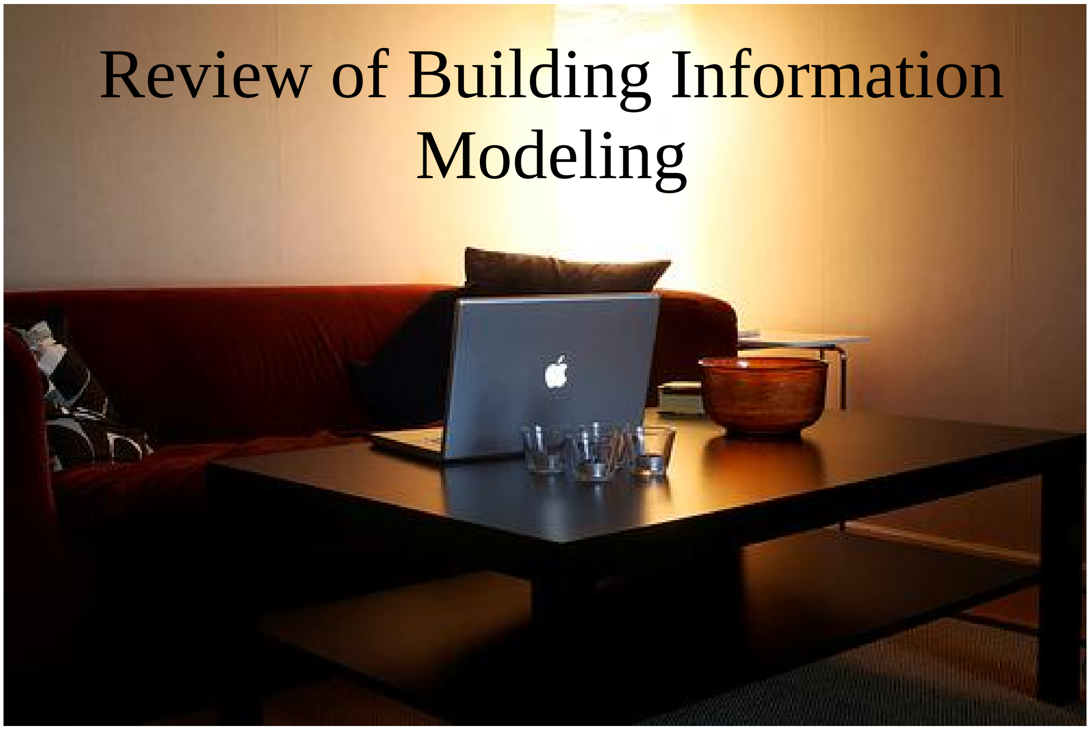

Review of Building Information Modeling

By

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Review of Building Information Modeling (BIM) and Its Application

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Abstract

Several countries have witnessed unprecedented growth across all sectors over the past two decades which includes highway and infrastructure projects, with a high number of projects already completed, several ongoing, and many more planned. On the cusp of this industrial apex, stakeholders of these projects are turning to groundbreaking technology, such as Building Information Modeling (BIM), to help reduce time and improve cost efficiency, without compromising the quality of their projects and the environment. These stakeholders are public agencies officials, project managers, transportation engineers, and contractors. The aim of this review is to explore the implementation characteristics of BIM in these projects. To achieve this aim, this report reviews the benefits and applications of BIM with a focus on highway and infrastructure projects.

Keywords: Building Information Modeling, BIM, highway projects, infrastructure projects

1 Concept of Building Information Modeling

The productivity of the construction industry has traditionally been much lower than that of other industries, especially the manufacturing industry. In the last few decades, no significant improvement in the productivity of the construction industry has been observed. As other industries have improved their productivity by using innovative methods and techniques, the construction industry is also adopting new technologies such as Building Information Modeling (BIM) to help improve the productivity. There is a need and continuous urge for its improvement by using those innovative techniques and methods already adopted by the other industries. Consequently, the automation approaches used for productivity enhancement in the manufacturing industry have been gradually adopted, developed and applied in the construction industry. BIM is one of the approaches that have emerged for collaboratively establishing automation in the design, construction and operation phases of the project lifecycle. The BIM concept has been derived from the 'Building Product Models (BPMs), which were developed in the United States in 1970s (Eastman, 1975). The BPMs later transformed into a process called 'Building Modeling' (Aish, 1986) before being routinely used as BIM. A number of BIM software have since been gradually developed with the advances in the processing and storage powers of computers.

The concept of BIM revolves around accurately creating and using a digitally constructed virtual model of a building, known as a building information model. The complete building information model contains precise geometry, and relevant data needed to support the design, procurement, fabrication, and construction activities required to realize the building (Eastman et al. 2008). This model has the potential to be used for operations and maintenance purposes of the constructed facility. A number of capabilities of a building information model can summarized as follows.

- Characterizing the geometry, spatial relationships and geographic information of the facility
- Calculating and determining the quantities and properties of building elements and cost estimates
- Preparing material inventories and visualized project schedules to show systems, assemblies, and sequences at convenient scales within the entire project or group of subprojects
- Demonstrating the entire project life cycle to be able to extract the quantities and properties of materials as and when needed (Bazjanac 2006)
- Highlighting, isolating and defining the scopes of work during the project execution
- Accomplishing interrelated construction documents such as drawings, procurement details, submittal processes, and other specifications (Khemlani et al. 2006).

Collectively, BIM can be regarded as a process that strives to cover almost all aspects, disciplines, and systems of a facility within a single model. This allows all design team members (owners, architects, engineers, contractors, subcontractors, and suppliers) to collaborate more accurately, frequently and efficiently as compared to using traditional approaches.

2 Benefits of BIM

For the professionals involved in a project, BIM enables a virtual information model to be handed from the design team (architects, surveyors, civil engineers, structural and building services engineers, etc.) to the main contractor and subcontractors and then on to the owner/operator. Each professional adds discipline-specific data to the single shared model. The perceived benefits of BIM for civil engineers on the highway and infrastructure projects include but are not limited to easily predict the performance of projects before they are built; respond to design changes faster; optimize designs with analysis, simulation, and visualization; and deliver higher-quality construction documentation (CRC, 2007).

Stanford University Center for Integrated Facilities Engineering (CIFE) figures based on 32 major projects using BIM indicates benefits such as (Gilligan and Kunz, 2007):

- Up to 40% elimination of the unbudgeted change.
- Cost estimation accuracy within 3%.
- Up to 80% reduction in time taken to generate a cost estimate.
- Savings of up to 10% of the contract value through clash detections.
- Up to 7% reduction in project time.

Over the years, BIM has found numerous applications in the project lifecycle, not only for the building projects but other projects such as infrastructure and highways projects. The applications of BIM include space analysis in the programming phase of the project (CICRP, 2009). The integration of BIM with a geographical information system (GIS) has been investigated by Berlo and Laat (2011), and Isikdag et al.(2008) for the selection of appropriate project site. Besides advances and economy of 3D laser scanning equipment has allowed practitioners to accurately scan existing utilities and integrate them into the BIM model (Azhar, 2011). In a case study cited by Azhar (2011), the owner achieved roughly $1,995,000 cost-savings at the schematic design stage by selecting the most economical design option using BIM. Besides BIM has been also useful in the detailed design and construction detailing phases of the project. In the preconstruction phase of the project, BIM has found applications for estimating, site coordination and constructability analysis.

In the construction phase, the project team can use BIM for the Project progress monitoring using 4D phasing plans; for trade coordination meetings; and integrating Request for Information (RFIs), change orders and punch list information in the BIM models. Rubenstone (2012) has mentioned various applications of BIM in handheld devices and the use of BIM in cloud computing during the construction phase of the project. The information extracted from BIM models is also useful for the facility management and post-construction operations (Azhar, 2011, Philips and Azhar, 2011, Ku and Taiebat, 2011). From the standpoint of project stakeholders, the designers, the owners, the constructors and facility managers can get benefits from BIM in their respective core functions in the project (Philips and Azhar, 2011). Also, BIM-based sustainability analysis is finding acceptance among the environmental engineers (Schueter and Thessling, 2008).

BIM is now being increasingly used on infrastructure projects. According to McGraw-Hill Construction's Smart Market Report ("The Business Value of BIM for Infrastructure", 2012), almost half of the infrastructure organizations in the United States used BIM technologies and processes on some parts of their infrastructure projects. The value of BIM was being realized by the vast majority of those organizations who were using BIM for infrastructure projects. Using BIM for infrastructure was particularly beneficial for reducing conflicts and changes during construction, reducing rework and improved productivity on projects. As far as business benefits, it was found that BIM was useful for winning new projects, and there was a positive return on investment (ROI) from the use of BIM on infrastructure projects. The use of BIM is expected to increase over time. On bridges, roads, and highways projects nearly 60% of projects are currently using BIM on some parts of the project. On average, the Architectural, Engineering and Construction (AEC) organizations are using BIM on nearly 50% of the infrastructure projects in the USA.

3 BIM Applications for Infrastructure Projects

BIM is useful for representing the ground conditions for civil works using a variety of inputs using GIS data, underground radar, laser scanning, and test borings to develop a reliable model of the existing civil conditions. This model is useful to simulate the impact of the proposed design solutions, engaging community stakeholders and visualization for business development. BIM for infrastructure projects has found the most use in the design and construction documentation phases of the projects. In the project processes, spatial coordination and structural analysis are most common applications of BIM. Most project stakeholders include the A/E, the contractors, and the owners consider that BIM is particularly useful for complex projects. A number of cases are presented here which illustrate the use of BIM on various kinds of infrastructure projects.

3.1 Road Projects

Although it is best to use BIM in a more collaborative environment such as design-build contracts, however, in many cases BIM can still be used in a design-bid-build environment. Although, in such cases it become difficult to mandate the use of BIM and the application of

BIM become limited. On a road intersection project, BIM modeling was done after the design was completed. Still the model was good to use for visualization, clash detection and 4D scheduling which saved the costs of construction (“WI: Mitchell”, 2014). On another project, the early creation of the BIM model for a road interchange saved the printing of 20,000 pages design-set documents (“Zoo Interchange”, 2014). The model was 4D-scheduling and 5D scheduling + cost capable. On a bridge replacement project (“Fore River Bridge”, 2014), the BIM model of 300 ft high bridge tower and bridge itself was created and the coordination of mechanical, electrical and plumbing (MEP), structural and architectural works was performed using the BIM model.

3.2 Airport Projects

These projects involve both the building and civil works such as taxiways and runways in addition to terminal buildings. On an airport development project (“Delta”, 2014), the civil works were coordinated, and constructability review were made using 4D BIM model which avoided scheduled slippage and provided rough cost estimates for the project. On another airport project (“The Green Build”, 2014) which included the parking and roadway in addition to terminal expansion programs, major contractors on various project packages worked in harmony through BIM which was the common model for the project. BIM model also helped create accurate as-built drawings about the underground utilities at the project site. On a terminal renewal and improvement project (“Dallas/Fort”, 2014), the use of BIM was more evident in the paperless use of project information which resulted in $8 million savings in only the printing costs alone.

3.3 Other Infrastructure Projects

The use of BIM in other infrastructure projects is summarized in Table 1.

Table 1 BIM applications in various infrastructure projects

Project Type	BIM Application/Scope	Source
Bus station of public transit project	Conceptual design to identify best site concept, systems coordination, cost estimating	http://tinyurl.com/4thrnv (Reno, Nevada, USA)
Public transit project	Coordination in tight spatial restricted areas	http://tinyurl.com/tornty (Toronto, Ontario, Canada)
Bus rapid transit system	Constructability checking, quantity takeoff, earthwork, structural elements modeling, 4D scheduling, laser scanning for as-built drawings	http://tinyurl.com/vivabr (York Region, Ontario, Canada)
Flood control dam project	Representing complex geometries, construction coordination, quantity takeoff	http://tinyurl.com/howhan (Ravensdale, Washington, USA)
Canal expansion project	Modeling water and earth retaining structures, MEP modeling, conflict resolution, potential for facility management	http://tinyurl.com/pnmexp (Panama Canal, Panama)
Sewer solids separation facility	3D modeling, conflict resolutions	http://tinyurl.com/nfr8de2 (Des Moines, Iowa, USA)
Water reclamation facility	Lifecycle application of BIM, schedule compression, bid package preparation for subcontractors, facility management	http://tinyurl.com/arbpri (Okaloosa, Florida, USA)
Wind Farms	4D scheduling, quantity takeoff, construction process modeling, clash detection between structural rebar and electrical ducts	http://tinyurl.com/k2zxerl (Various places, USA)
Electrical substations	3D model generation, bill of materials and cost estimating	http://tinyurl.com/enmaxp (Calgary, Canada)
Recreation parks	BIM for underground electrical and plumbing modeling	http://tinyurl.com/scitop (Columbus, Ohio, USA)

3.4 Lessons Learned from BIM Applications in Infrastructure Projects

The use of BIM for infrastructure projects is gradually getting pace compared with its use in building projects. The realization of BIM as a broadly applicable tool and process is on the rise. The use of BIM for infrastructure works needs engineering judgment on the part of the modeler as these works often include more unknown factors as compared with building projects. Some people argue that BIM for infrastructure work should be called as CIM, the Civil Information Modeling.

The most striking benefit for use of BIM on civil or infrastructure projects is the conflict and clash detection ability, improved information about underground conditions and 3D visualizations. Like for building projects, the creation of customized civil work elements is a useful ability from the use of BIM on these kinds of projects. There is still a need to grasp the full benefits of BIM. The ability to embrace the complexity of the infrastructure projects is also a great strategic benefit from BIM.

BIM has changed the way for working on the projects from individualized ways to more collective ways. It is a paradigm shift from a traditional project delivery method to a process that can be called as BIM delivery method. However, in a traditional environment, it may not be easy as it might need the willingness of the owners and designers to share their electronic design details with other stakeholders of the project.

It is relatively easy for one project to get other stakeholders involved in BIM because unlike building projects; infrastructure projects do not have many subcontractors on a project. However, infrastructure projects need more variety in the specialties required, and this might be a challenge to bring other stakeholders to work on a common BIM model on the project and they might not be conversant in BIM.

4 Need for Measuring the Benefits of BIM

By adopting BIM in a construction project, stakeholders can derive benefits in terms of time, cost and quality. In the past few years, BIM has revolutionized the approaches of construction project life cycle (Wong, 2006). However, its wider acceptance by professionals in the construction industry depends on their better understanding and recognition of its usefulness. Another factor that may affect the wider adoption of BIM in the industry is the effect on profitability. If the adoption of BIM becomes recognized as having a positive effect on profitability, this may guide the stakeholders to adopt BIM on future projects. For this purpose, there is a strong need for better understanding of the benefits, weaknesses, and impacts of BIM before its usefulness to both clients and construction professionals can be effectively disseminated.

The main objective is to identify and disseminate BIM applications and benefits for highway and infrastructure projects. This objective highlights on the industry background for BIM, which is needed to be understood by the BIM professionals. The second objective is to identify and disseminate the BIM attributes based on the content analysis of the various BIM definitions. This objective highlights on the theoretical background of BIM.

5 BIM Definitions and Attributes

BIM, being a relatively new technology for the AEC Industry, is in its formative years of development. Currently, there is a lack of consensuses on the adoption of universally acceptable standards regarding interoperability and associated legislation by the concerned organizations and the governing bodies. A number of BIM definitions have been proposed by various entities across the globe. These entities include the National Institute of Building Sciences of USA (2013), BIM Forum (2013), Autodesk Corporation (2013), Eastman et al. (2008), Mortenson Construction Company and Associated General Contractors of America. (AGC) (2005). These definitions have similarities and dissimilarities with each other in describing various attributes of BIM and can be qualitatively compared against various common attributes. The salient attributes of these definitions are presented in Table 2 and are discussed next.

6 BIM Attributes

6.1 Modeling Scope

Modeling scope is the extent of project phases to which BIM can be applied. This is taken to include both physical and functional characteristics of the project in the definition by NIBS. The BIM Forum restricts it to five dimensions. Eastman et al., however, generalize the scope to cover ‘n’ dimensions.

6.2 Modeling Approaches

This attribute relates the functions that can be performed with the input and processing needs in the building information model. These terms direct the user toward the modeling capabilities and vary from abstracted terms to relatively descriptive terms. The terms such as digital, object-oriented, spatial and intelligent digital are used in BIM definitions.

6.3 Modeling Functions

This attribute shows the various operations that can be performed with the building information model and the interrelationships between these functions. This attribute is described as a shared knowledge resource in the definition by NIBS, coordinated, internally consistent, computable information by Autodesk, data-rich building components by Eastman et al., measurable, comprehensive, accessible and durable data by Mortenson and intelligent and parametric digital representation of facilities by the AGC.

6.4 BIM Aims

The aims for BIM have been described as leading to reliable and fast decision making, more communicable building models, better quality, higher profitability, intelligent architectural simulation, and the provision of providing consistent and non-redundant data and improved delivery processes.

6.5 BIM Coverage

There is a general consensus that building life cycle can be covered with BIM applications from conception to demolition in terms of design, construction, and operation.

6.6 Stakeholders Interaction

The type of stakeholder interaction has been mentioned as one of collaboration in the NIBS definition. Autodesk describes it as integrated digital environment. In Eastman’s definition, it is called coordination.

6.7 Data Processing

Data processing functions have been described as inserting, updating, extracting, modifying, and accessing information.

6.8 BIM Users

The people who provide input into BIM processes are architects, engineers, builders, and owners. The definition by NIBS assigns this responsibility to each stakeholder.

6.9 Compatibility Recognition

Interoperability and intuitiveness of the software have been mentioned by BIM Forum (2013) and Mortenson's definition (AGC, 2005).

7 Overall Picture of BIM Attributes

Many pertinent BIM-related issues are covered with these definitions, particularly, the issue of collaboration by stakeholders in all phases of the life cycle of a facility for inserting, extracting, updating or modifying information in the building information model to support and reflect the roles of stakeholders. The definitions have covered this aspect of BIM in particular. The definition by NIBS seems to include most of the issues covered by Eastman's definition. One may argue that a BIM application for a particular project might not require all the attributes described in the above definitions. In that case, the key attributes needed should be determined by the scope of the project. It is expected that with the passage of time, various definitions will merge into a single universally acceptable definition. Such a definition must be comprehensive to include all the pertinent attributes.

Table 2 Comparison of the different BIM attributes

Attributes	**NIBS**	**BIM Forum**	**Autodesk**	**Eastman**	**Mortenson**	**AGC**
Modeling Scope	Physical & functional characteristics	5-D modeling		nD		
Modeling Approaches	Digital	Object-oriented		Intelligent digital representation	Digital, spatial,	Object-oriented
Modeling Functions	Shared knowledge resource		Coordinated, internally consistent, computable information	Data rich digital building components	Measurable, comprehensive, Accessible & durable data	Intelligent & parametric digital representation of the facility
BIM Aims	Reliable decision	Better communication	Better, faster decisions, quality & profitability	Produce, communicate, analyze building models	Intelligent simulation of architecture	Facilitate decisions & improve delivery process
BIM Coverage	Conception to demolition	Design, construction, operation	Design, Construction	All phases	All phases	
Stakeholders Interaction	Collaboration		Integrated digital environment	Coordination		
Data Processing	Inserting, extraction, updating, modification		Information on dating, accessibility,	Consistent & non-redundant data		
BIM Users	Each stakeholder		Architect, engineers, builders, owners		AEC team, Owner	
Compatibility Recognition		Interoperable			Interoperable & Intuitive	

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Review of Building Information Modeling - Quiz

Updated: 1/16/2019

1. The term BIM stands for ___________________________.
    a. Building Information Modeling.
    b. Building Information Media.
    c. Building Identity Modeling.
    d. Building Installation Mode.

2. Adopting new technologies such as BIM help ___________________.
    a. improve the productivity.
    b. increase the cost of the project.
    c. increase the time of the project.
    d. Improve the material used in the project.

3. BIM is one of the approaches that have emerged for collaboratively establishing automation in the ______________ of the project lifecycle.
    a. planning, design, and operation phases
    b. planning, bidding, and design phases
    c. planning, bidding, and negotiating phases
    d. design, construction and operation phases

4. The BIM concept was developed in ______________.
    a. Europe
    b. United States
    c. Asia
    d. Canada

5. The concept of BIM revolves around accurately creating and using a digitally constructed ____________________ of a building.
   a. virtual model
   b. physical model
   c. sound model
   d. demo model

6. A number of capabilities of a building information model include ________________.
   a. characterizing the geometry, spatial relationships and geographic information of the facility.
   b. calculating and determining the quantities and properties of building elements and cost estimates.
   c. preparing material inventories and visualized project schedules to show systems, assemblies, and sequences.
   d. All of the above.

7. BIM enables a virtual information model to be handed from the design team (architects, surveyors, civil engineers, structural and building services engineers, etc.) to the ________________.
   a. contractor
   b. owner
   c. operator
   d. All of the above.

8. In a BIM model, each professional adds discipline-specific data to ________________.
   a. single shared model.
   b. Multiple shared models.
   c. Multiple separate models.
   d. Single model managed by the project manager.

9. The perceived benefits of BIM for civil engineers on the highway and infrastructure projects include ______________________.

   a. easily predict the performance of projects before they are built;
   b. respond to design changes faster;
   c. optimize designs with analysis, simulation, and visualization; and deliver higher-quality construction documentation.
   d. All of the above

10. In the construction phase, the project team can use BIM for __________.

   a. monitoring using 4D phasing plans.
   b. trade coordination meetings.
   c. change orders.
   d. All of the above.

11. Using BIM for infrastructure was particularly beneficial for __________.

   a. reducing conflicts and changes during construction.
   b. reducing rework.
   c. improving productivity on projects.
   d. All of the above.

12. On bridges, roads, and highways projects nearly of projects are currently using BIM on some parts of the project.

   a. 20%
   b. 40%
   c. 60%
   d. 80%

13. On average, the Architectural, Engineering and Construction organizations are using BIM on nearly ______ of the infrastructure projects in the USA.

a. 10%

b. 30%

c. 50%

d. 70%

14. BIM is useful for representing the ground conditions for civil works using a variety of inputs using ________________to develop a reliable model of the existing civil conditions.

a. GIS data

b. underground radar

c. laser scanning

d. All of the above.

15. The most striking benefit for use of BIM on civil or infrastructure projects is ________________.

a. the conflict and clash detection ability.

b. improved information about underground conditions.

c. 3D visualizations.

d. All of the above.

16. If the adoption of BIM becomes recognized as having a positive effect on_________________, this may guide the stakeholders to adopt BIM on future projects.

a. planning

b. communication

c. profitability

d. management

17. In the construction phase, the project team can use BIM for __________.

a. monitoring using 4D phasing plans.
b. designing new parts of the project.
c. measuring dimensions in the field.
d. contacting the stakeholders.

18. There is a general consensus that building life cycle can be covered with BIM applications from conception to demolition in terms of ____________.

a. design
b. construction
c. operation.
d. All of the above.

19. In BIM, data processing functions have been described as __________ information.

a. inserting
b. updating
c. extracting
d. All of the above.

20. The people who provide input into BIM processes are ______________.

a. architects, engineers, bidders, and builders
b. architects, engineers, builders, and owners
c. architects, engineers, builders, and operators
d. architects, operators, builders, and owners