs (organization level)
- Space management
- Enhanced asset (facilities) management (organization level).

The single-largest BIM benefit identified for the project phase was reduced errors and omissions in construction documents used (McGraw-Hill 2012). Essentially, owners realize cost savings through the use of clash detection (i.e., spatial coordination) during construction, which saves time and reduces rework. During the operations phase, the owners realize increased building value through improved overall building performance as well as optimization of facility operations and maintenance using the as-built BIM as the database for rooms, spaces, and equipment (Eastman et al. 2011).

Early-stage BIM users need to compare performance metrics from pre-BIM projects to establish the value of basic BIM benefits, such as virtual coordination, and to justify their continued BIM investments. More experienced BIM firms are to analyze their completed BIM projects to refine the approach to more complex BIM uses on their new projects.

– McGraw-Hill (2014)

Metrics and Key Performance Indicators

Key performance indicators (KPIs) refer to the use of specific data to measure the performance of service delivery against previously defined metrics. KPIs will differ by industry and sector. For example, the six primary KPIs used in the construction industry are quality control, on-time completion, cost, safety, dollars/unit performed, and units per man hours. Typically construction organizations will utilize these same KPIs whether measuring “traditional” processes or BIM processes (Suermann and Issa 2009). However, the KPIs used for facility operations and asset management differ, as the purpose for establishing metrics is to measure performance data relative to the established business objectives and requirements of the enterprise. An organization’s KPIs are measures that most directly correlate with successful achievement of its strategic business objectives (Hollman 2006). Therefore, individual facility owners need to establish their own KPIs based on the key business objectives their organization seeks to achieve. The following is a brief list of possible KPIs for operations and maintenance and asset management:

- ROI
- No loss of business as a result of facility failure
- Safe environment
- Effective utilization of space
- Building performance as designed
- Meeting completion deadlines
- Correction of faults
- Management of building information
- Energy performance
- Open work orders versus closed work orders
- Response times and job closure
- Corrective versus preventive maintenance.

ROI is considered the most important business requirement for most enterprises and is defined as a single measure that expresses the value of an investment over its life cycle to the enterprise (Hollman 2006). A recent survey of BIM users revealed there is no industry-standard method to calculate ROI for BIM; however, most users have a perception about the value they receive through the time, money, and effort they have invested. Sixty-two percent (62%) of the survey respondents indicated a positive BIM ROI, and users self-reporting as being very high in their engagement level of BIM have seen a positive BIM ROI over 25% (McGraw-Hill 2012, p. 24). Reports indicate that the majority of BIM users have not formally measured their actual BIM ROI but rather report according to perceived ROI.

The Business Case for BIM at Massport

Massport uses information developed across projects and operational activities to make sound facility life cycle decisions supporting the public good. When used successfully, BIM offers higher quality information for better decision support. This information is more coordinated, reliable and reusable, allowing Massport teams to be more productive and the design solutions functional, cost effective, and sustainable. Facilities information, created during a BIM project, can be repurposed, reducing costly information management redundancies for post-construction operations.

– Massport BIM Guide (2015)

AIRPORT EXPERIENCE—SURVEY RESULTS AND CASE EXAMPLES

Figure 5 displays BIM benefits reported by the survey respondents (eight airports and four AECs) that have been realized during the facility life cycle. Improved visualization, through a representation of the facility or facility elements to support decision making about the facility’s design or construction, was the most commonly cited benefit. Better cost control/predictability was also cited by respondents, as it enables analysis of a facility and facility elements in all life-cycle phases. Consistent with literature, reduced errors and omissions (early detection of issues) was also frequently cited.

The San Francisco Airport Commission (SFO) and Los Angeles World Airports (LAWA) noted that BIM benefits—resulting from the modeling/simulating elements before construction—are related to enhancing construction and building performance through better information, which in turn fundamentally affects the quality of large capital projects at the airport. At the highest level of KPIs, BIM simulations can provide early detection of issues, or “red flags,” that indicate potential for escalating costs associated with changes in the construction or operations/maintenance phases if not addressed. Specifically, BIM use helps these airports to mitigate the negative impact on efficiency (e.g., schedule and cost) and risk.

Figure 6 also shows organization-level BIM benefits accrued by the two airport respondents that use BIM during the operations phase. Both airports cite benefits related to optimization of facility operations and maintenance and enhanced asset (facilities) management, consistent with literature.

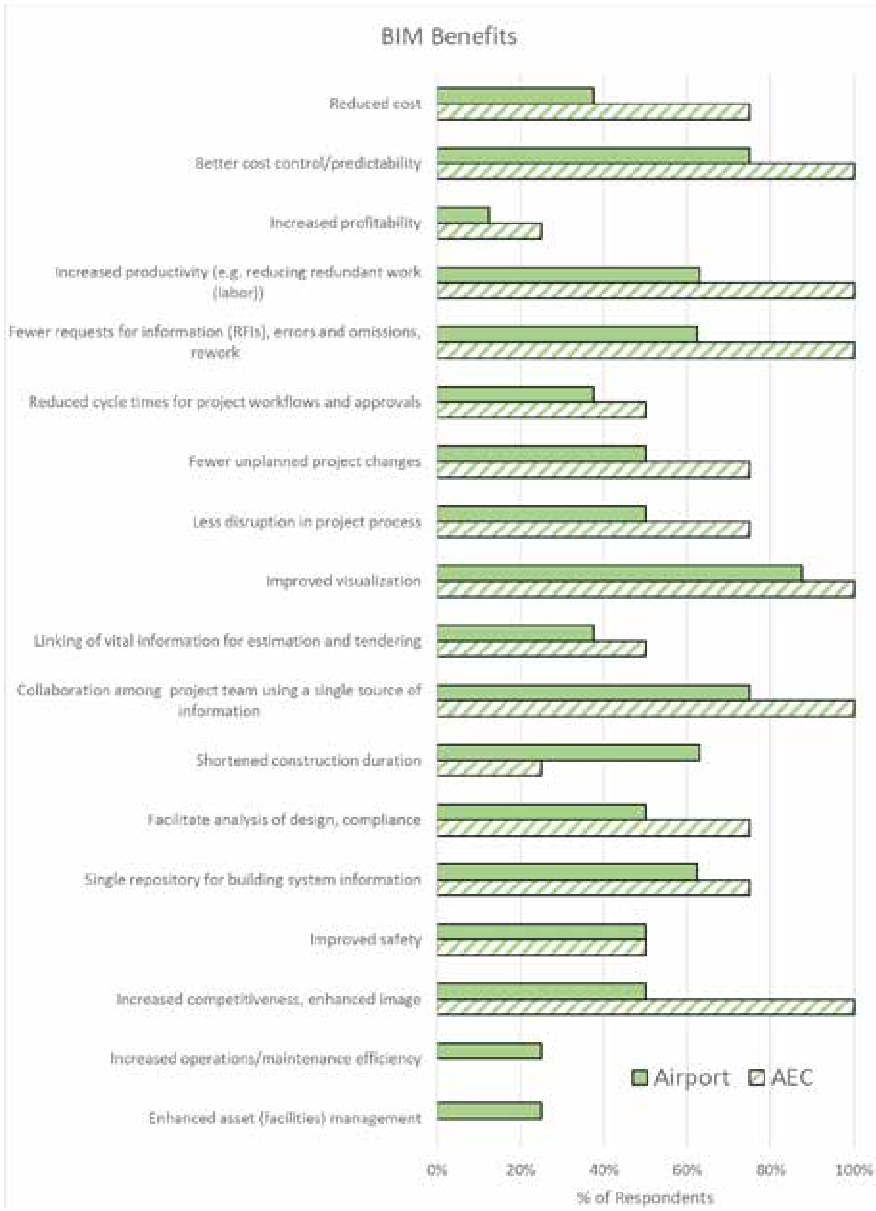


FIGURE 6 Survey results for BIM benefits (McCuen and Pittenger 2015).

> *Many owners currently do not understand (and therefore do not leverage) the value that BIM can bring to the operation phase.*
>
> – Balfour Beatty Construction

Both SFO and Anchorage International Airport (ANC) acknowledge that the BIM implementation program leverages the accumulating value of BIM data collection through design and construction for facilities maintenance and operations. The ANC BIM adoption approach is organization driven, not project driven (i.e., the effort is not tied to a specific project that provided an opportunity to implement BIM). Therefore, project-related BIM teams and tools are not currently in place at ANC. However, ANC is using BIM to document existing conditions for the purpose of sharing that information with current stakeholders and future project teams, supporting ANC's business case for BIM.

Many owners currently do not understand (and therefore do not leverage) the value that BIM can bring to the operation phase.

– Balfour Beatty Construction

Some of the performance metrics used by the few airport respondents that assess ROI are listed as follows. Most cited metrics are related to reduced errors and omissions and RFIs, consistent with literature. One airport indicated that KPIs and ROIs were currently being developed.

- Reduced design errors and omissions
- Reduced RFIs during construction
- Reduced initial costs
- Reduced life-cycle costs
- Shortened construction duration
- Compared life-cycle performance of past BIM projects with current BIM projects.

The results about BIM-added value related to BIM activity are consistent with literature. Eleven (of 12) respondents (92%) report value added in the design and construction phase. Seven of the respondents (representing medium to very high levels of BIM activity) report tracking costs or calculating ROI related to BIM. Of those who do not calculate ROI, four respondents perceive that BIM has added value and one (with low engagement level) perceives no added value. In the operations and maintenance phase, three of four respondents (75%) track costs/calculate ROI and report value added by BIM. The remaining respondent that stated "no added value" does not track ROI. These results are consistent with literature that states "[e]xpert level BIM users believe BIM contributes highly to reduction in total project cost and overall schedule. Beginner level BIM users are less likely to see these benefits. Survey results indicate that with experience users will realize the benefits of BIM on a project" (McGraw-Hill 2009).

ROI at Denver International Airport

Establishing ROI for BIM can be a little tricky, especially when an organization may not have historically been tracking the right key performance indicators to calculate ROI. Although a key part of BIM is data collection, DEN's biggest challenge has been the lack of sufficient and valid historical data.

Lessons Learned: A change management process is needed when implementing BIM because ROIs require valid historical asset data.

– Denver International Airport

Denver International Airport (DEN) has focused on a number of areas in which to assess ROI on its BIM use. Two examples in which it reports a positive ROI are tracking design fees and maintenance costs:

- BIM-savvy designers: Common belief holds that BIM increases project costs, but DEN has found that it can decrease them. Although one can expect an initial increase in design fees and construction costs, BIM projects can accrue overall project cost savings. DEN has found that when the designer and the client (owner) routinely use BIM, project costs can decrease. For example, DEN still uses "pre-BIM" project design budget estimation owing to availability of historical data. A clear trend has been observed between the fees of BIM-savvy designers (consistently below budget) and those not savvy with BIM (consistently above budget). This result is often attributed to design fees that are increased because of the anticipated BIM learning curve related to the designer's and/or client's limited or lack of experience with BIM tools and processes.
- Preventive maintenance: Although not all DEN assets are modeled in BIM, DEN is better at tracking the types of maintenance being done and the associated costs. DEN has been able to determine that on an airportwide scale, corrective maintenance *costs five times as much as* preventive maintenance on a man-hour basis. Therefore, DEN's goal is to reduce the amount of corrective maintenance required. For each 5% reduction in annual corrective maintenance, a cost savings of $5 million will be generated.

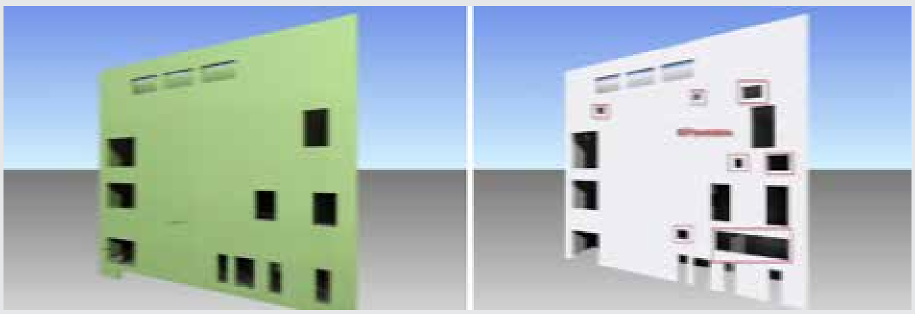
BIM benefits are not realized in the short term. It is critical to quantify benefit of BIM in terms of cost savings and commit to long-term implementation.

– Denver International Airport

SFO also cited the challenge of developing ROIs for BIM because BIM affects so many areas of airport operations. Another benefit that is difficult to quantify is the deeper understanding of BIM that allows the airport to provide the project team (consultants) with better initial information during the design/construction process, which positively affects the quality of large capital projects. Therefore, SFOs strategy is to identify specific business cases for stakeholder groups (throughout all life-cycle phases) and to track the effects of optimized processes related to BIM implementation.

ROI at Los Angeles World Airports

LAWA did a case study to evaluate the ROI associated with using BIM for cost avoidance on a large capital project it recently completed (Peters 2011). It was estimated that the cost avoidance and cost savings related to reduced design errors and omissions were significant. For example, BIM coordination allowed early detection of the issue related to the lack of required penetrations in the structural elements of the gate shear walls to accommodate the Mechanical-Electrical-Plumbing (MEP) systems. Because of the amount of reinforcing steel located in the wall, cutting the penetrations into the built walls would have rendered them nonstructural, which would not have been an option. It would have potentially cost $2.5 million to correct the issue in the field because the walls would have had to be demolished and reconstructed.



Gate shear wall as modeled from Structural Design Documents (left); gate shear wall as modeled after BIM coordination, additional wall penetrations required for MEPs (right).

Although LAWA focuses mainly on BIM ROI in the construction phase, it stated that it is currently working with its facilities management group to develop meaningful KPIs in an effort to calculate ROI for BIM use in the operations and maintenance phase. It noted that a primary benefit is improvement in the process of managing information that supports the executive decision-making process.

CHAPTER TWO

BUILDING INFORMATION MODELING PURPOSE, PROCESSES, AND TOOLS

BACKGROUND

The first step in an organization's BIM implementation is to clearly identify its end goals or purpose for using BIM. The next step is to determine which BIM processes and tools will best enable the organization to reach those goals. A BIM classification system, which describes BIM purpose, processes, and tools for use across the facility life cycle, has been developed to assist organizations in the process of defining BIM objectives and facilitating BIM implementation. This chapter provides general information about the classification system. It also provides the related airport experience.

BIM Purposes

> *Massport's decision to implement BIM represents a significant, multi-year change in how it executes projects and develops information about its assets.*
>
> – Massport BIM Guide (2015)

An organization can use BIM to *gather, generate, analyze, and communicate* facility information as well as realize a facility, which means to use BIM to make or control a physical element using facility information. The following list outlines these purposes (objectives) and provides the *subcategories* (Kreider and Messner 2013):

BIM may be used to *gather* facility information for the following purposes:

1. Capture the current status of the facility and facility elements
2. Quantify the amount of a facility element
3. Monitor the performance of facility elements and systems
4. Qualify facility elements' status.

BIM may be used to *generate* facility information for the following purposes:

1. Prescribe the need for and select specific facility elements
2. Arrange the location and placement of facility elements
3. Size the magnitude and scale of facility elements.

BIM may be used to *analyze* facility information for the following purposes:

1. Coordinate the efficiency and harmony of the relationship of facility elements
2. Forecast the future performance of the facility and facility elements
3. Validate the accuracy of facility information and that it is logical and reasonable information.

BIM may be used for the purpose of *communicating* facility information to

1. Visualize a realistic representation of a facility or facility elements

2. Transform information and translate it to be received by another process
3. Draw a symbolic representation of the facility and facility elements
4. Document the facility information including the information necessary to precisely specify facility elements.

BIM may be used for the purpose of *realizing* a facility using facility information to

1. Fabricate the elements of a facility
2. Assemble the separate elements of a facility
3. Control the operation of executing equipment
4. Regulate the operation of a facility element.

After defining the objectives for BIM implementation, the BIM uses within each purpose are specified to address areas of application. The 25 common BIM uses (Penn State 2013):

1. Maintenance Scheduling
2. Building System Analysis
3. Asset Management
4. Space Management/Tracking
5. Disaster Planning
6. Record Modeling
7. Site Utilization Planning
8. Construction System Design
9. Digital Fabrication
10. 3D Control and Planning
11. 3D Design Coordination
12. Design Authoring
13. Energy Analysis
14. Structural Analysis
15. Lighting Analysis
16. Mechanical Analysis
17. Other Engineering Analysis
18. LEED Evaluation
19. Code Validation

20. Programming

21. Site Analysis

22. Design Reviews

23. Phase Planning (4D Modeling)

24. Cost Estimation

25. Existing Conditions Modeling.

Each BIM use relates to a specific part of the facility life cycle, as shown in Figure 1. During the feasibility, planning, and development phase, BIM (facilitated by BIM uses) provides owners with information about the current state of the facility and can be used to generate information for analysis. During design and construction, BIM enables the generating of information, analysis, communication, and construction. During the operations phase, BIM can be used to continue gathering information to monitor the performance of a facility and its systems.

BIM Definitions

Purpose: the specific objective to be achieved when applying BIM during a facility's life.

Use: a method of applying building information modeling during a facility's life cycle to achieve one or more specific objectives.

Process: the process of utilizing BIM tools and approaches to improve "traditional" business process and bring value to projects.

Tool: support BIM processes at the project and organization levels and are generally categorized as authoring tools or audit and analysis tools.

Resource: the systems, tools and/or knowledge required in addition to BIM tools to support and complete the BIM process.

Sources: Kreider and Messner (2013); McGraw-Hill (2012); Penn State (2010).

BIM Processes

The term *BIM process* describes the "utilization of BIM tools and approaches to improve 'traditional' business process and bring value to projects" (McGraw-Hill 2012). BIM processes include planning, design, construction, facility maintenance and operations, and facility management processes.

BIM Tools

BIM tools support BIM processes at the project and organization levels. Tools are generally categorized as either authoring tools or audit and analysis tools. "Authoring tools create models while audit and analysis tools analyze or add to the richness of information in a model" (Penn State 2010). Authoring tools are used to create 3D designs of facilities; incorporate the "properties, quantities, means and methods, costs and schedules"; and facilitate BIM (Penn State 2010).

BIM Resources

BIM resources include additional systems, tools, and knowledge used to support and complete the BIM process. Resources include items such as a computer maintenance management system (CMMS), local code knowledge, and LEED building certification knowledge. Additional tools include laser scanning to capture existing conditions and integrate them with models, augmented reality to blend models with live camera views of reality, simulation and analysis to optimize logistical planning and decision making, hyper-realistic immersive visualization to communicate complex information, and radio frequency identification systems for facility operations (McGraw-Hill 2014).

Table 2 combines all of these concepts and displays each BIM use along with the purposes, processes, tools, and resources associated with each use.

TABLE 2
TYPICAL BIM USES, TOOLS, PROCESSES, AND RESOURCES

BIM Uses	BIM Use Purpose	BIM Use Purpose Subcategory	BIM Use Objective	BIM Tools	BIM Process	Resources
Maintenance scheduling	Analyze	Forecast	Predict timing for element maintenance/ replacement	Analysis	Facility maintenance	• Record model • Building automation system • Computer maintenance management system
Building system analysis	Analyze	Regulate	Regulate facility elements to optimize operations	Analysis	Design, facility operations	• Record model • Building systems analysis software
Asset management	Analyze	Forecast	Predict performance of facility over time	Analysis/audit	Facility operations and maintenance	• Record model • Asset management system
Space management/ tracking	Gather	Monitor	Observe the performance of facility elements and systems	Analysis/audit	Facility management	• Record model • Content management software
Disaster planning	Gather	Capture	Represent or preserve the current status of the facility and facility elements	Audit	Planning, design, facility management	• Record model • Building automation system knowledge • Emergency response knowledge
Record modeling	Communicate	Document	Create a record of facility information	Authoring	Design	• 3D model
Site utilization planning	Generate	Arrange	Determine location and placement of facility/ facility elements	Analysis	Construction	• 3D model • Design authoring software • Scheduling software
Construction system design	Analyze	Coordinate	Ensure the efficiency and harmony of the relationship of facility elements	Analysis	Construction	• 3D system design software
Digital fabrication	Realize	Fabricate	Use facility information to manufacture the elements of a facility	Authoring and analysis	Design and construction	• 3D modeling software • Fabrication equipment • Fabrication methods
3D control and planning	Analyze	Coordinate	Ensure the efficiency and harmony of the relationship of facility elements	Authoring	Design and construction	• 3D model
3D design coordination	Analyze	Coordinate	Ensure the efficiency and harmony of the relationship of facility elements	Analysis	Design and construction	• 3D model • Model review software
Design authoring	Generate	Arrange	Determine the location and placement of facility elements	Authoring	Design	• 3D modeling software
Energy analysis	Analyze	Forecast	Predict the future performance of the facility and facility elements	Analysis	Design, facility management	• 3D model • Engineering analysis software
Structural analysis	Analyze	Validate	Check or prove accuracy of facility information and that it is logical and reasonable	Analysis	Design	• 3D model • Engineering analysis software
Lighting analysis	Analyze	Forecast	Predict the future performance of the facility and facility elements	Analysis	Design	• 3D model • Engineering analysis software
Mechanical analysis	Analyze	Forecast	Predict the future performance of the facility and facility elements	Analysis	Design	• 3D model • Engineering analysis software

Table 2 continued on p. 18

BIM Uses	BIM Use Purpose	BIM Use Purpose Subcategory	BIM Use Objective	BIM Tools	BIM Process	Resources
Other engineering analysis	Analyze	Forecast	Predict the future performance of the facility and facility elements	Analysis	Design	• 3D model • Engineering analysis software
LEED evaluation	Analyze	Forecast	Predict the future performance of the facility and facility elements	Analysis	Planning, design, construction, operations	• 3D model • LEED credit knowledge
Code validation	Analyze	Validate	Check or prove accuracy of facility information and that it is logical and reasonable	Analysis	Design	• 3D model • Model checking software • Local code knowledge
Programming	Generate	Prescribe	Determine the need for and select specific facility elements	Authoring	Planning, design	• Design authoring software
Site analysis	Analyze	Coordinate	Ensure the efficiency and harmony of the facility elements	Analysis	Planning, design	• 3D model software • GIS software
Design reviews	Communicate	Visualize	Form a realistic representation of a facility or facility elements	Analysis	Design and constructions, facility management	• 3D model • Design review software • Interactive review space
Phase planning 4D modeling	Analyze	Coordinate	Ensure the efficiency and harmony of the relationship of facility elements	Analysis	Construction	• 3D model • Scheduling software • 4D modeling software
Cost estimation	Gather	Quantify	Express or measure the amount of a facility element	Analysis	Planning, design and construction, facility management	• Design authoring software • 3D model • Model-based estimating software • Cost data
Existing conditions modeling	Gather	Capture	Represent or preserve the current status of the facility and facility elements	Authoring	Design	• 3D model • 3D laser scanning • 3D laser scanning point cloud translation into objects

Source: McCuen and Pittenger (2015).

BIM Implementation Maturity Based on BIM Uses

BIM implementation maturity can be evaluated based on the type of BIM use utilized by an organization (Khosrowshahi and Arayici 2012). BIM use frequency can also provide insight about the implementation maturity in industry (Jung and Lee 2015).

The three BIM implementation maturity stages are progressive in nature (Khosrowshahi and Arayici 2012). The implementation stages are as follows:

- Stage 1 (Basic)—transitioning from 2D to 3D object-based modeling and documentation; does not require an interdisciplinary or collaborative effort.
- Stage 2 (Intermediate)—transitioning to collaboration (data sharing) and interoperability (integrated data communication) among the project team (stakeholders).
- Stage 3 (Advanced)—transitioning to integration throughout all project life-cycle phases.

Each stage adds more BIM uses. For example, using Design Authoring (creating 3D models—CAD) only to design/communicate project plans or to do 3D Design Coordination (clash detection) would be classified as Stage 1. At Stage 2, for example, the designer or constructor would develop and deliver a model to the owner that facilitates Maintenance Scheduling.

At Stage 3 implementation, "model deliverables extend beyond semantic object properties to include business intelligence, Lean construction principles, green policies and whole life cycle costing" (Khosrowshahi and Arayici 2012). Asset Management is an example of Stage 3 BIM implementation.

Although each stage provides benefit, Stage 3 is the basis of the BIM philosophy. Implementation at this level will generate the most benefits for owners and stakeholders (Khosrowshahi and Arayici 2012).

A recent survey of AECs and owners in North America assessed the use frequency (in parentheses) of the following BIM uses (listed in descending order) among the respondents (Jung and Lee 2015). A description of each use is as follows (Penn State 2010):

- 3D Coordination (95.5%): "Clash Detection software is utilized during the coordination process to determine field conflicts by comparing 3D models of building systems. The goal of clash detection is to eliminate the major system conflicts prior to installation."
- Cost Estimation (95.5%): "[A] BIM model can offer an accurate quantity take-off and cost estimate early in the design process and provide cost effects of additions and modifications with potential to save time and money and avoid budget overruns. This process also allows designers to see the cost effects of their changes in a timely manner which can help curb excessive budget overruns due to project modifications."
- Structural Analysis (90.9%): "[I]ntelligent modeling software uses the BIM model to determine the most effective engineering method based on design specifications. Development of this information is the base for what is passed on to the owner and/or operator for use in the building's systems (i.e., energy analysis, structural analysis, emergency evacuation planning, etc.). These analysis tools and performance simulations can significantly improve the design of the facility and its energy consumption during its life cycle in the future."
- Existing Condition Modeling (81.8%): "[A] project team develops a 3D model of the existing conditions for a site, facilities on a site, or a specific area within a facility. This model can be developed in multiple ways depending on what is desired and what is most efficient. Once the model is constructed, it can be queried for information, whether it be for new construction or a modernization project."
- Building System Analysis (72.2%): This analysis "measures how a building's performance compares to the specified design. This includes how the mechanical system operates and how much energy a building uses. Other aspects of this analysis include, but are not limited to, ventilated facade studies, lighting analysis, internal and external CFD airflow, occupant evacuation, and solar analysis."
- Design Authoring (63.6%): "3D software is used to develop a BIM model based on criteria that is important to the translation of the building's design. Two groups of applications are at the core of BIM-base design process are design authoring tools and audit and analysis tools."
- Maintenance Scheduling (54.4%): "[T]he functionality of the building structure (walls, floors, roof, etc.) and equipment serving the building (mechanical, electrical, plumbing, etc.) are maintained over the operational life of a facility. A successful maintenance program will improve building performance, reduce energy repairs, and reduce overall maintenance costs."

[Complete descriptions for each of the 25 BIM uses, including potential value, resources, and team competencies, are provided in the *BIM Project Execution Planning Guide* (Penn State 2010.)]

The results revealed that 3D Coordination and Cost Estimation were used most. Additionally, the types of uses, which are used across the life cycle, indicate a Stage 3 (Advanced) BIM implementation maturity for more than half of the respondents. When compared with results from six other continents, North America was most advanced in terms of BIM implementation (Jung and Lee 2015).

More information about BIM implementation is provided in the next chapter.

AIRPORT EXPERIENCE—SURVEY RESULTS AND CASE EXAMPLES

Respondents identified BIM purposes that support their use of BIM. The most cited reason by airports was to gather facility information to *determine the location and placement of facility elements.* Communicating facility information was also consistently cited by airports to *visualize, draw, and document facility (elements)*.

> *Balfour Beatty Construction is researching new ways to benefit owners, such as offering radio frequency identification tagging for elements hidden in walls and above ceilings to enhance facility management.*
>
> – Balfour Beatty Construction

Respondents' use of BIM tools is shown in Figure 7. Consistent with literature, the authoring tools are used by most respondents. Authoring tools are used to generate information about a facility to *prescribe, arrange, and size facility elements*. They are also used to communicate information to *visualize, transform, draw, and document facility elements.*

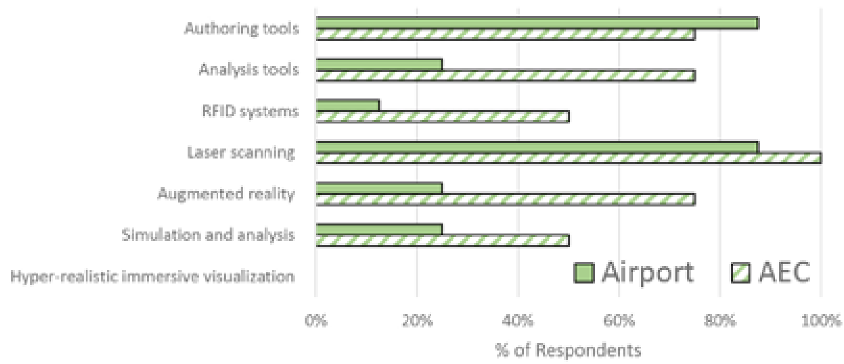


FIGURE 7 BIM tools used by respondents in 2015 (McCuen and Pittenger 2015).

> "know *what you have and* see *what you have.*"
>
> – Ted Stevens, Anchorage International Airport

ANC's long-term BIM objective is to create a repository of accurate, detailed, data-rich, and geospatially located BIMs of every airport building over 1,000 ft^2. These BIMs will contribute to effective facility management and future renewal/replacement projects. As part of this BIM effort, ANC houses a growing repository of photo-realistic digital images produced from laser scans and viewable through a web viewer. These images are intended to support the airport's operations and maintenance (O&M) "wayfinding" through enhanced visualization (e.g., to clearly identify objects such as a bag belt segment or the configuration of a specific drive motor). The mantra (and challenge) is to

ANC is determining how to most effectively deliver the 3D representations (through off-the-shelf tools) to the various stakeholders who would benefit from having the information. Because of a lack of interoperability between tools, it is necessary to consider tools that offer file formats that will transfer from one BIM business process, such as design, to another, such as facility management. ANC has implemented an asset structure (i.e., categorized its asset types) to integrate with BIM platforms, which will enable use of BIM for asset management and will allow ANC to add visualization to its operations and maintenance activities.

Figure 8 shows the respondents' BIM uses. Consistent with literature, 3D coordination (used for avoidance of utilities breaks during construction, for example) was most commonly cited.

Figure 9 shows the comparison of BIM use response from this study (illustrated by squares) compared with the Jung and Lee (2015) results for North America (illustrated by triangles) for the given BIM uses. Nine participants in this study currently report BIM uses (five airports, four AECs). The population demographics for the North America survey included AECs and owners, but the population distribution was unspecified (Jung and Lee 2015). Therefore, responses will have inherent differences. The reader is also cautioned about the purposive nature of this study. However, a comparison does yield some insight. Expectedly, the basic BIM uses have high use among all respondents. 3D Design Coordination (clash detection), noted in the previous chapter as being associated with the greatest project BIM benefit, was shown to have the most use. Results for Existing Conditions Modeling show similar high levels of use.

Design Authoring (developing a 3D model) has a higher reported use in this study, indicating an alignment with the results from a recent survey that found 73% of owner participants rated their increased understanding of proposed design solutions as one of the top-rated positive impacts of BIM (McGraw-Hill 2015). All of the AECs in this report have higher levels of BIM activity, a distribution that may not have the same representation in the other study. Among this study's participants, less frequency was reported for the more advanced uses (Building System Analysis and Maintenance Scheduling). However, according to responses related to future BIM use (holding the North America response constant), those gaps close, as shown in Figure 9.

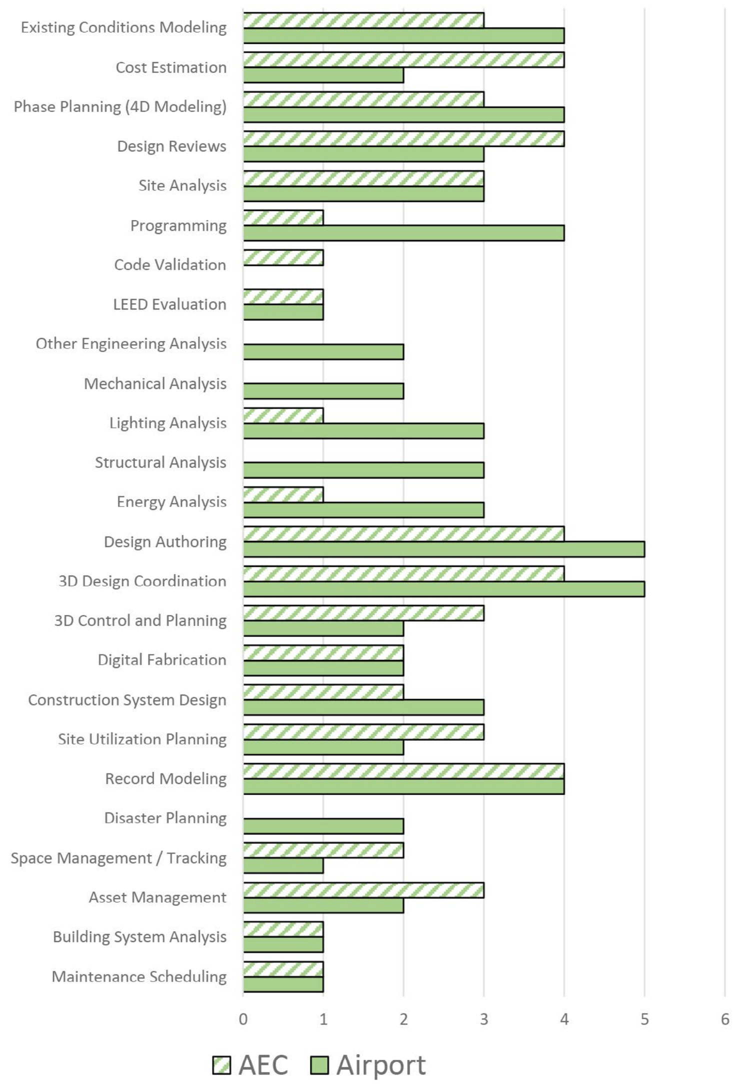


FIGURE 8 Survey responses for common BIM uses (McCuen and Pittenger 2015).

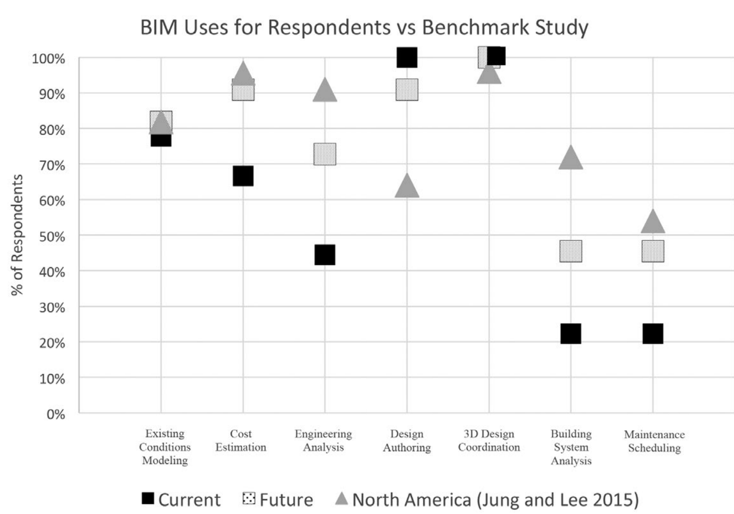


FIGURE 9 Current (2015) and future (expected) BIM uses survey results for this study contrasted with North America (benchmark) study (McCuen and Pittenger 2015).

Survey results from this study provided airport profiles for the sequence of BIM use implementation (listed in Appendix A). The general trend exhibited among the respondents is to implement BIM uses that correlate with the plan, design, and construction phases (project-based) first, then implement uses in the operations (organizational-based) phase.

The type of BIM uses utilized by an organization can be evaluated to determine its implementation maturity, as described in the literature section (Khosrowshahi and Arayici 2012). In addition, the number of BIM uses that an organization has integrated into its operations can also provide insight (Jung and Lee 2015). The methodology rests on the assumption that an increasing number of BIM uses indicates greater adoption/implementation. Table 3 shows BIM use categories for respondent airports. The most notable trend among respondents is the future (expected) shift from project-level (beginning to basic) implementation to an organization-level (intermediate to advanced) implementation, as evidenced by the addition of BIM uses that support the operations phase.

From Project-Based to Organization-Based

Denver International Airport's (DEN's) adoption of BIM was initially project driven (i.e., the effort was tied to a specific project that provided an opportunity for DEN to implement BIM). DEN has since become more organization-centric and has increased internal stakeholder buy-in by no longer outsourcing BIM services. However, it is not just about adding BIM, but about a change management process for the entire airport. DEN finds that the cost of maintaining the BIM staff (which is much greater than the investment in BIM software) is offset by the benefit that the group contributes in supporting DEN's BIM program and other departments' programs (e.g., maintenance, project management, finance). For example, the BIM group regularly works with the Planning Department to conduct analyses for project prioritization. DEN also invests a lot of time in cross-training personnel from other departments in BIM. Lessons Learned: DEN's in-house, dedicated BIM staff consists of five staffers. The challenge was in finding qualified applicants that have sufficient BIM experience, since the pool of BIM-proficient professionals is currently very small.

– Denver International Airport

TABLE 3
BIM USE CATEGORIES FOR RESPONDENT AIRPORTS

Organization	Years Using BIM	BIM Use Categories					
		BIM approach		No. of BIM uses		BIM implementation maturity based on BIM uses	
		Current	*Future*	*Current*	*Future*	*Current*	*Future*
1 - Airport	5	Organization	Organization	17	24	Advanced	
2 - Airport	3	Project	Organization	11	14	Intermediate	Advanced
3 - Airport	8	Organization	Organization	—	21	Basic	Advanced
4 - Airport	1	Organization	Organization	15	24	Intermediate	Advanced
5 - Airport	2	Organization	Organization	17	21	Advanced	
6 - Airport	1	Project	Organization	0	24	—	Advanced
7 - Airport	1	Project	Organization	4	11	Basic	Intermediate
8 - Airport	1	Project	Organization	0	12	—	Intermediate

Source: McCuen and Pittenger (2015).

Adding those BIM uses will facilitate the airports' expansion and advancement of their current use of BIM, as noted by the anticipated increase in BIM uses and BIM use types that relate to greater implementation maturity, which will, in turn, translate to greater benefits. This maturity assessment based on BIM uses reported is fairly consistent with those in next chapter, which are based on self-assessment and incorporate experience, project implementation, and BIM use across the life cycle.

CHAPTER THREE

ADOPTION AND IMPLEMENTATION

After an organization determines its end goals for BIM implementation, it develops its adoption and implementation strategy to chart the path for reaching those goals. This chapter provides general information about BIM adoption and implementation across the facility life cycle. Barriers to adoption and implementation optimization are presented. It also provides airport profiles that include experience, expertise, adoption, and implementation intensity over the project life cycle.

BACKGROUND

BIM Adoption and Implementation

BIM adoption generally precedes BIM implementation. The adoption phase begins when an organization decides to use BIM; however, an organization's adoption does not automatically translate to full-scale support for implementation by stakeholders within the organization. An organization's adoption of BIM can be simple or quite complex. An approach could begin with a particular technology, such as 3D laser scanning, and the BIM uses associated with that technology (e.g., Existing Conditions Modeling). Adoption could also be initiated for specific business processes (e.g., asset management) or functional areas (e.g., facilities maintenance) within the organization. Adoption may be project-focused or organization-focused depending on its strategy for implementation. For example, cost estimating and construction scheduling are project-level business processes, whereas asset management is an organization-level process.

A clear organizational strategy about the purpose and use of BIM can be developed during adoption to guide the subsequent implementation. The strategy first evaluates the existing organizational conditions before proceeding with implementation. Next, the implementation strategy aligns BIM goals and objectives with the organization's targeted uses and level of desired maturity for each use (Kreider and Messner 2013). The strategy addresses migration from traditional business processes to BIM processes in a methodical way that considers both the internal and external stakeholders affected by the implementation.

> *Massport's goals are foremost related to institutionalizing the use of BIM technologies (using BIM to facilitate Asset Management), which requires the development of a clear path to implementation that is shared with all stakeholders. To support the effort, it has developed the Massport BIM Roadmap* [located in Appendix B of this synthesis report] *and a written implementation plan.*
>
> – Massport BIM Guide (2015)

In addition to the level of implementation—project or organization—the strategy also identifies the phases in a facility's life cycle at which BIM will be used to add value to the owner's business operations. The detailed implementation plan includes measurable goals that will add value, such as reducing cost across the life cycle.

> An organization's implementation plan may include all of the phases with specific *value-added activities* as shown in the following example:
>
> - **Planning phase—**Conceptualize project, analyze program, and prepare pro forma for "*go-no go*" decisions.
> - **Design phase—**Perform design development and analyze building systems for life-cycle costs and operations processes.
> - **Construction phase—**Perform design reviews, coordination, estimating, scheduling, and fabrication for initial cost avoidance.
> - **Operations and maintenance—**Utilize record model of building systems and services information for preventative maintenance.
> - **Renewal—**Analyze existing conditions for renewal or disposal decisions.
>
> – CICRP 2013

SFO places great emphasis on organizational development parallel to technology implementation, which is critical in identifying the target systems (identifying life-cycle phases and BIM processes for implementation within each phase) and in gradually building an understanding of the associated standards related to the data resulting from large capital projects and BIM and how they are actually going to be used by the SFO internal stakeholders.

– San Francisco Airport Commission

Full BIM implementation can take from 1 to 10 years (Penn State 2013). The following activities and associated tasks support successful BIM implementation planning by facility owners (Penn State 2013):

- Establish a BIM implementation team
  - Determine BIM implementation team members
  - Establish roles and responsibilities
  - Engage a consultant to assist in BIM implementation as needed.
- Design BIM integrated processes
  - Select a standard method of documentation
  - Document the organizational structure
  - Document the current processes
  - Identify and design target processes
  - Form clear tasks for transition
  - Create the overall transition plan for the organization.
- Document model and facility data information needs
  - Determine information needs
  - Choose a model element breakdown structure for the organization
  - Determine model needs
  - Determine level of development
  - Determine facility needs
  - Compile organizational information needs.
- Determine infrastructure needs
  - Select software
  - Choose hardware.
- Education and training
  - Develop an educational program
  - Develop a training strategy.

BIM Adoption Barriers

Some common barriers attributed to BIM adoption, industrywide and cited in this study, are related to the following factors (McGraw-Hill 2009; Penn State 2010; Khosrowshahi and Arayici 2012):

- Lack of organizational readiness to change
- Lack of expertise
- Greater system complexity
- Lack of system interoperability
- Lack of industry standards
- Legal issues
- Lack of data-storage capacities
- Lack of systems to support real-time information for on-site decision making
- Prohibitive expenses for software and hardware upgrades.

All of these issues are inherent to the paradigm shift related to the emerging technology-intensive approach of BIM.

Optimizing BIM Implementation

There are various ways to address the barriers to adoption and optimize a BIM implementation program. Some of the methods, which enhance organization readiness, are listed in this section.

Breaking Down the Silo Development of Information Within an Organization

Commonly, valuable information is housed in various departments across an organization, yet the information is not easily accessible/useable by others outside of a specific department. As an organization discovers these information sources, it is very important that it leverages the data from the sources. This leads to SFO's emphasis on integration: it is not so much about replacing or overtaking existing systems or databases with BIM, but rather connecting all of the existing sources of information to form a centralized, accessible, and reliable information portal for the organization.

– San Francisco Airport Commission

"Technology is continuously changing, so it is important for owners to have a BIM Champion that has the expertise to analyze what benefits the specific technologies can bring to the organization."

– Massport

Enlist a BIM champion: A champion leads adoption efforts within the organization to ensure that the subsequent implementation phase is successful. The *BIM Planning Guide for Facility Owners* (Penn State 2013) describes a BIM champion as one who is technically skilled and motivated to guide an organization to improve its processes by advocating adoption, managing resistance to change, and ensuring implementation of a new technology or process. Champions may be designated or they may emerge, but either way, the organization's champion guides it at the strategic, operational, and tactical level on BIM use (GSA 2009; Suermann and Maddox 2015).

Describe the timeline for organizational goals for BIM implementation: An organization's goals and BIM objectives need to be clearly articulated and specified to occur within a given time frame.

Implement a change management plan: A plan for change management is necessary if the process changes associated with BIM adoption are to be realized and improve efficiency. The shift from traditional processes to BIM processes is a cultural change that can be planned for and managed. Respondents to a recent survey ranked change management as the top obstacle for owners (McGraw-Hill 2015).

Develop a written BIM implementation plan: BIM implementation will affect both the organization and project operations; therefore, it is essential to have a written plan to help streamline business operations, establish a consistent working environment, and increase the percentage of total work effort that is devoted to value-added tasks (Smith and Tardif 2009). The following elements can support the plan at the operational level (Smith and Tardif 2009):

- Ensure data are entered only once during the building or information life cycle by the most authoritative source.
- Send and receive data in the most structured electronic form possible.
- Integrate data entry and data maintenance tasks into the organization's business processes.
- Collect all relevant information the first time.
- Emphasize the value of data collection and data quality.
- Adopt open standards.

Ensure sufficient computer software proficiency: General computer software proficiency is a necessary skill for personnel; however, the need for proficiency with BIM software will vary based on the BIM use and the tools used to achieve the specified use. For example, use of a design model through a viewer uses more general skills, whereas the use of a record model in its native file format will require the ability to navigate through the model (Penn State 2013). An organization's technology strategies are to align with the organization's core competencies (Smith and Tardif 2009).

Ensure sufficient database management capabilities: Information is at the foundation of BIM. Having the capability to manage the model data to achieve the intended objectives is essential (Smith and Tardif 2009).

Ensure adequate facilities management expertise: Efficiently managing a facility using BIM involves personnel with expertise in managing the building elements and systems. Although standard contract documents require facility data in paper format, with BIM, the facility manager can define the specific information needed to operate and maintain the facility. As a result, it is critical that facility managers possess comprehensive knowledge about the systems and what will be needed to efficiently operate the facility (Kreider and Messner 2013).

Develop team organization and management: In general the organization's BIM team will execute the organization's strategic plan. At the organization level, the BIM team is to include individuals with background knowledge and experience with

BIM to create and execute the organization's BIM strategy (Kreider and Messner 2013). At the project level, the BIM team is to include representation from diverse disciplines and life-cycle phases.

Frequently, BIM projects go bad when consultants and owners think they can execute BIM without expertise. To mitigate risk, it is vital that the owner selects consultants that have actual BIM expertise and experience, not just proficiency in 3D modeling. It is also beneficial for the owner to scrutinize BIM service providers so that it is not "sold a bill of goods."

– Iron Horse Architects

Ensure adequate team members' experience with BIM: A team member's experience with BIM provides the team with support to accomplish the BIM objectives and provide the necessary competencies to facilitate the team's workflow (Kreider and Messner 2013).

AIRPORT EXPERIENCE—SURVEY RESULTS AND CASE EXAMPLES

Adoption and Implementation

An important element of evaluating current state-of-the-practice in BIM for respondent airports is to determine levels of adoption, implementation, and engagement. Survey questions were designed to gather information based on self-assessment that will feed a number of approaches (three of which are listed below) that, although somewhat subjective, cumulatively provide insight about the level of BIM adoption and implementation at the airports (Jung and Lee 2015):

1. Level of engagement (McGraw-Hill 2014)
2. Jung and Lee approach (2015)
3. Number of BIM uses (Penn State 2010; Kreider and Messner 2013).

Each method evaluates various attributes, as described in this section.

Level of Engagement Approach: This approach uses a methodology for quantifying the level of BIM engagement based on an organization's experience, expertise, and implementation (McGraw-Hill 2014). It can be expected that each airport has a unique BIM operation. However, based on the information gathered through responses to the questions, it is possible to determine an index of current level of engagement to gain insight about relative BIM engagement for responding entities (McGraw-Hill 2014).

Years using BIM informs the experience metric. The following descriptions are used for self-assessment to inform the expertise metric:

- Beginner user—1 year or less of experience, BIM implementation on less than 15% of projects
- Intermediate user—2 years of experience, BIM implementation on 15% to 29% of projects
- Advanced user—3 years of experience, BIM implementation on 30% to 59% of projects
- Expert user—4 or more years of experience, BIM implementation on 60% or more projects.

The implementation metric is described by the following:

- Light implementation (projects using BIM less than 15%)
- Medium implementation (15%–29%)
- Heavy implementation (30%–59%)
- Very heavy implementation (60% or more).

The index has a range of 3 points (representing low engagement) to 27 points (representing very high engagement). The weighted scoring system distributes the maximum of 9 points for BIM experience of 5 years or more, 10 points for expert user designation, and 8 points for very heavy implementation, resulting in the following engagement designations (McGraw-Hill 2012):

- 27 points: “Very High”
- 19 to 26 points: “High”
- 11 to 18 points: “Medium”
- 10 or fewer points: “Low.”

Table 4 shows the results for study participants. Two of the eight airport respondents and all of the AEC respondents exhibit high or very high BIM engagement.

TABLE 4
RESPONDENTS’ CURRENT LEVEL OF BIM ENGAGEMENT

Organization	Years Using BIM	Level of Expertise	Level of Implementation	BIM Engagement	
				Index	Description
Airport 1	5	Expert	Very heavy	27	Very high
Airport 2	3	Advanced	Heavy	24	High
Airport 3	8	Intermediate	Medium	18	Medium
Airport 4	1	Intermediate	Heavy	14	Medium
Airport 5	2	Intermediate	Medium	13	Medium
Airport 6	1	Beginner	Light	6	Low
Airport 7	1	Beginner	Light	6	Low
Airport 8	1	Beginner	Light	6	Low
AEC 1	7	Expert	Very heavy	27	Very high
AEC 2	7	Expert	Very heavy	27	Very high
AEC 3	7	Expert	Very heavy	27	Very high
AEC 4	7	Intermediate	Medium	23	High

Source: McCuen and Pittenger (2015).

Jung and Lee Approach: This approach incorporates evaluation of the potential and maturity of BIM to assess associated technology adoption patterns in a specific industry, such as airports (Jung and Lee 2015). This section presents survey results about adoption status for the various life-cycle phases to assess respondent state of the practice. The following question was used in this study to capture each organization’s self-assessment about these stages for the various life-cycle phases:

> *What do you consider the adoption status of BIM to be in your organization for each of the following life-cycle phases? Please assign (check) a status level of 1–5 for each phase according to the following adoption stages and descriptions:*
>
> Stage 1—**Interested** in adopting BIM, but not yet adopted
>
> Stage 2—**Beginning** the process of adopting BIM
>
> Stage 3—**Integrating** BIM adoption with existing operations, discovering barriers to adoption
>
> Stage 4—**Completing** BIM adoption—overcoming barriers to adoption
>
> Stage 5—Completed adoption—**realizing benefits** of BIM adoption

Based on this methodology, the five “stages” of adoption can be classified into maturity phases of BIM adoption referred to as “Early” (Stages 1 and 2), “Moderate” (Stage 3), “Mature” (Stage 4), and “Very Mature” (Stage 5). Survey results for the 12 respondents are shown in Table 5.

The results show that adoption is not as mature in the operate and maintain and renew and decommission phases. Although the survey results contain a few anomalies, which are inherent in self-assessment, these results are generally consistent with the results in the previous tables in this chapter and in the previous chapter.

Number of BIM Uses Approach: The correlation between frequency of BIM uses and level of implementation has been explored as "another potential index for understanding the BIM adoption level" (Jung and Lee 2015). Essentially, the assumption is that an organization that exhibits a greater status of BIM implementation also adopts and employs a greater number and variety of BIM uses. The output from the three assessment techniques measuring proficiency, BIM adoption, and use of BIM across life-cycle phases (BIM Engagement, Maturity, and Uses, respectively), which were subsequently analyzed, are listed in Appendix A. *An Airport BIM Activity Index* was created to assess relative robustness of the respondents' BIM programs based on BIM activity, noted as "Very High," "High," "Medium," and "Low." These results were introduced in Figure 3 in the introduction chapter and subsequently used in respondents' comparisons. This methodology allows for the capture of BIM activity in both project-based and organization-based implementations, which is not fully addressed by any of the individual approaches.

TABLE 5
LEVEL OF BIM ADOPTION FOR RESPONDENTS

	BIM Adoption Phases				
	Early		Moderate	Mature	Very Mature
	Interested	Beginning	Integrating	Completing	Realizing benefits
	Number of Respondents				
Plan	1	2	3	1	5
Design	0	4	1	2	5
Construct	1	2	1	2	6
Operate/Maintain	3	2	2	4	1
Renew/Decommission	2	3	2	1	0

Source: McCuen and Pittenger (2015).

The survey results provided the approximate percentage of total facility area currently modeled in BIM for responding airports. Most of the airports have about 25% of facilities modeled, whereas one airport reports 75%. This is consistent with survey results related to the level of BIM adoption by life-cycle phase. More than half of the respondents reported being in the *completing or realizing benefits* stage of BIM adoption in the planning, design, and construction phases. Modeled facility area and information are increasingly expected as projects are planned, designed, and constructed using BIM. The operate/maintain phase lags in the overall level of adoption reported, with only one airport reporting that it is *realizing benefits*. To realize benefits (e.g., to transition from adoption to implementation) at the operate/maintain phase, a facility model is needed. As other airports transition, the percentage of facilities modeled will increase.

Airports also provided the BIM method used to model existing facilities. Half of the airports reported having existing facilities for which the design originated in BIM, which indicates either that BIM deliverables were part of the project requirements or possibly that the design team delivered the model as a standard practice. Laser scanning is a modeling method that generates a point cloud of the existing facility from which a record model can be generated as an authoritative source of information about the facility elements and systems. Modeling from an existing digital drawings import or from existing printed construction documents can provide the same information for operations and maintenance as laser scanning, but with less initial cost. However, modeling from drawings is time consuming and may result in a higher net modeling cost in the end. Survey results indicate a preference for more efficient approaches to modeling existing facilities.

Figure 10 shows that half of the airports and most of the AECs have a written implementation plan in place to guide their organizations' implementation efforts. For the airports, results correspond with their BIM activity levels: those with a written plan have the highest levels of activity. Two of the airports with a written implementation plan are just beginning to implement it. The remaining respondents reported that they have executed at least 75% and up to 100% of their plans. More than half of the respondents (five airports, two AECs) also have an internal BIM guide (custom or standardized) to assist new BIM users.

ANC is finalizing its organization-centric BIM standards. However, finding guidance has been challenging, as available standards are commonly project-centric, developed by consultants with the aim of assisting owners in effectively implementing BIM uses important for design and construction such as Design Review, Clash Detection, 3D Coordination, and Digital Fabrication.

Adoption Barriers

Balfour Beatty Construction (BBC) has observed that BIM often generates interest among owners. Consultants, contractors, and vendors are quick to sell BIM, but one of the biggest barriers to BIM adoption is that owners do not know whom to trust. Therefore, the company spends time educating owners about BIM and demonstrating the technology to them. For example, on a recent nonairport project, an owner requested that the company demonstrate the uses of BIM on a small pilot project on its campus so that it could educate itself on the value of BIM. It has been observed that when owners understand BIM, they want to use it.

Massport's BIM Implementation Plan and Internal BIM Guide

At the time of this writing, Massport's BIM Guide was available at http://www.massport.com/business-with-massport/capital-improvements/resource-center/.

Massport's BIM Implementation Plan (Guide) includes the following:

- Massport's BIM vision and value proposition
- Collaboration for Lean BIM projects
- BIM execution planning and BIM uses
- Appendix that supports model content and development
- Data standards, modeling, and construction documentation requirements
- Development and submission of model and contract documents.

Massport is finalizing its internal BIM Guide that will provide assistance to personnel in managing BIM-enabled projects. Different roles require different levels of understanding and training related to BIM and BIM tools. For example, unlike the project manager, the director does not need to know how to run clash detection, but needs to understand the value of BIM in delivering a project. For the BIM/GIS teams, the Guide answers the questions (1) what do we do with the model after the consultant delivers it, and (2) how do we use the model?

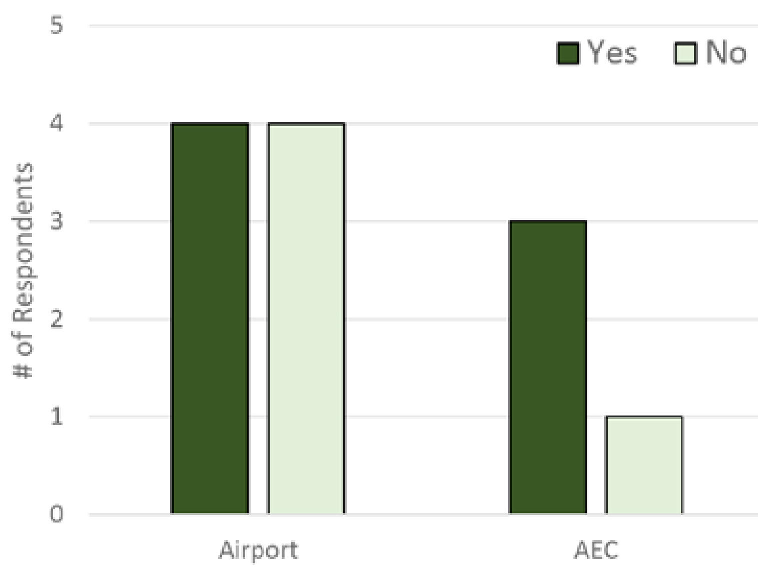


FIGURE 10 Survey results for BIM implementation plan.

BBC also noted that, from a contractor's perspective, the biggest challenge of working with airports on BIM-supported projects is that they are generally not structured in a way that is conducive to BIM. Commonly, there is limited cooperation between departments or there is resistance to expanding the IT infrastructure needed to support BIM.

Survey results, consistent with literature, cited BIM challenges related to system complexity, implementation duration, silos of information, and general lack of guidance for airports.

> *It is critical to have a senior-level BIM advocate. Hiring experts (internal staff or consultants) to facilitate implementation is also vital for realizing the benefits of BIM.*
>
> – Denver International Airport

Optimization

Seventy-five percent of the organizations (five airports, four AECs), most of which are classified as having advanced or intermediate levels of BIM implementation maturity (as noted in the previous chapter), report having a BIM champion in upper management. The one exception is an airport that is in the beginning phase of implementation. The 25% that do not have a champion are the remaining airports that currently have beginning to basic levels of implementation maturity.

However, all respondents noted the importance of having a BIM champion in an effort to optimize BIM implementation. The following list shows, in descending order, the importance attributed to each optimization (organizational readiness) issue:

- BIM champion
- Organizational goals for BIM implementation
- Team members' willingness to adopt BIM
- BIM implementation plan
- Computer software proficiency
- Team organization and management
- Team members' experience with BIM
- Database management capabilities
- Change management plan
- Facilities management expertise.

> *The goal of the SFO BIM Implementation Program is to eventually have the verified, virtual representation of the airport's infrastructures (i.e., converted models and related data), which will be used to support all airport operations, especially in facilities maintenance, throughout the life cycle of the infrastructures.*
>
> – San Francisco Airport Commission

All of the issues were considered moderately to very important by at least 75% of respondents. Besides having a BIM champion, having an implementation plan that outlines organizational goals and the team members' willingness to adopt BIM were considered most important. Having database capabilities, a change management plan, and facilities management expertise were considered the least important, although at least half of the respondents thought they were important or very important.

Anchorage International Airport reports that the value of its BIM champions at the various organizational levels is to provide an understanding of the value that BIM can bring to specific internal stakeholders (e.g., reducing facility management's workload associated with searching plan sheets to locate asset information).

San Francisco Airport Commission Champions (the airport director, COO, and deputy director of design and construction) initiated its organization-centric BIM implementation.

CHAPTER FOUR

TECHNICAL ISSUES—CONTRACTS, RESOURCES, AND REQUIREMENTS

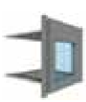
After an organization adopts and implements BIM, it then develops its strategy to execute BIM on projects and in its operations. This chapter provides general information about BIM technical issues across the facility life cycle. It also provides related airport experience.

BACKGROUND

Contracts

BIM supports an integrated, collaborative approach to project delivery and contracting strategies for new construction and renewal projects. The coordination and information-sharing capabilities of BIM facilitate efficient communication between team members for increased project knowledge and improved solutions. The need for improved contracts to support BIM is a continuing challenge for the industry, as 54% of respondents in a recent survey identified the need for more use of contracts to support BIM (McGraw-Hill 2012). Industry organizations such as the American Institute of Architects (AIA) with its BIM Agreement and the Association of General Contractors with its Consensus Docs are addressing the contracting issues. The AIA Digital Practice Documents include the *Building Information Modeling and Digital Data Exhibit* (E203), *Digital Licensing Agreement* (C106), *Project Digital Data Protocol Form* (G201), and *Project Building Information Modeling Protocol Form* (G202). The AIA documents are intended to be attached to the project agreement at the time the agreement is executed.

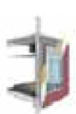
Perhaps the most widely adopted aspect of the original AIA documents is the definition of Level of Development (LOD) in terms of the expected accuracy of model element graphics and information content. NBIMS recently revised the original LOD categories to include LOD 350 (NBIMS 2015). LOD describes the minimum dimensional, spatial, quantitative, qualitative, and other data included in a model element to support the authorized uses associated with such LOD, as follows (AGC, AIA, and NBIMS 2015; images from Massport 2015, used with permission):



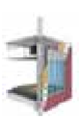
LOD 100—Model element may be graphically represented in the model with a symbol or other generic representation, but does not satisfy the requirements for LOD 200. Information related to the model element can be derived from other model elements.

LOD 200—Model element is graphically represented within the model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the model element.

LOD 300—Model element is graphically represented within the model as a specific system, object, or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the model element.



LOD 350—Model element is graphically represented within the model as a specific system, object, or assembly in terms of quantity, size, shape, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the model element.



LOD 400—Model element is graphically represented within the model as a specific system, object, or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the model element.

LOD 500—Model element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the model elements.

Within the collaborative environment of BIM, project delivery methods that integrate design and construction with the owner and facility operations will enable the greatest opportunity to optimize the project. Design-Build and Integrated Project Delivery assemble the team during the planning or early design phase, which, with the support of BIM, enables collaborative problem solving early in the project life cycle. As a result the facility owner benefits from cost avoidance and improved performance (Smith and Tardif 2009). Additionally, an integrated approach to project delivery distributes risk in a more equitable way, with the team collaborating on solutions that are best for the facility owner. The traditional method of Design-Bid-Build has built-in barriers between the designer and contractor, resulting in a potential adversarial and contentious relationship. Even with Construction Manager-at-Risk, BIM enables a more robust guaranteed maximum price associated with the shared project knowledge and problem solving between the design and construction team (McGraw-Hill 2012). Although in some cases, certain roles on the team may be assuming additional risks, such as the designers that share models; an integrated team agreement defining roles and responsibilities will assist with this issue.

Resources and Requirements

It is important that the BIM personnel, project team, and organizational stakeholders' roles and responsibilities be defined clearly and early. The *BIM Project Execution Planning Guide* (Penn State 2011) is a useful tool for developing the contracts, communication procedures, technology, and quality control to support BIM implementation at the project level. The guide includes 13 sections to be completed upon team formation:

1. Project information
2. Key project contacts
3. Project goals/BIM uses
4. Organizational roles/staffing
5. BIM process design
6. BIM information exchanges
7. BIM and facility data requirements
8. Collaboration procedures
9. Quality control
10. Technological infrastructure needs
11. Model structure
12. Project deliverables
13. Delivery strategy/contract.

A clear definition of the BIM roles and responsibilities within a facility owner's organization is essential if the owner is seeking BIM for operations and asset management. As presented in the previous chapter, critical to the organization's BIM implementation is a BIM champion, along with key personnel to execute the implementation. These key personnel include a BIM manager, BIM specialist, and technology specialist. The BIM manager and specialist should have the requisite skills and knowledge in design, construction, and operations roles. Although BIM relies on technology to enable improvement, the discipline-related competencies of individuals in these roles are critical to implementation if an owner is to realize improved personnel productivity.

Contracting BIM Project Services

When an owner contracts BIM services on a project, it is common to have a BIM Manager who guides BIM activities throughout design and construction. The first steps involve developing the team and establishing requirements for the final deliverable. The initial BIM project execution plan is developed and approved by the team. The project delivery method will affect how the BIM Manager facilitates the process:

- *Design-Bid-Build (DBB): The BIM Manager works with the owner to establish contractor BIM requirements to be included in the bid package.*
- *Construction Manager/General Contractor or Construction Manager-at-Risk (CM/GC or CMAR): The BIM Manager works with the CM/GC/CMAR to ensure that the contractor BIM requirements are included in the bid package.*
- *Design-Build (DB): The BIM Manager works with the contractor to ensure that both the design and construction deliverables are understood.*

– Iron Horse Architects

Without clients defining exactly what data they require and when—the employer's information requirements—then full asset data will not be extracted during construction.

– Gatwick Airport (2014)

Defining the information exchanges between project participants will ensure that the author and receiver for each information exchange transaction clearly understand the information content. The *Penn State Project Execution Planning Guide* (2011) includes an information exchange worksheet for use by the BIM coordinator and project team. The information exchange worksheet was created to be completed in the early stages of a project after the BIM process is designed and mapped. For example, if 3D coordination is one of the BIM processes to be used on a project, then the exchange process and information content between team members are to be defined to provide the information needed by each member to perform his or her tasks within the process. Information exchange standards are to be defined at the project level, unless a national or industry standard information exchange exists. NBIMS version 3 (2015) includes eight information exchange standards that were developed by industry experts, then vetted and approved by a majority vote of buildingSMART alliance™ members. Complete description and information exchange requirements are available in the NBIMS version 3. The eight standards are

1. Construction Operations Building information exchange (COBie)—version 2.4, Appendix A—Life-cycle information exchange for Product Data (LCie)
2. Design to Spatial Program Validation (SPV)
3. Design to Building Energy Analysis (BEA)
4. Design to Quantity Takeoff for Cost Estimating (QTOIE)
5. Building Programming information exchange (BPie)
6. Electrical information exchange (SPARKie)
7. Heating, Ventilating, and Air Conditioning information exchange (HVACie)
8. Water Systems information exchange (WSie).

In addition to BIM personnel, material and financial resources will be needed to successfully implement BIM. Developing the organization's strategy for BIM use so that it clearly details the intended maturity level of implementation, tools to support the BIM uses, and BIM processes for information exchanges will assist with successful implementation.

The Interactive Capability Maturity Model is a free resource that measures the level of maturity at the project level exclusively within an organization (NBIMS 2007, 2015). Tools (software) to consider as internal resources are (1) BIM estimating tools; (2) model validation, program, and code compliance tools; (3) project communication and model review tools; (4) model viewing tools; (5) model servers; (6) facility and asset management tools; and (7) operation simulation tools (Smith and Tardif 2009). The primary criteria for selecting tools include interoperability, or a common data exchange language, through which the exchange of information can be executed between technologies without redundant human input of the information. Without interoperability the tools will not support collaboration but instead will establish islands of information with no means for efficient sharing between team members.

Gatwick Airport aims to have 100% fully integrated asset information coordinated through BIM integrating and other databases. Reaching this goal will require compatibility and interoperability with existing management systems used across the various departments within the airport for operational maintenance and commercial billing.

– Gatwick Airport (2014)

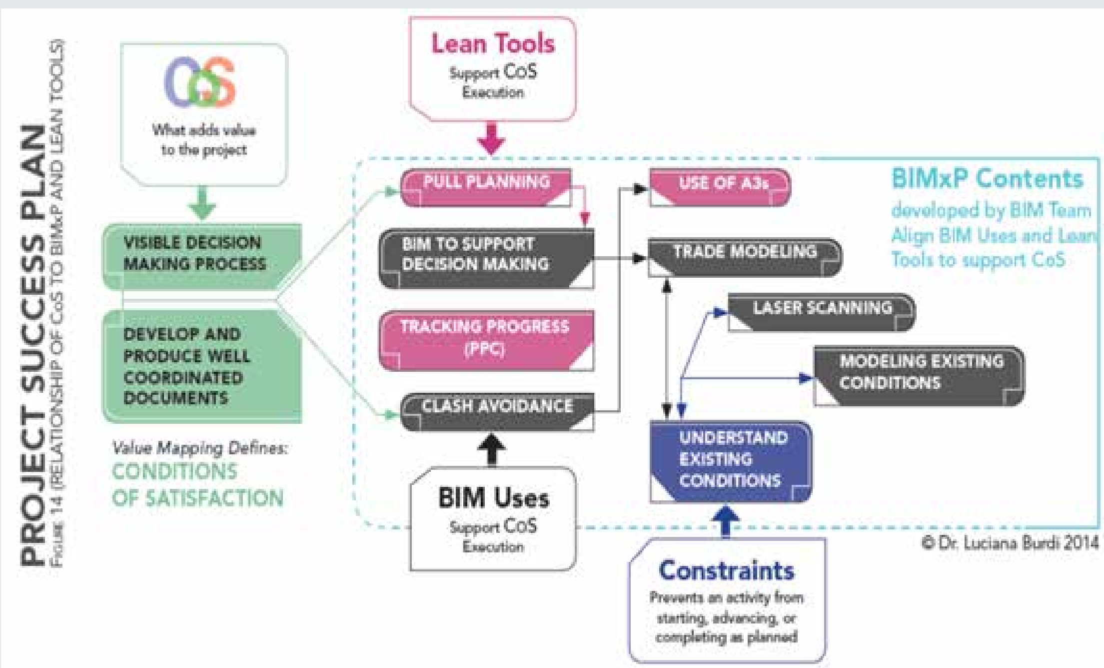
AIRPORT EXPERIENCE—SURVEY RESULTS AND CASE EXAMPLES

Seventy-five percent of the respondent airports require BIM for new projects. Most of the airports require BIM based on a project size of $5 million or greater; fewer airports require BIM on all projects, regardless of size.

Boston Logan International Airport (BOS) uses a BIM Decision Matrix (located in Appendix C) to determine when and how to use BIM for each project type. An organization's BIM strategy may change as technology evolves. Lessons Learned: Don't use BIM for the sake of using BIM. If BIM is misapplied, it can be costly and yield no benefit. Massport has shifted from a "BIM for all projects" to a "BIM for selected projects" philosophy.

Massport's Lean BIM Approach

There is great diversity in type and size of projects at an airport, and not all projects will benefit from BIM use. MPA has recently adopted a Lean BIM approach that requires process changes. Specifically, application of BIM tools and uses must be clearly linked with the success of a given project. The "Massport Decision Matrix" is used to determine if BIM application is appropriate for a specific project. If benefits can be derived, then a "Project Success Plan," a process that links Lean Principles to BIM use (see figure below; Massport BIM Guide 2015, p. 19) is initiated to determine which BIM uses are appropriate for the project and which are not. For example, if a project has no LEED requirements, MPA will not perform the energy modeling because it is costly and wastes effort.



"If an owner does not require BIM for a project but the consultant develops a model anyway, the owner may benefit from obtaining it."

– Boston Logan International Airport

LAWA is gradually removing the term "BIM" from its requirements because it is generally not well understood. It is being replaced by more concise language related to the "managing of information" for the purposes of decision making, which is a more familiar concept to executive management. LAWA is not receiving "BIM"; rather, it is receiving information that has been authored, vetted, and finalized in the form of asset data to be used by internal stakeholders (Asset Management, Facilities).

Iron Horse Architects state that 3D modeling is a standard business practice for many architects who use it for the purpose of spatial coordination, which adds value to the designer during the design process. On the contrary, architects generally provide BIM only on projects when specified (and purchased) because the benefit of BIM is not realized by the architect, but by the owner of the asset. BIM is more design-labor intensive and, therefore, more costly. However, since design fees/additional cost of BIM is the smallest portion of costs on large projects, it is often easily offset and justified, especially when the BIM data will be leveraged by the owner to create savings in the facility management phase. For this reason, even if an airport is not currently contracting BIM, it may be advantageous for it to do so on large projects so that it does not miss the opportunity to capture the data for future use.

Balfour Beatty Construction states that BIM is a standard business practice for many general contractors who use it (and require subcontractors to use it) for the purpose of spatial coordination (i.e., clash detection), which adds value to the contractor during the construction process. Therefore, contractors may use BIM regardless whether an owner requires it on a project.

"An owner is to clearly communicate what it wants in BIM and how it is going to use the information so that consultants can deliver."

– Iron Horse Architects

Figure 11 shows the BIM requirements that respondent airports add to their request for proposals (RFP) for new construction and renovation/renewal projects. All of the airports require a BIM project execution plan and specify technology (software requirements). Inclusion of risk allocation clauses was cited least by respondents. However, a recent case study with the American Institute of Steel Construction revealed a need to better define project team relationships and expanded roles and responsibilities, which need to align with the additional risks associated with BIM-related project activities (McGraw-Hill 2012).

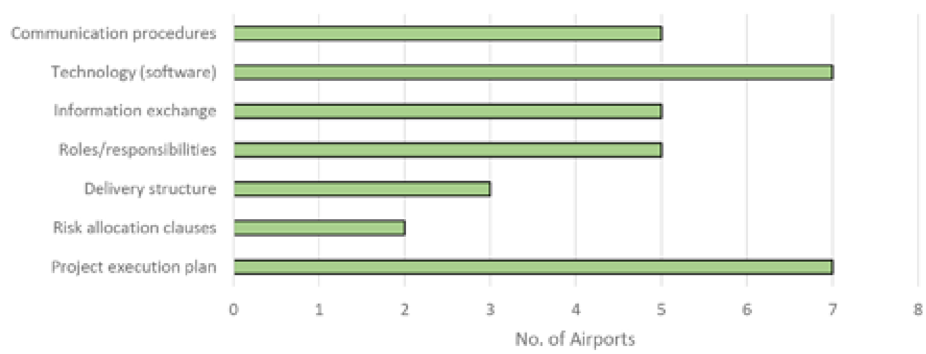


FIGURE 11 Airport RFP BIM requirements for new construction or renovation/renewal projects (McCuen and Pittenger 2015).

Balfour Beatty Construction states that another challenge general contractors face relates to getting owners to define and communicate BIM needs early enough in the project process so that the requirements can be seamlessly added into the process. Contractors need to know what the owner's end-of-project goals are, what type of data are required and in what format, and so on. On a current nonairport project, the owner initiated a predesign BIM meeting with the contractor that included the facilities operations and management groups, to establish the project-related BIM requirements.

Consistent with literature, respondents indicated a need for guidance for improving contracts to support BIM, as developing contract language is a continuing challenge.

"We want BIM" is not a useful owner's requirement. Owners need to specify the why-how-what-and-when aspects related to BIM deliverables. Perspective of BIM and associated benefits is unique to each organization. Therefore, it is imperative for owners to develop a written BIM Guide to direct consultants toward owner requirements and goals. The purpose of the Massport BIM Guide is to ensure that at the end of a project, MPA gets what it needs to manage and maintain the facility.

– Boston Logan International Airport

At the time of this writing, DEN's BIM/GIS design standards manual [*Electronic Data Collection and Interchange (EDCI) Compliance Design Standards Manual*] was available at http://business.flydenver.com/bizops/documents/denEDCIComplianceDSM.pdf. DEN is in the process of rewriting the manual to reflect the lessons learned during the execution of its recent large capital project.

Lessons Learned: Developing contractual language is an iterative process that results from the general lack of guidance. When contractually requiring consultants to record/provide asset data, it is important to be very specific in the contract language about what asset data are to be captured.

The *SFO BIM Guide* provides consultants with project performance requirements, which are outcome-focused, in terms of data and documents, instead of prescriptive requirements, which are process-focused. Specifically, SFO requires consultants to develop project-specific BIM execution plans, which facilitate "bringing them to the table as true partners." The goal is to benefit from the value being developed by the consultants according to their talents and skills during design and construction for the purpose of making outcomes directly useful to SFO facilities maintenance and operations as well.

Historically, the application of BIM in design and construction has been project-focused. Even when an owner required BIM as part of the project closeout package, it generally went unused by facilities' O&M. SFO is directly addressing that industrywide issue by partnering with consultants to develop project execution plans that include considerations for using data beyond construction closeout. This creates a valuable feedback loop that allows SFO to fine-tune the *SFO BIM Guide*. Currently, SFO is finalizing its RFP (contract) language and *BIM Guide*.

LAWA has specified in its RFP language the way that it expects information (e.g., asset location, make, model, serial number) to be made available at the end of the project (closeout data delivery requirements). Additionally, LAWA requires the information to be consolidated into the record models, which are defined per LAWA standards. Asset data are to be structured in a way that is useful to LAWA and to its CMMS. This enhances efficiency in the information transfer process. The data are also required to be verified during the commissioning process, enhancing the accuracy of the information. An example of one of LAWA's Project Requirement Documents (PR–20), for Virtual Design & Construction (VDC), Building Information Model (BIM) is located in Appendix D. Lessons Learned: Language about the definition of the required design model needs to be clear in procurement. For example, LAWA has a standard that the design must be composed in a specified BIM authoring tool.

Airports require different LODs for BIM deliverables at project handover. Most of the airports require LOD 300 or LOD 350, whereas one airport (which uses COBie) requires LOD 400 and one does not specify LOD requirements. Although the airport that requires LOD 400 is at the beginner level of expertise and at a light level of implementation, indications are that the airport's BIM strategy is to utilize it for robust operations and asset management. Model elements at LOD 400 are ready for fabrication and are modeled as specific systems, objects, or assemblies in size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information.

Anchorage International Airport is currently evaluating the optimal amount of detail to include in its BIMs. The initial thought was to model all facility elements to include complete graphical and properties data. However, the high-density scans contain a lot of detail; converting them to BIM (from point clouds to parametric objects) is resource intensive. A more gradual approach may be better if tools continue to be developed that can convert raw scan data into usable visual images.

Eighty-five percent of the airports stated that they have a requirement for file compatibility, since data exchange between software requires a common language.

Of the three airports where tenants are involved in BIM, only DEN requires a tenant BIM model (minimum LOD 350); however, it does not require an energy analysis (energy modeling).

Table 6 shows the relationship between an airport respondent's BIM activity level and the group that is managing its BIM activities.

The obvious trend is that the airports that have more BIM activity have a dedicated BIM staff or the facilities management group manage that activity. As the other airports expand their BIM activity into the facilities management/operations phase, how they manage the additional BIM activity may need to be considered.

Tenant BIM at Denver International Airport

Recently, Concourse C was expanded and new tenants were added at DEN. Although not contractually obligated to do so, the consultant designed the project in BIM according to DEN standards. DEN was able to get tenant BIM data and leverage the experience to develop/troubleshoot its Tenant BIM Guidelines to be implemented on future projects.

It is important to demonstrate the business case for BIM to airline tenants, since these stakeholders are DEN's customers. The airline tenants have exhibited buy-in to the concept of BIM. The obvious BIM-related benefit accrued to these stakeholders is in the enhanced ability to shift from corrective maintenance practices to preventive maintenance practices, which are less costly and result in better gate availability and fewer construction disruptions. However, buy-in is mixed with regard to actual implementation; some have adopted BIM companywide while others resist owing to stated reasons of higher initial project costs due to BIM.

There is a different dynamic with nonairline tenant buy-in because there is really no benefit to these stakeholders (therefore, no buy-in, although some of the DEN tenants see the value of BIM). The benefit of tenant BIM is realized by facility owners. Tenants are resistant, but DEN contractually requires it.

Lessons Learned: DEN BIM Managers must be prepared to spend a lot of time assisting tenants (and consultants) in applying DEN BIM Guidelines (e.g., teaching them how to get on shared coordinates, how to use a linked model).

– Denver International Airport

TABLE 6
AIRPORTS' BIM ACTIVITY MANAGEMENT GROUP AND BIM ACTIVITY LEVEL

Group That Handles Airport's BIM	BIM Activity Level			
	Very high	High	Medium	Low
Dedicated BIM staff	1	1		
Facilities staff		1		
Outsourced to consultants/other stakeholders			1	
Other: (1) CAD staff; (2) Design and construction;			2	2
(3) Engineering data; (4) Engineering staff				

CHAPTER FIVE

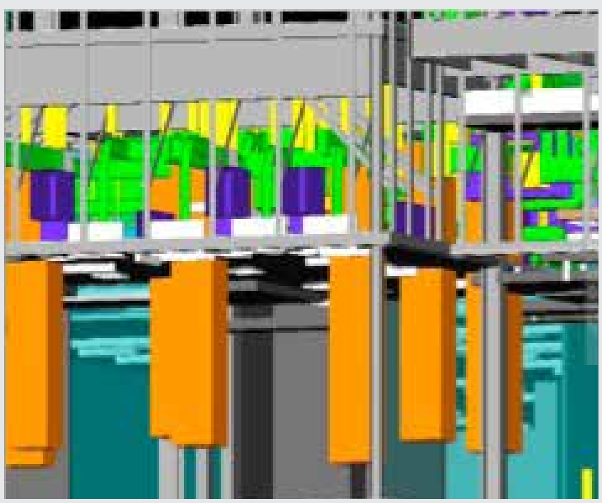
FACILITY LIFE-CYCLE MANAGEMENT

After developing its strategy to execute BIM on projects and in its operations, an organization begins the process of acquiring and implementing BIM throughout the facility life cycle. This will support its organizational goals of managing assets in ways that maximize facility life-cycle value and minimize the true cost of ownership. This chapter provides general information about facility life-cycle management with BIM. It also provides related airport experience.

BACKGROUND

Facility life-cycle management uses an "organizational infrastructure of people, processes and technology" (Motawa and Almarshad 2013). BIM is used in facility management (FM) to increase the efficiency of operations, save money over the life of the facility, and possibly extend the facility's useful life (Smith and Tardif 2009). Facility management functions use an extensive amount of information generated across an organization and its programs (Patacas et al. 2015). A facility management model could significantly streamline the FM process with comprehensive information about equipment warranty, routine maintenance, and estimated useful life of major building components. Additionally, the building systems controls could be integrated with the BIM to monitor the facility's performance. Depending on the owner's requirements, the FM BIM deliverable may be a design model with design intent information and as-built conditions, or it may also be the as-built model with complete construction and fabrication information.

A 3D model can provide only basic, generalized information—for example, the quantity and size of VAV [variable air volume] boxes on a project. But BIM supports FM because it can add data to the model that is specific to each VAV box on the project (e.g., geolocation, size, flow, speed, connections, filter type, maintenance plan, supplier information). – Iron Horse Architects.



(Image of above-ceiling HVAC location and maintenance space requirements) (McCuen and Pittenger 2015).

Methods for Implementing a Life-Cycle Approach

A life-cycle approach exists from the earliest conception to demolition of a facility (Kreider and Messner 2013). To implement BIM into the life cycle, the facility owner identifies BIM uses across the life cycle, information exchange requirements at each life-cycle phase, as well as stakeholders within each phase. The final phase involves managing the building and its valuable contents as financial assets. Although the existing guides and tools for general facility owners provide templates for projects, approaching life cycle from the organization's perspective can be facilitated with a merger of a comprehensive BIM strategy, goals, and champion. *ACRP Report 139* provides some guidance for using BIM in optimizing airport operations and maintenance to facilitate a whole-systems approach (Sebesta 2015).

Resources for Life-Cycle Management

The capabilities enabled through smart building technologies and monitoring of building systems are resources available to improve facility life-cycle management. *The U.S. Army Corps of Engineers Roadmap for Life-Cycle Building Information Modeling* (2012) focuses on an integrated facility life-cycle management of information for infrastructure. The Engineer Research and Development Center continues to develop an integrated framework for predicting, monitoring, and controlling activities in a facility, and the resources needed to support those activities are the R&D focus for the group.

> As BIM becomes an integral part of the FAA enterprise information management system, models used for design will form the basis of the information source for life-cycle management activities that BIM will enhance while improving resource and cost utilization by providing the capability to
>
> - *Reduce travel to confirm existing site conditions*
> - *Update as-built drawings to match existing conditions*
> - *Facilitate coordination between disciplines and organizations*
> - *Improve the accuracy of design reviews*
> - *Enhance cost estimating for all project life-cycle phases*
> - *Improve safety analysis*
> - *Monitor OSHA/EOSH compliance*
> - *Verify assets after a catastrophic event*
> - *Track assets throughout their life cycle for capitalization value.*
>
> – FAA (2015a)

Asset Management/GIS

Accurate representations of real-world property conditions modeled in BIM can help reduce the information gap between those conditions and the typical stored tabular data about the facility (Smith and Tardif 2009). Building geospatially located information enables asset management by associating the real-property location with the model for space use tracking, analysis, and forecasting. A geographic information system (GIS) tool provides the link between systems. Linking the facility management system bidirectionally to the record maintenance model will provide the necessary information for financial decision making, short-term and long-term planning, and work-order scheduling by the facility management team. The bidirectional link between the facility management software and the record model allows for the visualization of assets in the model prior to work orders, thus potentially reducing time and cost investments (Penn State 2013).

Determining Downstream Information Needs

The owner's facility management team should first determine the model elements for which the BIM will be used and then define the level of development for each model element specified. Depending on the BIM deliverable requirement, the facility management team may need personnel with skills to navigate the design or record model to view the building elements and associated information. In some instances the owner may specify both, using the as-built construction model for as-built documentation and the record model (in its native file format) to update and use for renovation throughout the facility life cycle (Penn State 2013).

Ensuring Appropriate Information Exchanges

The facility data, attributes, and properties of the facility's elements will be needed for efficient facility management. The COBie is a performance-based specification for system-to-system facility information delivery without user intervention (National Institute of Building Sciences 2014). The COBie worksheets enable information exchanges and provide a standard structure for facility data (Penn State 2013). The biggest challenge for information exchange is the facility management team defining the information needed in the model at the time of handover. Defining the information exchange requirements is a multistep team process in which the exchanges between project participants are clearly defined along with the information content of the exchanges, using a process map. Based on the BIM process map, the steps to creating the information exchange requirements are as follows (Penn State 2011):

1. Identify each potential information exchange from the process map
2. Choose a model element breakdown structure for the project
3. Identify the information requirements for each exchange, in terms of output and input
4. Assign responsible parties to author the information required
5. Compare input versus output content.

As a shared knowledge resource, BIM can reduce the need for re-gathering information. This can result in an increase in the speed and accuracy of transmitted information, reduction of costs associated with a lack of interoperability, automation of checking and analysis and unprecedented support of operation and maintenance activities.

– GSA (2016)

The primary BIM uses for Facilities Management (operate phase) are defined as follows (Penn State 2010):

- **Maintenance Scheduling**—defined in the second chapter of this report.
- **Asset Management**—a "process in which an organized management system will efficiently aid in the maintenance and operation of a facility and its assets. These assets, consisting of the physical building, systems, surrounding environment, and equipment, are to be maintained, upgraded, and operated at an efficiency which will satisfy both the owner and users at the lowest appropriate cost. It assists in financial decision-making, as well as short-term and long-term planning. Asset Management utilizes the data contained in a record model to determine cost implications of changing or upgrading building assets, segregate costs of assets for financial tax purposes, and maintain a current comprehensive database that can produce the value of a company's assets."
- **Space Management/Tracking**—a "process in which BIM is utilized to effectively allocate, manage, and track assigned workspaces and resources. A BIM model will allow the facility management team to analyze the existing use of the space and appropriately manage changes in clientele, use of space, and future changes throughout the facility's life cycle. Space management and tracking is an application of the record model."
- **Disaster Planning**—a "process in which emergency responders would have access to critical building information in the form of model and information system. The BIM would provide critical building information to the responders, that would improve the efficiency of the response and, more importantly, minimize the safety risks. The dynamic building information would be provided by a building automation system (BAS), whereas the static building information, such as floor plans and equipment schematics, would reside in a BIM model. These two systems would be integrated through a wireless connection and emergency responders would be linked to an overall system. The BIM coupled with the BAS would be able to clearly display where the emergency was located within the building, possible routes to the area, and any other harmful locations within the building."
- **Building System Analysis**—defined in the second chapter of this report.

Process of Converting Design/Construction Models to Facility BIM

Generally, closeout as-built models generated from large capital projects require conversion through a thoughtful and thorough process (series of steps) that "cleans out the models (rids the model of no-longer-necessary elements), normalizes the naming and attributions (if needed) of the remaining elements to make them directly useful" to other stakeholders. For example, when design/construction models contain information that is not specifically relevant to the operations and maintenance phases (e.g., information related to preconstruction coordination, collision detection), a distinct calibration phase is required after construction to convert the models into something that the Facilities Maintenance group can use to operate and maintain the assets with better ease. Keeping all of the elements given the current state of technology may make the model "too heavy" for daily use by facilities maintenance and operations.

– San Francisco Airport Commission

AIRPORT EXPERIENCE—SURVEY RESULTS AND CASE EXAMPLES

Since there is currently no standard process or guidance governing the most effective way to institutionalize BIM for asset management, BOS has found that the greatest challenge to developing a strategy stems from the fact that, unlike other parts of the life cycle, FM approaches can vary widely. For example, how does an owner determine what information to include in the record model and how to include it into its facility management processes? The answer to this question will differ among each organization. BOS is exploring three different ways of getting BIM data for FM: (1) through the architect, (2) through the commissioning agent, and (3) through other consultants. Lessons Learned: It may not be advisable for the public owner to specify inclusion of FM-related BIM data in the design model (which is often proprietary) resulting from public bidding statutes, as information (e.g., equipment make, model) may change in the course of the bidding process.

BOS has taken a process-oriented approach in analyzing what the FM team's needs are, then identifying appropriate technology solutions, versus a technology-oriented approach that tries to "fit" available technology to an organization's processes.

Although most of the surveyed airports specify handover of BIM from construction, as discussed in the previous chapter, only one specifies LOD 400 for BIM deliverables. A minimum LOD 300 is specified to facilitate asset management. Model elements at LOD 400 may enhance facilities management through detailing, fabrication, assembly, and installation information. LOD 300 and LOD 350 provide information about size, shape, location, quantity, and orientation; these elements are not ready for fabrication. The model element information needed to achieve LOD 400 is the same detailing, fabrication, assembly, and installation information that could enhance operations and maintenance. The 300 and 350 levels align with traditional construction documents, whereas the LOD 400 is considered the equivalent of construction submittals.

Only one airport utilizes the COBie standard for BIM handover from the construction phase. This finding of a low adoption rate by airports is consistent with the recently reported adoption rate of COBie by the AEC industry. COBie was created to facilitate data transfer from BIM to FM systems and has been incorporated into more than 20 different BIM software packages and tools; however, it is still not well understood by facility owners (Giel et al. 2015).

Four airports (50%) are using BIM to document existing facilities and conditions, which are not part of a new program or construction project.

BIM supports DEN in developing a more robust and cost-effective asset management program owing to such benefits as (1) allowing the tracking of a sufficient number of (more) asset types and (2) reducing the amount of missing or invalid asset data. The process of collecting BIM data throughout the project process enhances the availability and integrity of the data. Specifically, BIM allows for the capture of location information by the designer, asset information (e.g., make, model, serial number) by the contractor, and data verification by the commissioning agent.

DEN is in the process of starting a new program related to the smoother linking of BIM with its GIS and asset management programs. Essentially, DEN is replacing its recent platform with a newer, out-of-the-box software tool that provides a direct link between BIM and a CMMS that permits a bilateral exchange of information (i.e., eliminates the need to transfer data using spreadsheets) and also allows flexibility (e.g., user-defined parameters) that addresses DEN's data transfer needs. Initially, DEN considered developing a centralized database that would serve as a clearinghouse for all of the data generated from BIM, GIS, and asset management programs, allowing real-time data availability to all users. However, DEN determined that developing and maintaining this entirely custom system would be cost prohibitive.

> *The efforts to standardize team collaboration, automate modeling processes, and utilize data standards remain fragmented across standards groups, process silos, competing software vendors, and industry organizations. Currently, the AEC industry does not have a culture that focuses on facility life cycle, well-understood collaboration, or data standards to support current technology capabilities. As an owner, MPA is forced to bring together several disparate industry initiatives in this guide to gain BIM efficiencies on projects.*
>
> – Massport BIM Guide (2015)

DEN is the only respondent airport that has a comprehensive FM program in place. It currently uses BIM for space management/tracking, asset management, and maintenance scheduling. Table 7 provides a profile.

TABLE 7
DENVER INTERNATIONAL AIRPORT FACILITY LIFE-CYCLE MANAGEMENT PROFILE

Survey Question	Yes	No
Is your organization currently using BIM for operations and maintenance and/or facilities management?	√	
Is your organization's computerized maintenance management system (CMMS) integrated with BIM software for data exchange?		√
Is your organization linking BIM with a geographic information system (GIS) for operations and maintenance?	√	
Is your organization's asset management system integrated with BIM software for data exchange?		√
Is your organization currently using BIM data for asset management?	√	
Does your organization use BIM data for the following asset management activities: integrated decision making, life-cycle analysis, and real property inventory?	√	
Does your organization utilize metrics to assess the value of BIM utilization for asset management?		√
Has the use of BIM added value to your organization's asset management plan?	√	

BIM data, based upon open standards, integrates with the Computerized Maintenance Management Systems (CMMS) and the Geographic Information Systems (GIS). This BIM, CMMS, and GIS infrastructure will hold the "ground truth" for MPA assets and provides dashboard data for a future Integrated Workplace Management System (IWMS) streamlining MPA's analysis, consideration, and prioritization of projects.

– Massport BIM Guide (2015)

CHAPTER SIX

CONCLUSIONS

SUMMARY

Because Building Information Modeling (BIM) is an emerging technology, it is only recently being implemented in airports in North America. The objectives of this study were to synthesize information about current state of the art and practice related to BIM in general industry and to determine the status of BIM in targeted airports. The study concludes that although many of these airports have not implemented BIM throughout all of the facility life-cycle phases, they are making progress toward that goal.

TRENDS AND ISSUES

More than half of the airport respondents are in the early phases of BIM adoption where they are between the *interested* and *integrating* stages of adoption. Most are *discovering barriers* and *overcoming barriers* to adoption related to integration issues, such as data silos and lack of industry standards and contract language.

Although the BIM activity levels for the airports currently range from low to very high, airports are realizing (basic) project-level BIM benefits, such as cost savings generated from early detection of issues. However, most have not yet fully integrated BIM throughout their organizations and are, therefore, not yielding organization-level benefits.

There were consistencies, however, in the benefits reported at the project level and organization level. *Improved visualization* was the number one benefit reported by airports. Two other top benefits cited were *better cost control* and *collaboration among project team using a single source of information.* Visualization provides communication (through facility information and facility representations) to critical stakeholders and decision makers that can support decision making throughout the airport's organization without requiring architecture, engineering, and construction professionals (AEC)-level training in design or construction. Although visualization is considered a byproduct of other BIM processes, such as design and three-dimensional coordination, it provides vital support for improved communication that an airport's BIM champion can leverage as one of the main benefits.

The results also indicate a shift of airport BIM activity from project-level (beginning to basic) implementation to an organization-level (intermediate to advanced) implementation. All airports report adding more BIM uses that will facilitate the airports' expansion or advancement of their current use of BIM throughout all facility life-cycle phases. This leads to greater BIM implementation maturity (experience, project implementation, and BIM use across the life cycle) and, in turn, will translate to greater benefits. BIM will also use designated resources in its infrastructure of people, processes, and technology.

Airports are challenged in developing the custom, organization-level strategy for BIM implementation because each airport is unique, with its own business case and resources to support its BIM strategic plan and its BIM use across the facility life cycle. Therefore, the results from respondent airports in this study cannot be generalized to all airports. However, the results provide insight for airports as they progress through the adoption phases within each life-cycle phase.

Respondents reported organizational readiness to be important in the implementation process. An organization's implementation strategy can be optimized through having a BIM champion, having an implementation plan that outlines organizational goals, and ensuring team members' willingness to adopt BIM. Massachusetts Port Authority's Implementation Roadmap in Appendix B illustrates such a strategy.

The lack of contractual language that specifically defines the asset data to be included or the model level of development is another issue for airports implementing BIM at the organization level. Once again this issue corresponds with the need for a BIM Strategy and Implementation Plan that is unique to each airport.

KNOWLEDGE GAPS AND FUTURE RESEARCH

This study identified a number of knowledge gaps related to business processes and BIM.

Although reported as one of the top benefits of BIM, *better cost control* was not the number one metric being used as a key performance indicator (KPI) by respondent airports. One airport reported tracking reduced initial costs and reduced life-cycle costs in their return on investment (ROI) calculations related to BIM. The gap between identifying *better cost control* as a BIM benefit and actually having cost-related KPIs in place to calculate the ROI related to reduced cost reflects a gap common across the AEC industry implementation of BIM. Further research is needed in this area to support an airport's ability to operationalize the identified benefit of reduced costs through metrics that provide the information needed for airports to calculate their ROI for BIM. The complexity and uniqueness of an airport facility in terms of its existing conditions and lack of available data about initial costs and life-cycle costs is a barrier to implementing meaningful KPIs and calculating ROI.

That some of the respondent airports reported that they are *realizing benefits* in the planning, design, and construction life-cycle phases is promising. However, the noticeable gap in this area relates to the full understanding of the lack of BIM use in the operations and maintenance phase of the life cycle. Only one of the airports reports full implementation in this phase and is *realizing benefits*. This gap provides further support for the need to develop KPIs and ROI calculations specific to the airport industry. Most of the respondent airports require BIM deliverables that are inadequate for operations and maintenance. The effect is marginalized facility management and compromised opportunities to realize benefits and determine ROI.

It will become increasingly important for airports to share information related to implementing a comprehensive facility management strategy, developing meaningful key performance indicators, calculating return on investment, and creating the contract language and documents to facilitate a full BIM implementation.

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APPENDIX A

Survey Questionnaire and Consolidated Responses (McCuen and Pittenger 2015)

Survey: ACRP Synthesis 09-07: BIM for Airports [The survey used "skip logic" (all respondents did not receive all questions).]

Please select the category that best describes your organization.

Value	Percent	Count
Airport project manager, operations, facility management or other decision maker	56.3	9
Airport BIM professional (3 airport, 2 AEC)	31.3	5
Designer	6.3	1
Constructor	6.3	1
Total Respondents		16

Does your organization currently engage in building information modeling (BIM)?

Value	Percent	Count	
		Airport	AEC
Yes	77.8	10	4
No	22.2	4	0
Total Respondents		14	4

In general, what do you consider the adoption status of BIM in your organization to be?

(adoption stages and descriptions: Stage 1 - Interested in adopting BIM, but not yet adopted; Stage 2 - Beginning the process of adopting BIM; Stage 3 - Integrating BIM adoption with existing operations—discovering barriers to adoption; Stage 4 - Completing BIM adoption—overcoming barriers to adoption; Stage 5 - Completed adoption—realizing benefits of BIM adoption)

Value	Percent	Count	
		Airport	AEC
1-Interested	33.3	6	0
2-Beginning	16.7	3	0
3-Integrating	11.1	2	0
4-Completing	11.1	1	1
5-Realizing benefits	27.8	2	3
Total Respondents		14	4

How many years ago did your organization adopt BIM?

Count	Response
1 - Airport	Less than 1 year
1 - Airport	2
1 - Airport	3
1 - Airport	5
1 - AEC	5
3 - AECs	7
1 - Airport	8

Does your organization have a BIM champion in upper management?

Value	Percent	Count	
		Airport	AEC
Yes	75.0	5	4
No	16.7	2	0
Other: There is awareness, but not a specific BIM champion	8.3	1	0
Total Respondents		8	4

Does your organization have a written implementation plan for BIM in place?

Value	Percent	Count	
		Airport	AEC
Yes	58.3	4	3
No	41.7	4	1
Total Respondents		8	4

At what approximate percentage complete has your organization executed the implementation plan?

Value	Percent	Count	
		Airport	AEC
25%	0.0	0	0
50%	0.0	0	0
75%	28.6	1	1
100%	42.9	1	2
Other: Starting to implement	28.6	2	0
Total Respondents		4	3

Does your organization use an internal BIM guide (custom or standardized) to assist new users?

Value	Percent	Count	
		Airport	AEC
Yes	58.3	5	2
No	41.7	3	2
Total Respondents		8	4

Is/are part or all of your facility/facilities currently modeled in BIM?

Value	Percent	Count - Airport
Yes	60.0	6
No	40.0	4
Total Airports		10

What is the approximate percentage of total facility area modeled in BIM?

Value	Percent	Count - Airport
25%	83.3	5
50%	0.0	0
75%	16.7	1
100%	0.0	0
Total Airports		6

What method was used to develop your facility/facilities in BIM? (Check all that apply.)

Value	Percent	Count - Airport
Modeled from existing printed construction documents	50.0	3
Modeled from existing digital drawings import	50.0	3
Modeled from laser scan point cloud	66.7	4
Designed/originated in BIM	66.7	4
Other: In process of converting design/construction models to facility BIM	16.7	1
Total Airports		6

Does your organization require BIM for any new projects?

Value	Percent	Count - Airport
Yes	75.0	6
No	12.5	1
Other: Based on internal BIM decision guide	12.5	1
Total Airports		8

For what size projects does your organization require BIM? (Check all that apply.)

Value	Percent	Count - Airport
Large projects ($10M or greater)	66.7	4
Midsize projects ($5M or greater, but less than $10M)	50.0	3
Small projects (less than $5M)	50.0	3
Other: (1) All projects evaluated for BIM use; even repair/maintenance (2) BIM has only been required for one pilot project to date	33.3	2
Total Airports		6

Does your organization require a BIM execution plan for new construction projects?

Value	Percent	Count - Airport
Yes	100.0	6
No	0.0	0
Total Airports		6

What minimum level of development (LOD) does your organization require for BIM deliverables at project handover?

Value	Percent	Count - Airport
LOD 100	0.0	0
LOD 200	0.0	0
LOD 300	33.3	2
LOD 350	33.3	2
LOD 400	16.7	1
Not specified	16.7	1
Total Airports		6

An airport's BIM activity score was developed proportionately to the maximum measurement:

- BIM Engagement Index value was divided by 27
- BIM Maturity score for each phase was divided by 4
- Number of BIM Uses was divided by 24

To combine the three analyses, weighted average based on standard utility theory was used (West and Riggs 1986). All three parameters were given the same weight (33.3%) as follows:

$$\text{ABAI} = 33.3\% * (\text{BEI}) + 33.3\% * (\text{BIM Maturity}_{(\text{D\&C} + \text{Operate})}) + 33.3\% * (\#\text{BU})$$

Where,

ABAI is the Airport BIM Activity Index,

BEI is the BIM Engagement Index,

BIM Maturity$_{(\text{D\&C + Operate})}$ is the combined value for the Design/Construct and Operate phases, and #BU is the number of BIM Uses.

ABAI values were used to designate activity levels: 0.85 or greater equates to "Very High," 0.84 to 0.60 is "High," 0.59 to 0.30 is "Medium," and a lower index is "Low." These results were introduced in the introduction chapter and subsequently used in respondents' comparisons. This methodology allows for the capture of BIM activity in both project-based and organization-based implementations, which is not fully addressed by any of the individual approaches.

Summary Table: ABAI for Surveyed Respondents (after Jung and Lee 2015, McGraw-Hill 2014)

		BIM Activity					
			BIM Maturity		BIM Uses	Airport BIM Activity Index (ABAI)	
Organization	BIM Approach	BIM Engagement	*Design/ Construction*	*Operate*		*Index*	*Level*
1 - Airport	Organization	27	Very Mature	Mature	17	0.85	Very High
2 - Airport	Project	24	Mature	Early	11	0.61	High
3 - Airport	Organization	18	Very Mature	Very Mature	—	0.83	High*
4 - Airport	Organization	14	Moderate	Moderate	15	0.54	Medium
5 - Airport	Organization	13	Early	Moderate	17	0.51	Medium
6 - Airport	Project	6	Early	Early	0	0.16	Low
7 - Airport	Project	6	Very Mature	Early	4	0.34	Medium
8 - Airport	Project	6	Early	Early	0	0.16	Low
1 - AEC	Project	27	Very Mature	—	5	0.73	High
2 - AEC	Project	27	Very Mature	—	13	0.84	High
3 - AEC	Project	27	Very Mature	—	20	0.93	Very High
4 - AEC	Project	23	Mature	—	13	0.71	High

- None listed/not applicable
* Estimated

What level would you currently describe your organization's BIM experience?

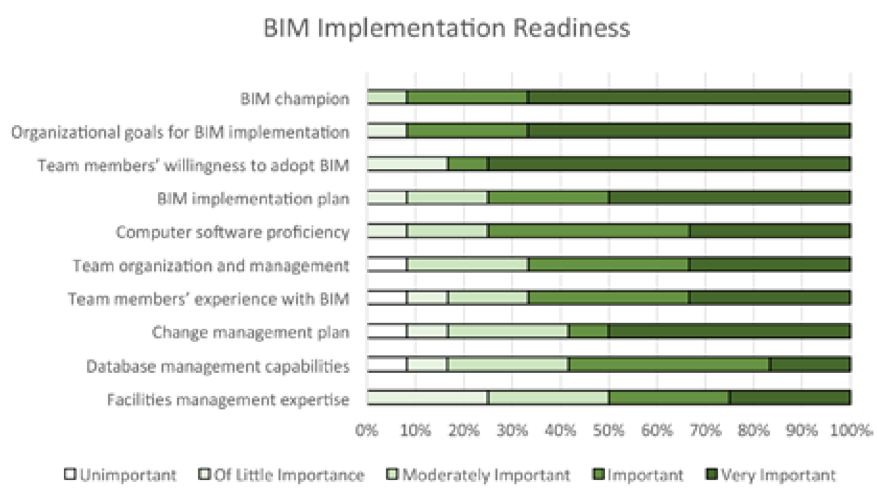
Value	Percent	Count	
		Airport	AEC
Beginner user - 1 year or less experience and less than 15% BIM implementation on projects	25.0	3	0
Intermediate user - 2 years of experience and 15% to 29% BIM implementation on projects	33.3	3	1
Advanced user - 3 years of experience and 30% to 59% BIM implementation on projects	8.3	1	0
Expert user - 4 years or more experience and 60% or more BIM implementation on projects	33.3	1	3
Total Respondents		8	4

What level of BIM implementation do you expect your organization will achieve in the near future?

Value	Percent	Count	
		Airport	AEC
Light implementation (less than 15% of projects using BIM)	16.7	2	0
Medium implementation (15%–29%)	25.0	3	0
Heavy implementation: (30%–59%)	8.3	0	1
Very heavy implementation (60% or more)	50.0	3	3
Total Respondents		8	4

Based on your organization's experience with BIM implementation, please rank how important each of the following are to optimizing BIM implementation.

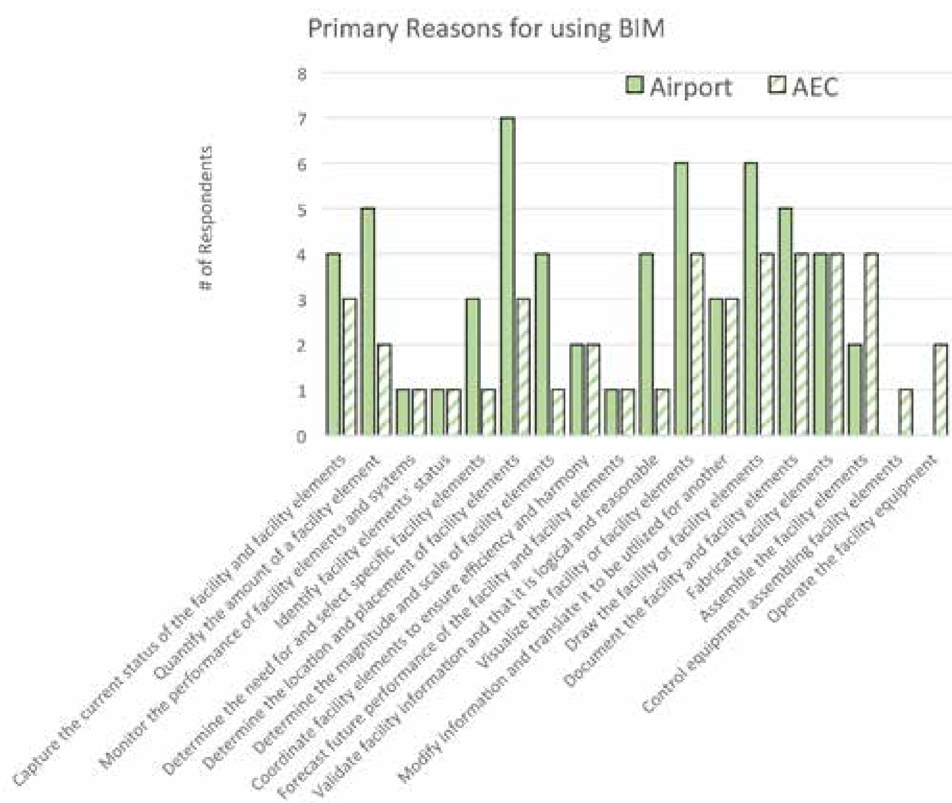
	Unimportant	Of Little Importance	Moderately Important	Important	Very Important	Responses
Organizational goals for BIM implementation	0.0% 0	8.3% 1	0.0% 0	25.0% 3	66.7% 8	12
Change management plan	8.3% 1	8.3% 1	25.0% 3	8.3% 1	50.0% 6	12
BIM implementation plan	0.0% 0	8.3% 1	16.7% 2	25.0% 3	50.0% 6	12
Computer software proficiency	0.0% 0	8.3% 1	16.7% 2	41.7% 5	33.3% 4	12
Database management capabilities	8.3% 1	8.3% 1	25.0% 3	41.7% 5	16.7% 2	12
Facilities management expertise	0.0% 0	25.0% 3	25.0% 3	25.0% 3	25.0% 3	12
Team organization and management	8.3% 1	0.0% 0	25.0% 3	33.3% 4	33.3% 4	12
Team members' experience with BIM	8.3% 1	8.3% 1	16.7% 2	33.3% 4	33.3% 4	12
Team members' willingness to adopt BIM	0.0% 0	16.7% 2	0.0% 0	8.3% 1	75.0% 9	12
BIM champion in your organization's upper management	0.0% 0	0.0% 0	8.3% 1	25.0% 3	66.7% 8	12



Summary of Survey Respondents' Views about BIM Implementation Optimization Issues

How does your organization currently use BIM? (Check all that apply.)

Value	Percent	Count	
		Airport	AEC
Capture the current status of the facility and facility elements	58.3	4	3
Quantify the amount of a facility element	58.3	5	2
Monitor the performance of facility elements and systems	16.7	1	1
Identify facility elements' status	16.7	1	1
Determine the need for and select specific facility elements	33.3	3	1
Determine the location and placement of facility elements	83.3	7	3
Determine the magnitude and scale of facility elements	41.7	4	1
Coordinate facility elements to ensure efficiency and harmony	33.3	2	2
Forecast future performance of the facility and facility elements	16.7	1	1
Validate facility information and that it is logical and reasonable	41.7	4	1
Visualize the facility or facility elements	83.3	6	4
Modify information and translate it to be utilized for another process	50.0	3	3
Draw the facility or facility elements	83.3	6	4
Document the facility and facility elements	75.0	5	4
Fabricate facility elements	66.7	4	4
Assemble the facility elements	50.0	2	4
Control equipment assembling facility elements	8.3	0	1
Operate facility equipment	16.7	0	2
Other: (1) Renderings; (2) Still in pilot project phase	16.7	2	0
Total Respondents		8	4



Which of the following BIM uses does your organization currently utilize? (Check all that apply.)

Value	Percent	Count	
		Airport	AEC
Maintenance Scheduling	18.2	1	1
Building System Analysis	18.2	1	1
Asset Management	45.5	2	3
Space Management / Tracking	27.3	1	2
Disaster Planning	18.2	2	0
Record Modeling	72.7	4	4
Site Utilization Planning	45.5	2	3
Construction System Design	45.5	3	2
Digital Fabrication	36.4	2	2
3D Control and Planning	45.5	2	3
3D Design Coordination	81.8	5	4
Design Authoring	81.8	5	4
Energy Analysis	36.4	3	1
Structural Analysis	27.3	3	0
Lighting Analysis	36.4	3	1
Mechanical Analysis	18.2	2	0
Other Engineering Analysis	18.2	2	0
LEED Evaluation	18.2	1	1
Code Validation	9.1	0	1
Programming	45.5	4	1
Site Analysis	54.6	3	3
Design Reviews	63.6	3	4
Phase Planning (4D Modeling)	63.6	4	3
Cost Estimation	54.6	2	4
Existing Conditions Modeling	63.6	4	3
Other: Initializing utilization	18.2	2	0
Total Respondents		7	4

In what general order did your organization implement the BIM uses listed in the previous question? (You may use numbers more than once.)

Maintenance Scheduling	
Count	Response
1	3
1	4

Building System Analysis	
Count	Response
2	3

Asset Management	
Count	Response
1	13
2	3
2	4

Site Utilization Planning	
Count	Response
1	1
1	10
1	2
2	3

Construction System Design	
Count	Response
1	11
4	3
1	7

Design Authoring	
Count	Response
4	1
2	2
1	3
1	4

Energy Analysis	
Count	Response
1	2
1	4
1	6
1	7

Space Management / Tracking	
Count	Response
2	2
1	4

Disaster Planning	
Count	Response
1	4

Record Modeling	
Count	Response
1	1
1	10
1	14
1	2
2	3
1	6

Other Engineering Analysis	
Count	Response
1	4
1	7

Code Validation	
Count	Response
1	2

Cost Estimation	
Count	Response
3	2
1	4
1	6

Digital Fabrication	
Count	Response
1	11
1	13
3	3

3D Control and Planning	
Count	Response
1	12
3	2
1	3

3D Design Coordination	
Count	Response
2	1
4	2
1	3
1	4

Design Reviews	
Count	Response
1	1
3	2
1	8
1	9

Phase Planning (4D Modeling)	
Count	Response
1	10
1	12
4	2
1	5

Site Analysis	
Count	Response
2	1
1	2
1	3
1	4
1	8

Structural Analysis	
Count	Response
1	1
1	2
1	4

Lighting Analysis	
Count	Response
1	4
2	5

Mechanical Analysis	
Count	Response
1	3
1	4

LEED Evaluation	
Count	Response
1	15
1	2

Programming	
Count	Response
1	1
1	2
1	4
1	8
1	9

Existing Conditions Modeling	
Count	Response
4	1
1	2
1	3
1	9

Summary Table: BIM Use Implementation Sequence Profiles for Responding Airports

Phase	BIM Use	BIM Activity Level						
		Very High	*High*	*Medium*			*Low*	
ALL	Existing Conditions Modeling	1	2	3	1	Future	—	NONE CURRENTLY, BUT EXPECT FULL IMPLEMENTATION IN FUTURE
	Cost Estimation	2	—	Future	4	Future	Future	
PLAN, DESIGN and/or CONSTRUCT	Phase Planning (4D Modeling)	2	8	—	2	1	Future	
	Design Reviews	2	7	—	2	—	—	
	Site Analysis	3	—	4	—	1	—	
	Programming	2	6	—	4	1	—	
	Code Validation	Future	Future	—	—	Future	—	
	LEED Evaluation	Future	—	—	—	1	Future	
	Engineering Analysis (structural, lighting, energy…)	Future	4	—	4	1	Future	
	Design Authoring	2	3	1	2	1	—	
	3D Design Coordination	3	1	2	2	1	Future	
	3D Control and Planning	3	—	Future	2	Future	Future	
	Digital Fabrication	3	—	Future	—	1	—	
	Construction System Design	3	—	Future	3	1	Future	
	Site Utilization Planning	2	—	Future	Future	1	—	
OPERATE	Record Modeling*	3	5	Future	3	1	Future	
	COBie Standard*	—	Future	—	Future	—	—	
	Disaster Planning	4	—	—	Future	Future	—	
	Space Management/ Tracking	4	—	—	—	Future	—	
	Asset Management	4	Future	Future	3	Future	Future	
	Building System Analysis	Future	—	—	3	Future	—	
	Maintenance Scheduling	4	—	—	Future	Future	—	

*Transitions between construction phase and operations phase

Which of the following opportunities in BIM do you expect your organization will require on projects in the future? (Check all that apply. Do not include current uses selected in previous question.)

Value	Percent	Count - Airport
Cost estimation	75.0	6
Existing conditions modeling	62.5	5
Phase planning	50.0	4
Programming	37.5	3
Site analysis	37.5	3
Energy analysis	62.5	5
Structural analysis	62.5	5
Mechanical analysis	62.5	5
Lighting analysis	62.5	5
LEED evaluation	50.0	4
Code and standards validation	62.5	5
3D coordination	62.5	5
Site utilization planning	50.0	4
Construction system design	62.5	5
Digital fabrication	25.0	2
3D control and planning	75.0	6
Record model	62.5	5
Maintenance scheduling	50.0	4
Building system analysis	62.5	5
Asset management	87.5	7
Space management and tracking	37.5	3
Disaster planning	37.5	3
COBie standard	37.5	3
Total Airports		8

Which tools does your organization use to support BIM operations? (Check all that apply.)

Value	Percent	Count	
		Airport	AEC
Authoring tools	83.3	7	3
Analysis tools	41.7	2	3
Radio frequency identification (RFID) systems for facility operations	25.0	1	2
Laser scanning to capture existing conditions/integrate with models	91.7	7	4
Augmented reality to blend models with live camera views of reality	41.7	2	3
Simulation and analysis to optimize logistical planning/decision making	33.3	2	2
Hyper-realistic immersive visualization to communicate complex information	0.0	0	0
Total Respondents		8	4

Do you have any methods in place for calculating return on investment (ROI) on BIM use?

Value	Percent	Count	
		Airport	AEC
Yes	33.3	2	2
No	66.7	6	2
Total Respondents		8	4

ROI Airport Results Summary Table: BIM Activity Level (from Figure 2) versus BIM Value

BIM Activity Level	Track Costs, Calculate ROI	Design and Construction Phase		Operations and Maintenance Phase	
		# of Respondents	BIM has added value	# of Respondents	BIM has added value
Very High	100%	2	100%	1	Yes
High	60%	5	100%	2	50%
Medium	67%	3	100%	1	Yes
Low	0%	2	50%	0	-

Have all the initial costs associated with BIM implementation been accounted for?

Value	Percent	Count	
		Airport	AEC
Yes	50.0	3	3
No	41.7	5	0
Not applicable	8.3	0	1
Total Respondents		8	4

Does your organization have a system in place to track and analyze recurring costs associated with BIM implementation?

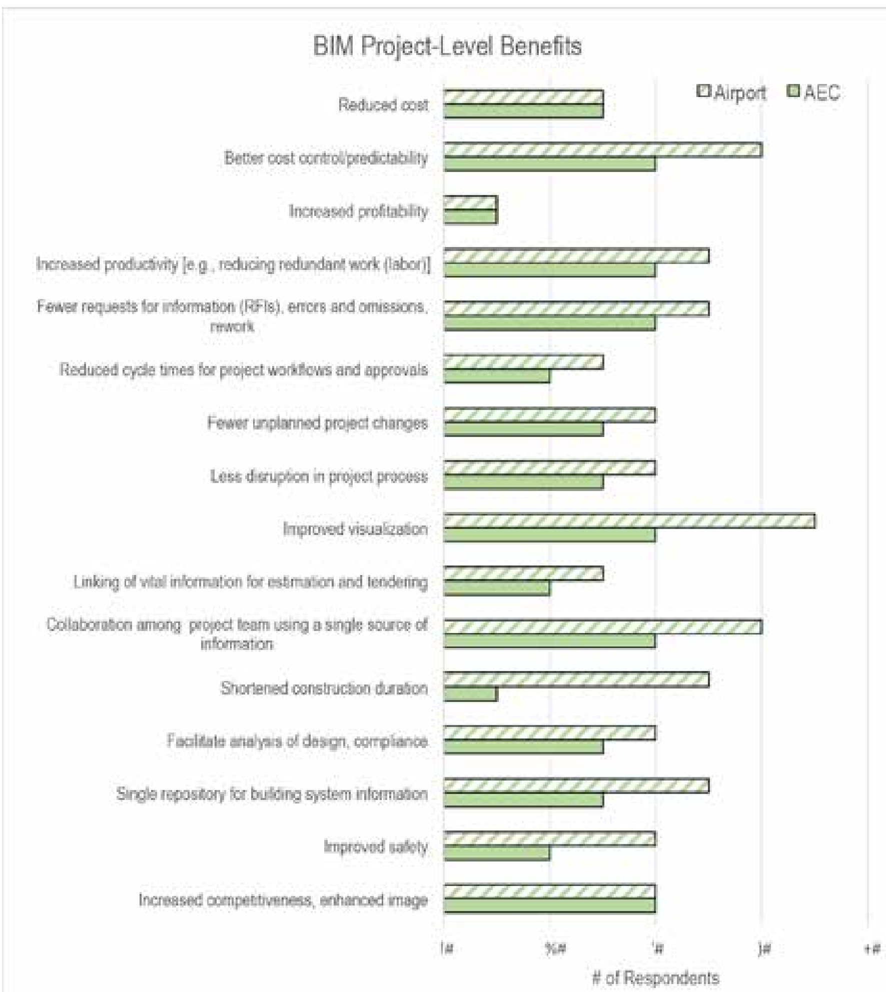
Value	Percent	Count	
		Airport	AEC
Yes	33.3	2	2
No	66.7	6	2

Which of the following performance metrics does your organization have in place to calculate or assess ROI? (Check all that apply.)

Value	Percent	Count	
		Airport	AEC
Reduced initial costs	33.3	1	0
Reduced life cycle costs	33.3	1	0
Increased profitability	0.0	0	0
Increased (labor) productivity	0.0	0	0
Increased operations/maintenance efficiency	0.0	0	0
Reduced requests for information (RFIs) during construction	66.7	1	1
Reduced design errors and omissions	66.7	1	1
Shortened construction duration	33.3	0	1
Compared life cycle performance of non-BIM projects with BIM projects	0.0	0	0
Compared life cycle performance of past BIM projects with current BIM projects	33.3	1	0
Other: Establishing ROIs and KPIs (key performance indicators) are in progress	33.3	1	0
Total Respondents		2	1

What benefits do you believe are realized by your organization in using BIM during design and construction? (Check all that apply.)

Value	Percent	Count	
		Airport	AEC
Reduced cost	50.0	3	3
Better cost control/predictability	83.3	6	4
Increased profitability	16.7	1	1
Increased productivity [e.g., reducing redundant work (labor)]	75.0	5	4
Fewer requests for information (RFIs), errors and omissions, rework	75.0	5	4
Reduced cycle times for project workflows and approvals	41.7	3	2
Fewer unplanned project changes	58.3	4	3
Less disruption in project process	58.3	4	3
Improved visualization	91.7	7	4
Linking of vital information for estimation and tendering	41.7	3	2
Collaboration among project team using a single source of information	83.3	6	4
Shortened construction duration	50.0	5	1
Facilitate analysis of design, compliance	58.3	4	3
Single repository for building system information	66.7	5	3
Improved safety	50.0	4	2
Increased competitiveness, enhanced image	66.7	4	4
Other: Many of these benefits are realized due to results of partnering	8.3	1	0
Total Respondents		8	4



What benefits do you believe are realized by your organization in using BIM during operations? (Check all that apply.)

Value	Percent	Count - Airport
Not applicable	33.3	2
Reduced cost	33.3	2
Better cost control/predictability	33.3	2
Increased profitability	16.7	1
Increased productivity [e.g., reducing redundant work (labor)]	33.3	2
Reduced cycle times for project workflows and approvals	16.7	1
Fewer unplanned project changes	16.7	1
Less disruption in project process	16.7	1
Improved visualization	50.0	3
Linking of vital information for estimation and tendering	33.3	2
Collaboration among project team using a single source of information	33.3	2
Shortened construction duration	16.7	1
Facilitate analysis of design, compliance	33.3	2
Single repository for building system information	16.7	1
Improved safety	33.3	2
Increased competitiveness, enhanced image	0.0	0
Increased operations/maintenance efficiency	16.7	1
Enhanced asset (facilities) management	33.3	2
Total Airports		6

Has the requirement for BIM added value during the design and construction phases?

Value	Percent	Count	
		Airport	AEC
Yes	91.7	7	4
No	8.3	1	0
Total Respondents		8	4

Has the use of BIM added value to the operations and maintenance (O&M) of your organization's facility/facilities?

Value	Percent	Count - Airport
Yes	50.0	2
No	25.0	1
Not applicable	25.0	1
Total Airports		4

What BIM requirements are included in your organization's RFP for new or renovation projects?

Value	Percent	Count - Airport
Project execution plan	100.0	6
Risk allocation clauses	16.6	1
Delivery structure	33.3	2
Roles/responsibilities	66.7	4
Information exchange	66.7	4
Technology (software)	100.0	6
Communication procedures	66.7	4
Total Airports		6

Because data exchange between software requires a common language, do you have a requirement for file compatibility?

Value	Percent	Count - Airport
Yes	83.3	5
No	16.7	1
Total Airports		6

Do tenants in your organization have any involvement in BIM?

Value	Percent	Count - Airport
Yes	37.5	3
No	62.5	5
Total Airports		8

Are tenants required to create a BIM model?

Value	Percent	Count - Airport
Yes	33.3	1
No	66.7	2
Total Airports		3

What minimum level of development (LOD) do you require of tenants at occupancy?

Value	Percent	Count - Airport
LOD 100	0.0	0
LOD 200	0.0	0
LOD 300	0.0	0
LOD 350	100.0	1
LOD 400	0.0	0
Not specified	0.0	0
Total Airports		1

Do you use energy analysis (energy modeling) for tenants?

Value	Percent	Count - Airport
Yes	0.0	0
No	100.0	3
Total Airports		3

What group within your organization maintains BIM?

Value	Percent	Count	
		Airport	AEC
Dedicated BIM staff	41.7	2	3
Facilities staff	8.3	1	0
Outsourced to consultants/other stakeholders	8.3	1	0
Other: (1) CAD staff; (2) Design and construction; (3) Engineering data; (4) Engineering staff	41.7	4	1 (all staff)
Total Respondents		8	4

Is your organization currently using BIM for operations and maintenance and/or facilities management?

Value	Percent	Count - Airport
Yes	12.5	1
No	75.0	6
Other: Not now	12.5	1
Total Airports		8

Which of the following operations, maintenance, and facilities management processes are used your organization? (Check all that apply.)

Value	Percent	Count - Airport
Building system operating analysis	0.0	0
Building performance against specified design	0.0	0
Maintenance scheduling	100.0	1
Space management and tracking	100.0	1
Asset management	100.0	1
Total Airports		1

Is your organization's computerized maintenance management system (CMMS) integrated with BIM software for data exchange?

Value	Percent	Count - Airport
Yes	0.0	0
No	100.0	1
Total Airports		1

Is your organization linking BIM with a geographic information system (GIS) for operations and maintenance?

Value	Percent	Count - Airport
Yes	100.0	1
No	0.0	0
Total Airports		1

Is your organization's asset management system integrated with BIM software for data exchange?

Value	Percent	Count - Airport
Yes	0.0	0
No	100.0	2
Total Airports		2

Is your organization linking BIM with a geographic information system (GIS) for asset management?

Value	Percent	Count - Airport
Yes	50.0	1
No	50.0	1
Total Airports		2

Does your organization require handover of the BIM from the construction phase?

Value	Percent	Count - Airport
Yes	85.7	6
No	14.3	1
Total Airports		7

Does your organization utilize the Construction Operations Building information exchange (COBie) standard for handover of the BIM from the construction phase?

Value	Percent	Count - Airport
Yes	16.7	1
No	83.3	5
Total Airports		6

Does your organization require a BIM handover for new construction/renovation by tenants?

Value	Percent	Count - Airport
Yes	100.0	1
No	0.0	0
Total Airports		1

Is your organization using BIM to document existing facilities and conditions, which are not part of a new program or construction project?

Value	Percent	Count - Airport
Yes	50.0	4
No	50.0	4
Total Airports		8

Is your organization currently using BIM data for asset management?

Value	Percent	Count - Airport
Yes	22.2	2
No	67.6	6
Not applicable	11.1	1
Total Airports		9

For which of the following asset management activities is your organization utilizing the BIM data?

Value	Percent	Count - Airport
Integrated decision making	50.0	1
Life cycle analysis	50.0	1
Real property inventory	50.0	1
Other: Transfer of data from Construction to Operations	50.0	1
Total Airports		2

Does your organization utilize metrics to assess the value of BIM utilization for asset management?

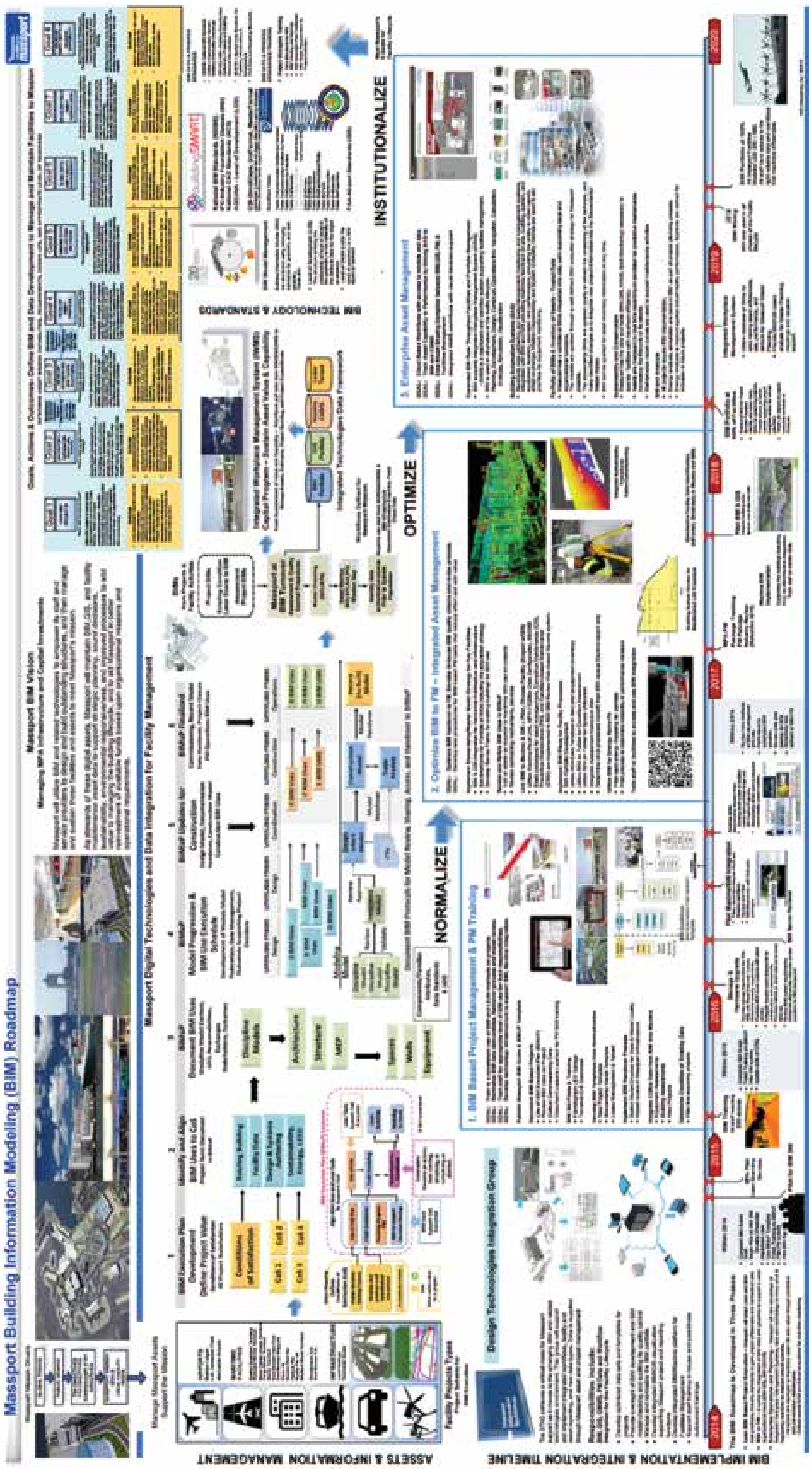
Value	Percent	Count - Airport
Yes	0.0	0
No	100.0	2
Total Airports		2

Has the use of BIM added value to your organization's asset management plan?

Value	Percent	Count - Airport
Yes	100.0	1
No	0.0	0
Total Airports		1

APPENDIX B

Massport BIM Roadmap



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APPENDIX C

Massport BIM Decision Matrix

FIGURE 1 (BIM DECISION MATRIX)

PROJECT TYPES	TAAs More detailed TAA BIM Guides are available in the Guide to Tenant Construction			HORIZONTAL PROJECTS		VERTICAL PROJECTS					
ADDITIONAL DESCRIPTION	Large Developments	Tenant Spaces and Buildings		Utilities and Runways		Including Garages and Bridges					
ESTIMATED CONSTRUCTION COST	ECC > $10M	$1M < ECC < $10M	ECC < $1M	After Jan 2016	Before Jan 2016	ECC > $10M	$1M < ECC < $10M: Major Equipment	$1M < ECC < $10M: Building Renovations	$1M < ECC < $10M: New Construction	ECC < $1M	Engineering and Architectural Studies
REQUIREMENTS	DTIG to evaluate project type and capabilities of team to determine BIM requirements		AutoCAD (no BIM)	Civil 3D with attributes at closeout	AutoCAD/Civil 3D	BIMxP managed by Design and Construction Teams. Lean and Co-Location	AutoCAD (no BIM) if A/E is standardized with BIM No BIMxP Clash detections managed by GC/CM	BIMxP managed by DTIG, clash detections managed by GC/CM	BIMxP managed by Design and Construction Teams	AutoCAD (no BIM) if A/E is standardized with BIM no BIMxP	DTIG to evaluate project type and capabilities of team to determine BIM requirements
BIM AND NON-BIM DELIVERABLES (REVIT, AutoCAD, OR CIVIL 3D)	BIM As-Built delivered at project end	BIM As-Built delivered at project end	As-Built	Civil 3D: - 30-60-100% and - As-Built with attributes	30-60-100% and As-Built (without attributes	Lean / BIM deliverables: - 30-60-100% and As-Built - Clash detection reports - As per BIMxP	30-60-100% and As-Built	BIM deliverables: - 30-60-100% and As-Built - Clash detection reports	BIM Deliverables: - 30-60-100% and As-Built - Clash detection reports	30-60-100% and As-Built	BIM delivered at project end as agreed upon between DTIG and Team
DISCIPLINES (IF BIM)	All disciplines for project	ARCH, MEP, and STR	Any major discipline	Civil disciplines, Site, Utilities	Civil disciplines, Site, Utilities	Major disciplines for project: ARCH, MEP, and STR, and 3D Site, Utilities	BIM modeled ARCH, MEP, and STR., Civil model only if needed or required by MPA	Major disciplines for project: ARCH, MEP, and STR., Civil model only if needed or required by MPA	Major disciplines for project: ARCH, MEP, and STR., Civil model only if needed or required by MPA	BIM modeled ARCH, MEP, and STR., Civil model only if needed or required by MPA	ARCH, MEP, and STR as agreed upon between DTIG and Team

Massport BIM Guide, page 3. Retrieved on August 10, 2015, from http://www.massport.com/business-with-massport/capital-improvements/resource-center/.

APPENDIX D

LAWA Project Requirement (PR-20)

PROJECT REQUIREMENT, PR – 20
VIRTUAL DESIGN & CONSTRUCTION (VDC), BUILDING INFORMATION MODEL (BIM)

A. GENERAL:

1. **Summary:** Design/Builder will employ VDC and BIM tools to facilitate the construction, coordination, scheduling, phasing, and close out of the Work. The VDC and BIM requirements will be developed and refined with LAWA via BIM Execution Plan (BXP), the final BXP shall be formally submitted to LAWA for review and approval. The BIM Process shall be an integral part of project delivery and shall be used for:

   a. Enabling all stakeholders to view and track the project throughout design, construction and closeout.

   b. Enabling a coordinated Design Build delivery of Construction Documents and Shop Drawings. The Design/Builder, its Design Professionals and Consultants, its Subcontractors and their Subcontractors shall assist, integrate and use the BIM model for the creation of construction documents and shop drawings.

   c. Enabling cost and schedule project tracking via 4D and 5D BIM model information. 5D BIM model information will not be required through 30% submittal.

2. **BIM Manager:** The Design/Builder shall appoint a BIM manager to develop and oversee the BIM Execution Plan (BXP) as defined in Section D of this PR. His detailed responsibilities will include overseeing the development of the model, its integration and execution, and coordinate between all entities of the Design Build Delivery. The Design/Builder's BIM manager will coordinate with LAWA's BIM manager concerning setting up the appropriate templates and project boundaries.

B. COORDINATION AND DETAILING ACTIVITY (CDA)

The Design/Builder's Coordination and Detailing Activity (CDA) shall include a formal process to document, track and confirm the coordination and detailing process of the design and construction teams. CDA ensures agreement among Subcontractors regarding field coordination aspects of the Projects. CDA and BIM coordination are complementary processes to the review of construction drawings for their completeness, constructability, and code compliance.

1. Conflicts shall be resolved through the CDA process rather than at the installation stage. Conflicts occurring at the installation stage will not be the basis for additional costs or time extensions. Failure to perform the CDA process satisfactorily will not be the basis for additional compensation or extension of the Contract Time.

2. CDA is performed to assure that all utilities, architectural and structural building systems are inter-coordinated and agreed upon by Design/Builder, its design professionals and Subcontractors, minimizing field changes. CDA is to be utilized as a validation mechanism to the BIM coordination process and clash / collision detection and resolution. The end product of this effort shall be a fully coordinated model and set of drawings, consistent with the design intent and Applicable Code Requirements for the Work. Upon the completion of the CDA process,

Design/Builder, its Design Professional and Subcontractors shall indicate in writing that they have coordinated their Work prior to starting construction.

3. CDA shall occur at a minimum on a weekly basis as soon as the first Subcontractors are engaged on the project, and concurrently with development of the Construction Drawings. CDA milestone submittals shall be required with the 60%, 90%, and 100% progress submittals.

4. **The provisions** of this Section shall not reduce the Design/Builder's responsibility to provide adequate coordination for all Work including Work not indicated above.

5. LAWA, the Design/Builder's Project staff, Subcontractors, and Design Professionals shall participate in this program. At the completion of the CDA, the Design/Builder, its design professionals and Subcontractors are required to sign off on their acceptance. Signatures shall indicate that the Work represented on the CDA drawings is constructible and has been reviewed by Design/Builder, Design/Builder's Design Professionals, and Subcontractors and all are in concurrence with information contained on the CDA Drawings.

6. CDA drawings shall be 2d or axonometric print outs of the BIM models and shall be usable as field documents aimed at coordination and allocation of work between different trades (structure, framing, casework, ceilings, ductwork, plumbing and mechanical piping, electrical and LV conduits and outlets, MEP and architecturally or structurally significant equipment, miscellaneous anchorage, supports and bracing of different trades, exterior wall components, code clearances, etc.).

7. **Exterior Wall Coordination:** Separate Overlay Drawings for Coordination of All Miscellaneous Steel and/or Structural Stud Systems on Background Drawings and Elevations: Illustrate the connection points of the precast, windows, curtain wall, stone, metal panel systems, as well as all elements that will be contained in the exterior wall systems including but not limited to recessed electrical, communications outlets, security devices, panels, telephones, recessed water connections, lighting and alarms, the Design/Builder's Design Build team shall prepare an overlay CDA drawing for all recessed systems.

8. **CDA Drawings:** The Design/Builder shall prepare CDA Drawings to optimize the utilization of space, provide for efficient installation of different components, and coordinate the installation of products and materials. The CDA drawings shall be the basis for coordinated shop drawings. Additional shop drawings shall not be produced after signing off CDA drawings without review, verification, and sign-off by all trades that changes did not impact agreed-upon coordination. There are other potential areas of the building systems that will require a process for completion. These should be illustrated in the Design/Builder's work plan and schedule.

9. **Orientation Meeting**: The Design/Builder, its Design Professionals, Consultants, Subcontractors, and LAWA shall hold an orientation meeting prior to the beginning of the CDA effort. The purpose of this meeting is to develop a mutual understanding of the administration of the CDA, and the scope of the required submittals and Drawings. All personnel involved in coordination and detailing of the work and the BIM model of shall attend the Orientation Meeting. The meeting shall be administered by the Design/Builder's BIM manager and the Design/Builder's MEP / Systems Coordinator.

10. **CDA Meetings:** During CDA meetings the Design/Builder, its design professionals and its Subcontractors shall discuss and coordinate the locations of utilities and building elements, problems of fit, trade interfaces, and constructability. As a minimum, CDA meetings will be biweekly prior to the CDA finish milestone. LAWA may attend all CDA meetings. The Design/Builder shall prepare and distribute meeting minutes to document session resolution decisions or track issues requiring further rework of the drawings and re-coordination.

11. **Conflict Resolution Plan:** Design/Builder must provide leadership in the space allocation, and adjusting of previous designs in order to resolve BIM conflicts in an effective and timely manner while maintaining design quality, and maintenance space allocation. Specialty Subcontractors shall work with the Design/Builder's MEP Coordinator to identify alternate acceptable routes to resolve conflicts. The Design/Builder shall be present to provide leadership and assign responsibilities as required to find alternate routing methods for conflict resolution. Resolve Conflicts and Re-detail or re-model as required. Generate a conflict list that shall identify all systems that are in conflict with another building system. Revise discipline models as required to avoid a particular building systems that cannot be relocated. Revise the discipline models with the intent of eliminating the interference's and conflicts.

C. BUILDING INFORMATION MODEL (BIM):

Design/Builder's BIM MODEL shall include at a minimum the following:

1. Development and maintenance of a three-dimensional building information model of the Work that includes Design/Builder - developed, shop-drawing level information of the following building components and systems:

   a. Underground, including but not limited to, utilities: piping, connections, vaults, manholes, tanks, valves, vents, and structural: shoring, shafts, tunnels, and impact zones.

   b. Airfield civil including Aircraft aprons and taxilanes, underground hydrant fueling and other systems.

   c. Building structure, including but not limited to foundations, columns, beams, joists, purlins, floor and roof decking and fill, bracing, and load-bearing walls.

   d. HVAC systems, including but not limited to HVAC piping and pumps, air distribution ductwork, fans, air terminal units, tanks, grease, interceptors, air outlets and inlets; central cooling equipment compressors, chillers, condensers, and cooling towers; boilers, heat exchangers and packaged and/or custom air-handling units, tanks, grease interceptors, and thermal storage systems and supplementary structural support members, hangers, and seismic support.

   e. Plumbing systems, including but not limited to water distribution, storm drainage and sanitary sewerage waste and vent piping, water-heaters and plumbing fixtures systems and supplementary structural support members, hangers, and seismic support.

   f. Fire suppression systems, including but not limited to, standpipes, sprinkler systems, fire pumps, and non-water-based fire-extinguishing systems and supplementary structural support members, hangers, and seismic support.

g. Electrical systems, including but not limited to conduit 1-112 inches in diameter and larger , or bundled conduits, cable-tray, transformers, switchgear, panel boards, generators, lightning protection and lighting and supplementary structural support members, hangers, and seismic support.

h. Communication, security, access control, alarm monitoring (ACAMS), and wireless systems, including but not limited to, structured cabling, premise wiring distribution system, equipment room fittings, racks, frames and enclosures, data communications switches, hubs, and routers, common use systems, and paging systems and supplementary structural support members, hangers, and seismic support.

i. Conveying systems including elevators, escalators, and moving walks and equipment control cabinets, passenger boarding bridges and ramp service equipment.

j. Baggage handling systems including indication of clear right-of-way required around conveyors and catwalks, access ramps, no-fly access zones, supplementary structural support, and equipment Control cabinets.

k. Architectural building systems including interior and exterior walls, windows, curtain walls, ceilings, and roof.

2. **Coordination and Detailing Activity (CDA) and Collision Detection:** Based on information developed and included in the Design/Builder's three dimensional BIM model, perform weekly collision/interference checking and develop reports for review and resolution by the integrated Design/Builder team, including the design team, Subcontractors, manufacturers and suppliers, prior to release of fabrication drawings. Ensure all drawings and backgrounds are coordinating at all levels of detail necessary for fabrication and field installation. Refer to the Coordination and Detailing Activity section in this PR for requirements.

3. **Schedule and Cost Visualization (4D and 5D):** Develop, update and maintain Schedule and Cost tracking information and all meta data required by LAWA and described in this PR. Develop and maintain 4D and 5D BIM information with the expressed purpose of visually demonstrating and communicating proposed project construction schedule, phasing, and cost tracking to LAWA and its consultants, the Design/Builder's design team, and Subcontractors and their Subcontractors and suppliers as applicable. The model shall include all major building systems and shall be constructed in such a fashion as to permit animation showing sequential construction of the project based on and driven by the approved construction schedule.

4. **Architectural Visualization:** Develop three dimensional renderings using the BIM model and enhance with rendering programs to clearly illustrate the architectural (aesthetic) design, as described in the Project Requirement – Scope of Work.

5. **Use of BIM for Facility Management and Maintenance:** Upon completion and commissioning of the Project, LAWA's goal is to use the Design/Builder's Record Model prepared in BIM software for integration into its Building Management and Maintenance. During the preparation of Construction Documents, the Design/Builder shall meet with LAWA's operations and maintenance staff and discuss specific

requirements that shall be built into the BIM model. It is the intent that any implementation of additions to the BIM design model for Building Monitoring Management and Maintenance will be included as part of future task authorizations. Refer to Project Requirement for Project Closeout.

D. BIM EXECUTION PLAN (BXP):

1. The Design/Builder shall prepare a BIM Execution Plan (BXP) to include master information/data management and assignment of roles and responsibilities for model creation and data integration at project startup. The BXP shall be submitted no later than 30 days after the first NTP and shall address use of multiple software products, training of staff, collaboration and sharing of information models on a common review software platform for open communication and effectiveness of clash detection, and graphic presentations of multi-discipline integrated design. The plan shall highlight responsible individuals designated to manage discipline coordination, and attend regular Design/Build Team coordination meetings. The plan should include, or address the following:

    a. List of specialty Subcontractors using digital fabrication.

    b. Proposed BIM Software to be used by the Design/Build Team and fabrication modelers.

    c. Proposed specialty Subcontractor BIM workshops and training integrated into project schedule.

    d. Proposed uses of digital fabrication.

    e. Strategy to assure all trade information is modeled and coordinated.

    f. Discipline coordination strategy for clash detection via the CDA process.

    g. Development strategy from Design to Construction Model.

    h. Constructability analysis with BIM.

    i. Development of graphics showing installation methods for building equipment and systems.

    j. Space allocation showing space clearance reservations for operations, repair, maintenance, and replacement.

    k. Strategy for software compatibility, file formats, hosting, transfer, and access of data between disciplines.

    l. Use of model server, extranet, access security, etc.

    m. Use of 4D scheduling and construction sequencing technology, including submission and monthly update process.

    n. Use of 5D cost loading technology, including submission and monthly update process.

    o. Use of Commissioning and facilities management related technology.

    p. List of final BIM deliverable for each respective discipline.

q. Updating as-built conditions in As-built/Record BIM.

2. **Model Management during Construction:** The BXP shall describe the process of developing the Record As-built Model from continuous updates of the Construction Model. All as-built information shall be reconciled and included in the record model. The Design/Builder shall continuously update the BIM model to include RFI's, Change Orders, Submittals, and all other changes affecting the project's design and construction. The Design/Builder shall demonstrate continuous updating of the model and submit status on a monthly basis. An updated model is a payment requirement as stated in the Special Conditions.

3. **As-built Construction Model Creation and Delivery**: The BIM model, as it is updated throughout the project duration, shall represent in electronic format the physical design and construction of the project throughout all trades. The Design/Builder shall provide the Record as-built model as required in the Project Requirements for Project Closeout.

E. BIM MODELING REQUIREMENTS

1. **Summary:** The Design/Builder shall develop and submit for approval a Federated Model (Fed Model) of the Project utilizing a Building Information Modeling (BIM) system as defined by this Section. The Design/Builder shall:

   a. Manage communication and coordination between the Design/Builder's design professionals and Subcontractors to develop the Fed Model throughout the Work of the Project.

   b. Submit a LOD 300 Fed Model to LAWA for review and approval as part of the 60% Drawings submission.

   c. Use the Fed Model to facilitate the construction methods and means.

   d. Update the Fed Model progressively throughout the construction period to incorporate all construction actions so that the Fed Model shall be developed to LOD 400 construction level, including:

      1) Shop Drawings

      2) Approved Change Orders

      3) Fabrication, assembly and detailing

      4) Field Modifications

   e. Submit the Model to LAWA for review and approval at 90% and 100% completion of the Work of the Project.

   f. Provide a final "as-built" LOD 500 Fed Model to LAWA as part of the Project Close-Out phase.

2. **Definitions: (Refer to General Conditions for definitions)**

3. **Use of Federated Model and As-Built Model (Reconciled Design Model RDM)**

   a. The Design/Builder shall prepare and maintain the Federated Model and the Design Model throughout the duration of the project. At the completion of the Work these models shall be turned over to LAWA. LAWA shall have exclusive rights to the models for their use: 1) as an as-built model for future modification to the constructed facilities and 2) as a source of data in operating and maintaining the facility. The Reconciled Design Model (s) (RMD), prepared by licensed design professionals, shall have the legal bearing of the Design Intent.

   b. Basis of Information for Modeling: The Construction Documents (drawings and specifications) shall be the basis of information for the Fed Model described herein. If any or all of the LAWA'S own models are available for use by the Design/Builder in developing the Fed Model, such usage shall be for convenience only and shall not carry contractual implication.

   c. Relation of BIM to other Contract Documents: If the Design/Builder through developing and/or use of the BIM or Fed Model identifies any potential changes that the Design/Builder thinks should be reflected in changes to the Contract Documents, the Design/Builder shall produces the necessary changes via Change Order **after** notifying LAWA of a potential Change Order(s).

   d. Changes by Others: All changes to the Fed Model, subsequent to completion of the Work, including additional modeling by others, shall be solely the responsibility of the entity providing the changes or additions.

4. **ASTM UNIFORMAT II Classification System:** Every Object in the Native Model shall have a classification code. The UNIFORMAT II system is a combination of letters, numbers and nomenclature, and is formatted as shown in the following example:

   a. Level 1; Major Group Elements: for example: B Shell.

   b. Level 2; Group Elements: for example: B20 Exterior Enclosure.

   c. Level 3; Individual Elements: for example: B2030 Exterior Door.

   The Design/Builder shall include the appropriate UNIFORMAT II classification in the list of attributes that is assigned to the Objects.

5. **OmniClass Construction Classification**

   a. General: The OmniClass Construction Classification System (known as OmniClass or OCCS) is a classification system for the construction industry developed by the Construction Specification Institute (CSI). It builds upon MasterFormat for work results, UniFormat for elements and EPCI (Electronic product Information Cooperation) for structuring products. OmniClass is a reference library system that will serve as the foundation upon which information is transferred between the construction and operations phases.

   b. OmniClass automatically assigned: The Design/Builder shall include the appropriate OmniClass classification in the list of attributes that are automatically assigned to the Objects by the Model software.

c. Exception when OmniClass not automatically assigned: The Design/Builder is not required to include the appropriate OmniClass classification in the list of attributes a discipline Native Model if that particular Native Model software does not automatically assigned the classification to its Objects. This exception applies only to the Native Model software that does not automatically assign the classification; for all other Native Models that do automatically assign the classification, it shall still be provided.

6. **Commissioning and COBIE Requirements**

a. General: If commissioning activities and/or COBIE data is required by other sections of these specifications, the Design/Builder shall comply with the requirements of those sections in addition to the requirements of this section.

b. Commissioning requirements: The scope of work related to Commissioning, if required, shall be provided in accordance with the Commissioning section. In addition, and in support of, the extent of Model and Object parametric data required by this section shall be provided as described herein with modifications as follows:

1) The submittal of the Model data shall be as scheduled by the Commissioning requirements.

2) The Model data shall be formatted as required by the COBIE Data Sets requirements.

3) The submittal of the Model data shall be as scheduled by the COBIE requirements.

7. **Level of Development (LOD)**

The American Institute of Architects has developed a Level of Development (LOD) system which serves as the basis for this Project with Project-specific modifications as shown in the following requirements.

a. General: Regardless of LOD, the model(s) shall be capable of being presented in three dimensions, and shall be an object-based parametric database system.

b. LOD 100: This is the “programming” level. Buildings and/or structures shall be modeled as masses indicative of area, height, volume, spatial location, and orientation.

c. LOD 200: This is the “planning” level. Buildings and/or structures including major architectural, structural, mechanical, electrical, and plumbing objects shall be modeled as generalized systems or assemblies with approximate quantities, approximate configuration, spatial location, and orientation. Each enclosed space shall be identified as a unique Room with associated parameters.

d. LOD 300: This is the “design” level. Buildings and/or structures including all objects shall be modeled as specific systems or assemblies with accurate quantities, recognizable configuration, spatial location, and orientation. Each enclosed space shall be identified as a unique Room with associated parameters.

e. LOD 400: This is the "construction" level. Buildings and/or structures including all objects shall be modeled as specific systems or assemblies with accurate quantities, recognizable configuration, spatial location, and orientation, with complete fabrication, assembly, and detailing information. Each enclosed space shall be identified as a unique Room with associated parameters.

f. LOD 500: This is the "as-built" level. Buildings and/or structures including all objects shall be modeled as constructed systems or assemblies with accurate quantities, shape, spatial location, and orientation, with complete fabrication, assembly, and detailing information. Each enclosed space shall be identified as a unique Room with associated parameters.

8. **Native Model Software – Minimum Requirements**

a. General: The Native Model(s) shall be developed to include parametric components of major building and site elements as defined in this Section. All discipline Native Models shall be linked to the Architectural Native Model.

b. Accuracy of the Models: The Fed Model and each of its Native Models shall be developed to within a tolerance of ¼" plus or minus.

c. BIM application(s) and software(s) for the Fed Model shall:

1) Have maximum interoperability between systems models, and shall be fully compatible with the current version of Autodesk® Navisworks software.

2) Be provided in a format that is compatible with a free software download for viewing the Design/Builder's models with the ability to save and track user annotations and notes.

3) Contain reports/logs of:

a) Discrepancies and/or clarifications in the Construction Documents identified during the modeling process.

b) Conflicts between location and alignment of model elements with resolutions developed by the Design/Builder.

c) Quantities of modeled building element.

d) Schedule for each building element.

d. For any additional electronic model information that is not supported by the Revit or the primary software solution approved by LAWA, and for constructing 4D models, the Design/Builder shall utilize Navisworks software (Manage, Review, Simulate and Freedom) to create and utilize .nwd files.

e. The Design/Builder shall use the latest version of Native Model software listed in the matrix below:

Acceptable Native Model Software Matrix		
Discipline	**Native Model Software**	**Comments**
Architectural	Revit Architecture	
Fixtures, and Equipment	Revit Architecture	Applies to stationary items only
Structural	Revit Structure	
HVAC	Revit MEP AutoCAD MEP CAD-Duct	
Plumbing	Revit MEP AutoCAD MEP CAD-Pipe	
Fire Protection	AutoSPRINK v 7	
Electrical	Revit MEP AutoCAD MEP	
Security Electronics	Revit MEP AutoCAD MEP	
Civil	AutoCAD Civil 3D	
Hardscape	Revit Architecture	

9. **Object Identification**

a. General: Every Object in the Model shall have a Unique Identification (UID) parameter and a Common Name parameter attached to it in the Native Model.

b. Unique Identification: The UID shall be readable by the user of the Native Model software without additional software applications. The UID may be in the form of alpha, numeric, or alpha-numeric.

1) If the UID form is alpha-numeric, it shall be a consistent string format for all Objects, within its discipline, and shall be readable by any commonly available database. The UID is an “Instance” parameter.

2) If the Native Model software is not a full object-based, parametric, database platform, such as some of the older 3D CAD programs, the UID shall be attached to the Object manually, if necessary, so that it can be read by the user without additional software applications.

c. Common Name: In addition to the UID, each Object shall have a Common Name parameter attached to it in the Native Model. The Common Name shall be approved by LAWA prior to modeling. Examples of a Common Name include such as: door, window, toilet, VAV Box, etc. Typically the Common Name will be generated automatically by the software, but if not, it shall be input manually in the Native Model. The Common Name is an Object "Type" parameter.

10. **Object Parametric Attributes – Minimum Requirements**

The following attributes shall be attached to each Object. Note: If a required attribute is not automatically generated by Native Model software, it shall be manually input in the Native Model, or provided in an Excel or Access document that includes the UID.

a. Unique Identification (Instance parameter).

b. Common Name (Type parameter).

c. Uniformat II Classification Code Levels 1, 2, and 3 (Type parameter).

d. Omni Code Classification (Type parameter).

e. Native Model Assembly Code (Type parameter).

f. Manufacturer (where applicable) (Instance parameter).

g. Model Number (where applicable) (Instance parameter).

11. **Object Association**

a. Every Object in the Model shall be associated with either a Room or a Floor and shall have an association "Instance" parameter attached to it in the Native Model.

b. Room association: Any Object that will be visible in a Room of the completed facility shall be associated with that specific Room. This includes all Objects regardless of responsible discipline; examples include without limitation: electrical switches and outlets, electrical switch gear and panel boards, plumbing equipment and fixtures, access panels to concealed Objects, cabinets, doors and frames, wainscot, light fixtures, HVAC supply and return grilles, fire sprinkler heads and valves, etc.

c. Floor association: Any Object that will be concealed in a wall or interstitial space (but would be visible if the finish surface or item was non-existent) shall be associated with the specific Floor level that it is within. This includes all Objects regardless of responsible discipline; examples include without limitation: electrical conduit, plumbing piping and valves, HVAC supply and return ducts, HVAC equipment, fire sprinkler lines and valves, etc.

d. Objects extending beyond Room boundaries: Floors, walls, and/or ceilings are sometimes modeled as objects that extend beyond individual Room boundaries. Where this occurs, the architectural discipline Native Model shall be modeled as follows:

1) Floors: Structural floor Objects may extend beyond Room boundaries, however, finish flooring such as carpet, resilient flooring, etc., shall be modeled as Objects, with extents contained within the Room boundaries, and with appropriate Room association.

2) Walls: Structural wall and non-structural partition Objects may extend beyond Room limits, however, the surface material such as gypsum wallboard, wall covering, etc., shall be modeled as Objects, or scheduled in the Room Finish Schedule, with extents contained within the Room boundaries, and with appropriate Room association.

3) Ceilings: Structural ceiling Objects may extend beyond Room limits, however, finish surface material such as gypsum wallboard, acoustical ceiling tiles, etc., shall be modeled as Objects, with extents contained within the Room boundaries, and with appropriate Room association.

12. **Building Information Modeling System Discipline Models**

a. Civil Systems: The Civil Systems Model shall be a sub-system model linked to the Architectural System Model. The Civil Systems Model shall serve as the basis for project shared coordinates through which the position of building elements on the site will be coordinated. Where applicable, provide model Objects of:

1) Topography:

a) Existing natural and/or graded contours.

b) New grades and finish contours.

2) Planting:

a) Existing major landscaped areas.

b) Existing trees to remain.

c) New landscaped areas.

d) New trees.

e) Irrigation lines over 2” diameter.

3) Surface Improvements:

a) Pavements (aprons, taxilane, taxiways).

b) Curbs and gutters.

c) Retaining walls.

d) Exterior non-building structures such as tanks, shade structures etc.

4) Existing Structures:

a) All buildings within the project area intended to remain

b) Buildings intended to be demolished.

c) All existing structures may be modeled exterior surface only.

d) Interior elements are not required.

5) Storm Water and Sanitary Sewers:

a) Existing lines (over 3” diameter), boxes and structures within project area,

b) All new lines, boxes and structures.

c) Existing public lines, boxes and structures beyond the project area but serving as points of connection for the project.

6) Utilities:

a) Existing domestic and fire water main and branch lines (2” and larger diameter) within project area.

b) All new domestic and fire water lines.

c) Existing electrical overhead and underground lines within project area, all new electrical lines outside buildings.

d) Existing telephone and data lines within project area.

e) All new telephone and data lines outside buildings.

f) Existing gas lines within project area.

g) All new gas lines outside buildings.

7) Other requirements:

a) Quantities: data to reflect accurate quantities of the above elements.

b) Schedules: data for installation of the above elements.

b. <u>Architectural Systems</u>: The Architectural Systems Model shall be the primary model to which others are linked. Provide model Objects of:

1) Spaces:

a) Net square footage of all occupied spaces.

b) Gross constructed floor area.

c) Room names and numbers.

d) Floor, base, wall, and ceiling finishes. NOTE: Model room names and numbers shall match LAWA’s Architectural Program space names and numbers.

2) Exterior Walls and Curtain Walls:

a) Type and composition.

b) Height, length, and width.

c) Thermal, acoustic, fire, and security ratings.

3) Partitions:

a) Type and composition.

b) Height, length, and width.

c) Thermal, acoustic, fire, and security ratings.

4) Floors:
   a) Type and material.
   b) Thickness.
   c) Finishes with manufacturer's name and product numbers. Link floor structure to the Structural Systems Model.
5) Ceilings:
   a) Type and composition.
   b) Height, length, and width.
   c) Thermal, acoustic, fire, and security ratings.
6) Roof Coverings and Openings:
   a) Configuration.
   b) Drainage system.
   c) Penetrations for modeled building components.
7) Exterior Doors, Windows, and Louvers:
   a) Type and material.
   b) Height, width, and thickness.
   c) Thermal, acoustic, fire, and security rating.
   d) Location.
   e) Hardware elements or group.
8) Interior Doors, Windows, and Louvers:
   a) Type and material.
   b) Height, width, and thickness.
   c) Thermal, acoustic, fire, and security rating.
   d) Location.
   e) Hardware elements or group.
9) Stairs and Ramps:
   a) Stairs and railings.
   b) Ramps and railings.
   c) Handrails and guardrails.
10) Elevators and Escalators:
   a) Elevator cabs and doors.
   b) Elevator hoist-way doors and trim.
   c) Elevator machinery and equipment.

- d) Escalator belts and railings.
- e) Escalator machinery and equipment.

11) Casework and Counters:
- a) Type and material.
- b) Height, width, and depth.
- c) Location.
- d) Hardware.

12) Plumbing Fixtures
- a) Type and material.
- b) Location.
- c) Trim.
- d) Finishes: Link fixtures and trim to the Mechanical Systems Model.

13) HVAC Grills and Registers:
- a) Type and material.
- b) Location.
- c) Trim.
- d) Finishes: Link fixtures and trim to the Mechanical Systems Model.

14) Electrical Fixtures and Equipment:
- a) Type and material.
- b) Bulb type and wattage.
- c) Location.
- d) Trim.
- e) Finishes: Link fixtures and trim to the Electrical Systems Model.

15) Miscellaneous Fittings:
- a) Toilet partitions.
- b) Toilet room accessories.
- c) Grab bars.
- d) Personal storage lockers.
- e) Display cases.
- f) Other surface applied quasi-permanent items such as mirrors etc.

16) Other requirements:
- a) Quantities: data to reflect accurate quantities of the above elements.
- b) Schedules: data for installation of the above elements.

c. Structural Systems: The Structural Systems Model shall be a sub-system model linked to the Architectural System Model. Provide model Objects of:

1) Foundations and footings:
   a) Type and configuration.
   b) Depth, length, and width.
2) Slab(s) on-grade:
   a) Type and configuration.
   b) Under-slab base and waterproofing.
   c) Recesses, curbs, pads, closure pours.
   d) Major penetrations.
3) Basement Walls:
   a) Type and composition.
   b) Height, length, and width.
   c) Thermal, acoustic, fire, and security ratings.
4) Elevated Floors:
   a) Columns and beams.
   b) Primary and secondary framing members.
   c) Bracing.
   d) Connections.
   e) Framed, composite, and/or slab decks.
5) Roofs:
   a) Columns and beams.
   b) Primary and secondary framing members.
   c) Bracing.
   d) Connections.
   e) Framed, composite, and/or slab decks.
6) Joints:
   a) Expansion and/or contraction.
   b) Seismic.
7) Stairs and Ramps:
   a) Openings and framing.
   b) Railing supports.
8) Shafts and Pits:

a) Openings and framing

b) Railing supports.

9) Other requirements:

a) Quantities: include data to reflect accurate quantities of the above elements.

b) Schedules: data for installation of the above elements.

c) Fireproofing: Fireproofing is not to be included in the BIM but clash detection studies shall include definition of tolerances for conflict detection.

d) Color Code: color code structural steel from other elements.

d. Mechanical: The Mechanical Systems Model shall be a sub-system model linked to the Architectural System Model. Provide model Objects of:

1) Heating, Ventilating, and Air Conditioning:

a) All heating, ventilating, air-conditioning, exhaust fans, and specialty equipment.

b) Air supply, return, ventilation and exhaust ducts, including space-consuming elbows and transitions.

c) Fire dampers with ratings.

d) Mechanical piping.

e) Registers, diffusers, grills and hydronic baseboards. Coordinate and link fixtures and trim to the Architectural Systems Model.

2) Plumbing:

a) All domestic plumbing piping and fixtures.

b) Floor and area drains.

c) Valves (regardless of pipe size).

d) Related equipment.

a) Piping larger than 1 .5" diameter shall be modeled.

3) Roof Drainage:

a) All piping and fixtures, and 2) related equipment.

b) Piping larger than 1 .5" diameter shall be modeled.

4) Other requirements:

a) Quantities: data to reflect accurate quantities of the above elements.

b) Schedules: schedule data for installation of the above elements.

c) Equipment Clearances: Clearances for major equipment and all M/E/P Equipment and Architecturally Significant Specialty Equipment, as model objects for conflict detection and maintenance access requirements.

d) Color Code: separate color code for each type element.

e. Electrical and Low Voltage: The Electrical and Low Voltage Systems Model shall be a sub-system model linked to the Architectural System Model. Provide model Objects of:

1) Interior Electrical Power and Lighting:
   a) All interior electrical components.
   b) Lighting, receptacles, special and general purpose power receptacles.
   c) Lighting fixtures.
   d) Panel-boards and control systems.
   e) Conduit and cable trays.
      (i) Individual conduit larger than 1 .5" diameter shall be modeled.
      (ii) Groups or clusters runs, and cable trays of conduit of all sizes shall be modeled.

2) Exterior Building Lighting:
   a) All exterior electrical components.
   b) Lighting, receptacles, special and general purpose power receptacles.
   c) Lighting fixtures.
   d) Panel-boards and control systems, and transformers.
   e) Utility connection and equipment.
      (i) Individual conduit larger than 1 .5" diameter shall be modeled.
      (ii) Grouped or clustered runs of conduit of all sizes shall be modeled.

3) Telephone, Data, Television, and Other Low Voltage:
   a) All interior low voltage components.
   b) Outlets, receptacles, special and controls.
   c) Fixtures.
   d) Panel-boards, equipment racks, and control systems.
   e) Conduit and cable trays.
      (i) Individual conduit larger than 1 .5" diameter shall be modeled.
      (ii) Groups or clusters runs of conduit of all sizes shall be modeled.

4) Other requirements:
   a) Quantities: data to reflect accurate quantities of the above elements.
   b) Schedules: schedule data for installation of the above elements.
   c) Equipment Clearances: Clearances for major as model objects for conflict detection and maintenance access requirements.
   d) Color Code: separate color code for each type element.

f. Fire Suppression: The Fire Suppression Systems Model shall be a sub-system model linked to the Architectural System Model. Provide model Objects of:

1) Fire Suppression System:
   a) Valves and risers.
   b) All main, branch, and drains lines.
   c) Sprinkler heads, and fittings.
   d) Pumps.
2) Fire Alarms:
   a) Alarm and notification devices.
   b) Detection systems.
3) Other requirements:
   a) Quantities: data to reflect accurate quantities of the above elements.
   b) Schedules: schedule data for installation of the above elements.
   c) Equipment Clearances: Clearances for major equipment as model objects for conflict detection and maintenance access requirements.
   d) Color Code: separate color code for each type element.

h. Specialty Equipment: The Specialty Equipment Model shall be a sub-system model linked to the Architectural System Model. Specialty Equipment includes without limitation such specialties as: service equipment and systems, concessions / food service equipment and systems, security equipment and systems, conveyance equipment and systems, manufacturing equipment and systems, etc. Provide model Objects of:
   1) Specialty Equipment:
      a) Equipment.
      b) Related mechanical, plumbing, and electrical requirements.
   2) Quantities: data to reflect accurate quantities of the above elements.
   3) Schedules: schedule data for installation of the above elements.
   4) Equipment Clearances: equipment clearances as model objects for conflict detection and maintenance access requirements.

13. **Cost and Schedule Information**

Fed model with 4D and 5D Data shall be submitted with the Phase 2 preliminary and baseline schedule submittals and updated monthly thereafter. Continuously update cost and schedule information in the BIM model so that information provided monthly in the payment application and schedule update is reflective of the project's progress as stated in the monthly submissions. Refer to the General Conditions for cost and schedule requirements.

a. Schedule Data (4D):
   1) Provide construction activity sequences, including rough-in, finish, and phasing schedules for major elements of all models.
   2) Breakdown the schedule of elements by individual Subcontractors.
   3) Link the activity sequence to the Schedule of Values.

b. Cost Data (5D):

1) Provide quantity-based, installed cost breakdown of labor and material for major elements of all models.

2) Provide a complete Schedules of Values based on the models.

3) Link data to the Project Cost Database in Microsoft Excel format.

14. **Development and Submittal of the Models**:

a. BIM Submittal Execution: The Design/Builder shall develop the Fed Model and its discipline systems Native Models in compliance with the Contract Documents and the following:

1) Develop and submit all of the discipline systems Native Models concurrently. Note: if any of the discipline systems Native Models qualify as deferred approvals, they may be submitted separately.

2) Submit the Fed Model with 300 LOD at 60% completion of the Work of the Project for LAWA's review and coordination.

3) Submit updated Fed Model and all linked Native Models at any time when the Design/Builder requests changes and/or clarifications.

a) Submit fully completed Fed Model and its systems models, prior to construction.

b) Submit updated discipline systems Native Models complying with final approved shop drawing submittals.

c) Submit the "as-built" Fed Model and its discipline systems Native Models as part of the close-out process.

b. Updating Models during Construction:

The BIM **Model** shall be routinely updated/revised to keep it current with construction activity as follows:

1) Updating: issue the Fed Model and its discipline systems Native Models one week before each regularly scheduled LAWA, Design Professional and Design/Builder meeting or quarterly whichever is more frequent.

2) Revising: issue the revised Fed Model and/or its discipline systems Native Models immediately after each meeting or other activity where revisions have been made. Include a report that indicates every change.

3) Submit the updates and revisions to LAWA.

c. Closeout Requirements:

Refer to the "Project Closeout" PR for Requirements.

~END OF THIS PR~

APPENDIX E

BIM for Airports: A PowerPoint Presentation (web-only)

Abbreviations 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
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
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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