Final Summary Report

Developing Standards-Based Education Modules for Building Information Modeling

(Project 70NANB22H207)

for

National Institute of Standards & Technology

by

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Abstract

This project aimed to develop four standards-based education modules for building information modeling (BIM). These modules cover semantic data modeling, BIM for building design and construction, BIM for information delivery from construction to operation, and BIM for information exchange between a building and the third-party service providers for the purpose of grid interaction and energy analytics. The modules are featured with strong connections between building information models and their technology foundations and corresponding documentary standards. Each education module has one or two sessions while each session includes the following components: 1) learning objectives and expected outcomes, 2) lecture slides, 3) video lectures, and 4) homework and reading. The modularized design enables the education materials to be adopted or built on by interested course instructors. The education modules can be used to improve existing BIM courses, develop new courses on advanced BIM technology and applications, and train industry professionals.

1. Introduction

According to the U.S. National Building Information Modeling Standard, Building Information Modeling is a digital representation of physical and functional characteristics of a facility. With a shared knowledge resource for information about a facility, BIM enables the consistent and continuous use of digital information across the entire lifecycle of a built facility, including its design, construction and operation. By reducing the laborious and error-prone manual re-entry of information from application to application, the implementation of BIM technology can significantly increase the performance of all stakeholders (e.g., architects, engineering designers in different disciplines, construction contractors, facility managers and operators, and energy service providers) involved at all stages of the built facility.

BIM is offered as a standalone course or a course module in Civil Engineering and Construction Management programs in many universities at both undergraduate and graduate levels. There are also many programs that plan to add a BIM course or a course module to their existing curriculum to meet the increasing industrial needs of workforce with BIM skills. Based on our knowledge, most BIM courses emphasize the use of BIM software (e.g., Autodesk Revit) for model development and BIM applications (e.g., quantity take-off and energy simulation). This means that most current BIM courses have a strong focus on the training of students' practical drawing-generation skills for building design and construction but are weak or even totally miss the following aspects:

- BIM technology foundations such as object-oriented modeling concepts and schematic metadata modeling skills,
- Key BIM-related standards such as the Industry Foundation Classes and the Construction Operations Building Information Exchange, and
- BIM in building operation that aims to provide semantic interoperability between building automation systems and building energy service providers.

As a result, most students, even those who have taken BIM courses, are not aware of the technical standards and their significance in advancing BIM and achieving interoperability across the fields of architecture, engineering, construction, and facility operation and management. Students' ignorance of BIM technology foundations and BIM applications beyond the design phase can be a constraint of their career development.

2. Project Goals

This project aimed to develop standards-based education modules for building information modeling, which can be used to improve existing BIM courses and develop new courses on advanced BIM technology and applications. More specifically, the education modules are expected to strengthen the connection between BIM and its fundamental technology and the connection between BIM and documentary standards.

The original project goals also include the adoption of the developed course modules by one new graduate course at UNC Charlotte. However, this goal was not achieved due to unexpected curriculum changes, as will be discussed in the Section of Lessons Learned.

3. Project Approach

Sacks and Pikas (2013) compiled a framework for BIM education that lays out the necessary topics and the levels of achievement required at each stage of degree programs. Table 1 below summarizes BIM education requirements with respect to technology. This table indicates that BIM technology encompasses a wide range of topics with different recommended levels of achievement for first degree (bachelor's), second or higher degree (master's), and work experience. This project concentrates on Topic 2.6: Interoperability, as highlighted in Table 1.

Table 1: BIM Education Requirements with respect to Technology (Sacks and Pikas 2013)

		Recommended level of achievement		
Number	BIM skills and technologies	First degree	Masters/30 credits	Experience
2.1	Basic BIM operating skills	3	4	5
2.2	Modeling with standard catalog elements	3	3	4
2.3	Creating and modeling with custom elements	3	4	5
2.4	Massing/solid modeling	3	4	6
2.5	Central databases/information repositories	2	4	5
2.6	Interoperability (file formats, standards, and structure for data sharing)	2	3	5
2.7	Communication tools, media, channels and feedback	3	5	6
2.8	Ways to store and share information (e.g., cloud computing, networking, big-room equipment)	3	3	5
2.9	Choosing right BIM technologies/processes/tools for specific purposes	3	5	6
2.10	Laser scanning	2	3	4

There is extensive BIM-related work, so it is not feasible to cover all building information models and related standards. We have focused on the following three applications:

- BIM for building design and construction,
- BIM for information delivery from construction to operation (facility management), and
- BIM for information exchange between a building and the third-party service providers for the purpose of grid interaction and energy analytics[1].

[1] In literature, the semantic interoperability to enable information exchange between building automation systems and grid or building energy service providers is not explicitly called BIM. We include the above case in BIM because it has similar intent, approach, and underlying technology and processes as conventional BIM applications.

Figure 1 shows the relationship mapping between education modules, BIM technology, building information models, and documentary standards to be covered in this project. Accordingly, the four education modules include:

- Module 1: Semantic data modeling
- Module 2: Industry Foundation Classes (IFC)
- Module 3: Construction operations building information exchange (COBie)
- Module 4: Semantic interoperability for grid-interactive efficient buildings

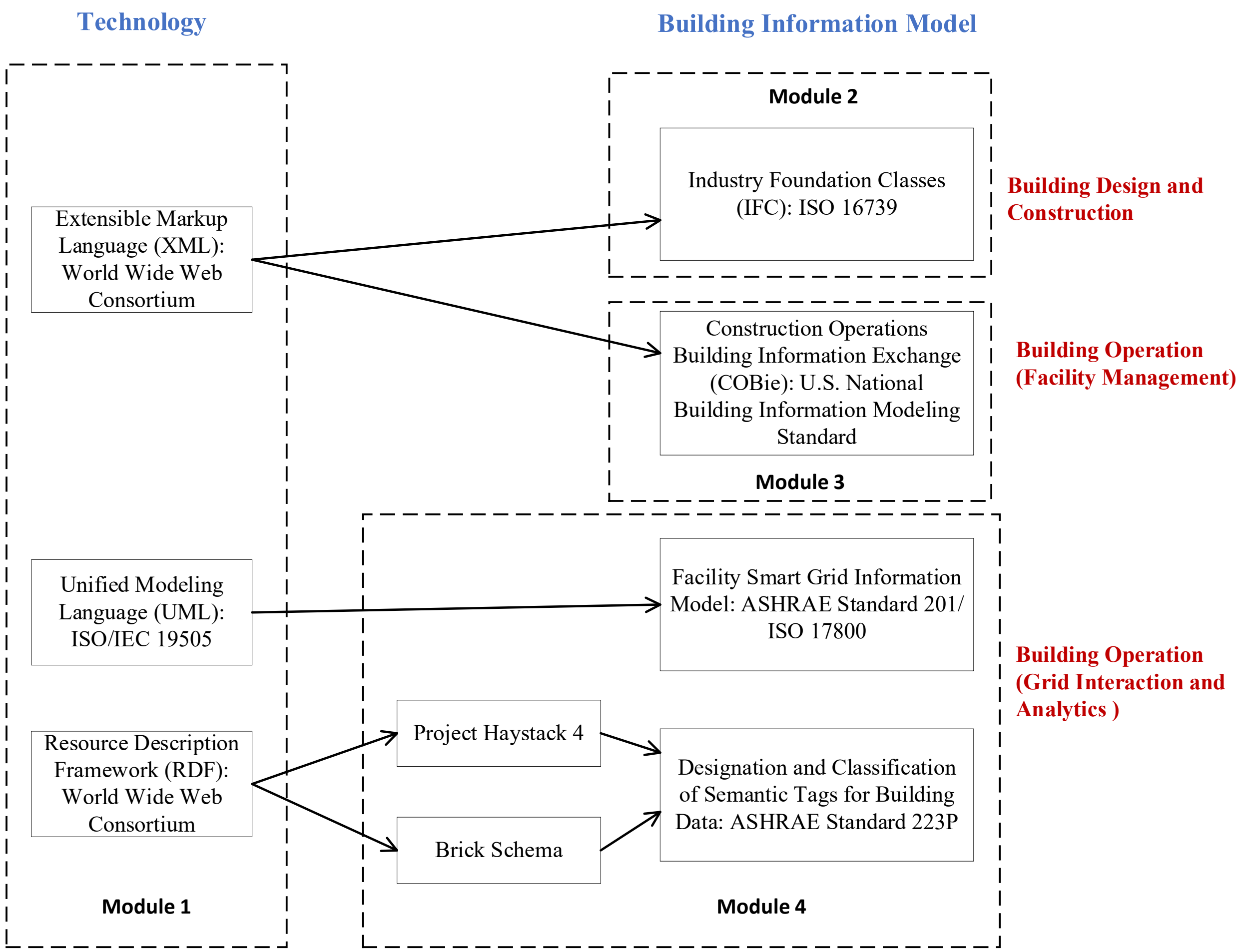

Figure 1: Relationship mapping between education modules, BIM technology, building information models, and documentary standards to be covered in this project

4. Project Outcomes

Our project deliverables mainly include two parts: 1) four standards-based education modules for BIM education, and 2) a website dedicated to the share and dissemination of resources on BIM education including this NIST-funded project.

4.1 Education modules

These education modules are divided into six sessions. Each session includes lecture slides and recorded video presentations (~ 3 hours in total). For all sessions, the lecture video is divided into several segments, called video clips. All these video clips are around 10 minutes because many studies suggested the optimum length of online lecture videos being 6 to 10 minutes for engineering students (Manasrah et al. 2021). The lecture slides include learning objectives, in-class exercises, homework and further readings. Table 2 summarizes the education modules and associated sessions.

Table 2: Summary of education modules, sessions and video lengths

Module	**Sessions**	**Video Length**
Semantic data modeling	2 (UML and XML)	~110 minutes
Industry Foundation Classes (IFC)	2 (Fundamental IFC and Advanced IFC)	~30 minutes
Construction operations building information exchange (COBie)	1 (COBie)	~25 minutes
Semantic interoperability for grid-interactive efficient buildings	1 (ASHRAE Standard 201)	~30 minutes

Module 1: Semantic data modeling

This module covers the technology foundation of building information models. Understanding building information semantics is critical for interoperable information exchange between systems throughout the building's life cycle. Topics in semantic data modeling include 1) object-oriented modeling concepts such as classes, objects, relationships and associations, aggregations and compositions, specialization and generalization, and 2) semantic modeling languages such as Extensible Markup Language (XML) and Unified Modeling Language (UML). Object-oriented modeling concepts and the information modeling languages are the technology underlying many prevalent building information models.

Module 2: Industry Foundation Classes (IFC)

IFC is an open, vendor-neutral data exchange format through which any BIM information may be exchanged and shared among software applications. IFC is an official International Standard ISO 16739-1:2018. IFC is a complex data model to represent both the geometry and semantic structure of a building model using an object-oriented approach. Topics covered in this education module include the object-based inheritance hierarchy (i.e., IfcRoot, IfcObject, IfcProduct and their subclasses) and object relationships (such as spatial aggregation hierarchy, relationships between spaces and their bounding elements, and the specification of materials).

Module 3: Construction operations building information exchange (COBie)

COBie is an information exchange specification that streamlines the handover of specific data from the design and construction phases to the facility's operation and maintenance. As a National Building Information Modeling Standard in the U.S., COBie uses a common definition of assets such as facility, floor, space, and equipment as well as individual components. It addresses specific requirements for the delivery of non-geometric building information. Topics covered in this education module include COBie file formats (i.e., IFC, XML, and SpreadsheetML) and the content of COBie spreadsheets.

Module 4: Semantic interoperability for grid-interactive efficient buildings

There are growing volumes of data that can be collected from building automation systems. However, scalable analytics and practical use of the collected area for building operational performance improvement are very limited. One major reason is the lack of semantic interoperability between building automation systems and the third-party energy service providers. Without accurate and sufficient semantics, it is difficult to determine what the data represents and what relationships exist among different systems, equipment, and spaces. In this module has a focus on the Facility Smart Grid Information Model (ASHRAE Standard 201/ISO 17800), which uses UML to define an abstract, object-oriented information model to enable appliances and control systems in buildings to manage electrical loads and generation sources within the context of building to grid interactions.

One of the project goals is to strengthen the connection between BIM and documentary standards. We achieved this goal by either using a standard as the topic directly or referring relevant standards in the lecture slides. Table 3 lists the standards covered in our education modules.

Table 3: Standards covered in the education modules

Module	**Standards**
Semantic data modeling	• ISO/IEC 19505: Information technology — Object Management Group Unified Modeling Language (OMG UML) • Word Wide Web Consortium: Extensible Markup Language (XML) 1.0 Specification • gbXML: Green Building XML
Industry Foundation Classes (IFC)	• ISO 16739: Industry Foundation Classes for data sharing in the construction and facility management industries
Construction operations building information exchange (COBie)	• National BIM Standard - US: COBie Version 3 • Construction Specifications Institute: OmniClass

Semantic interoperability for grid-interactive efficient buildings	• ASHRAE Standard 201: Facility Smart Grid Information Model (FSGIM)
	• Organization for the Advancement of Structured Information Standards (OASIS):
	  ○ OASIS Energy Interoperation Standard
	  ○ OASIS Energy Market Information Exchange Standard

	○ OASIS WS-Calendar Standard • IEC 61850 series of standards (IEC 61850-7-2,3,4 and 420) • The NAESB Energy Usage Information Model • The Weather Information Exchange Model

4.2 Project website

A project website (https://bim.charlotte.edu/) has been developed to host all lecture slides and videos from this project. We plan to continue to maintain and expand the materials on this website to make it a recognized source for BIM education. Figure 2 provides a snapshot of the project website portal, through which all four education modules can be navigated.

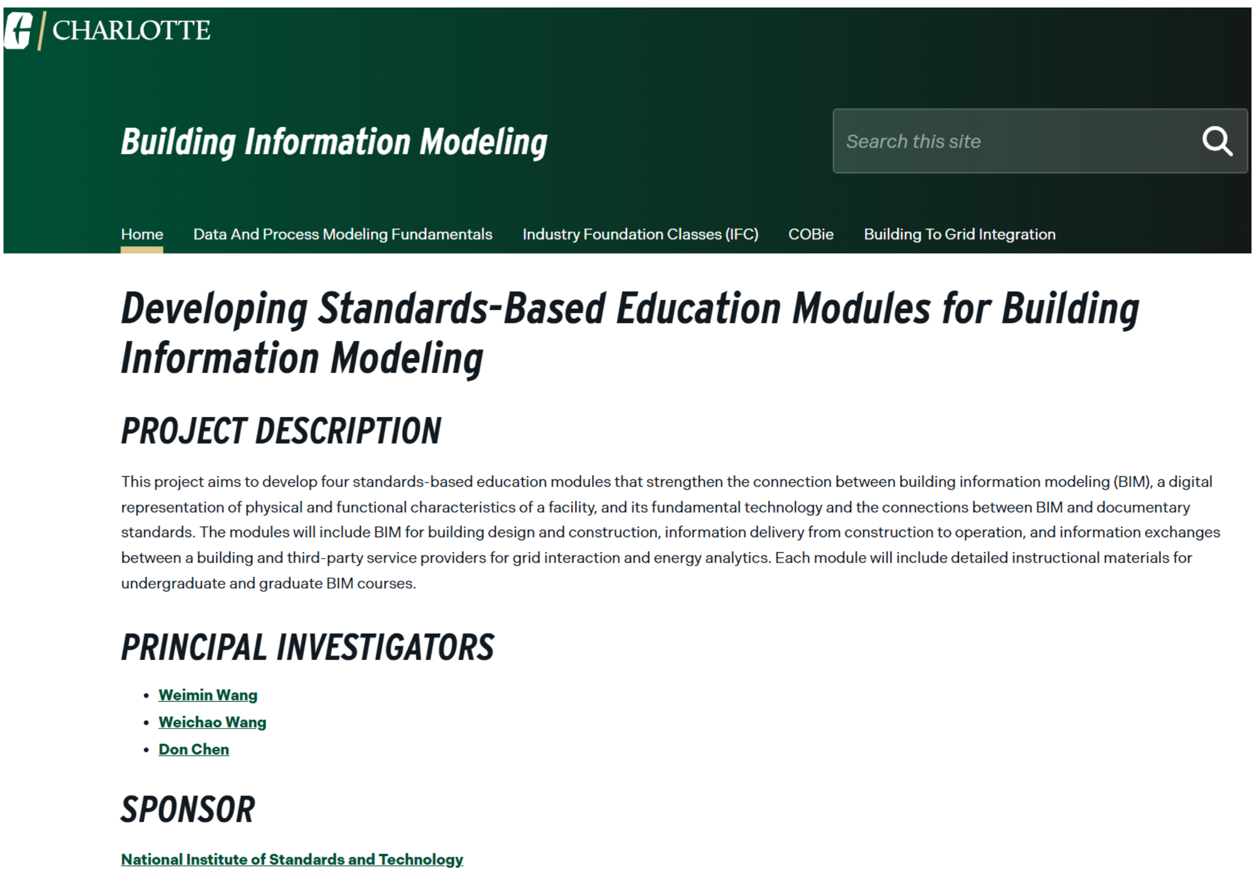

Figure 2: Project website portal (https://bim.charlotte.edu/)

We think a publicly accessible project website facilitates sharing and dissemination. The website was launched in August 2025. It is our plan to monitor the site and analyze the website metrics such as the number of unique visitors, the time on page, and the number of file downloads.

5. Evaluation

External peer reviewers were relied on to evaluate the education modules. After developing the lecture slides, we shared them with three external reviewers from the following universities: North Carolian A&T University, Western Carolina University, and University of Houston. All these three reviewers are active in teaching BIM-related courses.

To facilitate the evaluation, we prepared the following five questions for peer reviewers' feedback:

- Question 1: To what degree will the course modules achieve the goal of strengthening the connections between BIM and its fundamental technology and the connections between building information models and documentary standards?
- Question 2: Do you think the overall structure and contents of the education modules and the slides of each module align well with the learning objectives and the project goals?
- Question 3: Do you see any missing contents/components that should be covered in the context of the proposed work?
- Question 4: Do you see any potential of using these course materials in your own courses or any other courses you are aware of in your department? If there is any potential, how do you plan to use them?
- Question 5: Except for the previous comments, what other inputs do you like to share with us?

All three reviewers provided professional comments. In particular, we received quite encouraging feedback on Question 4 regarding the potential adoption of our education modules. Here are some quotes:

- *There is clear potential to use these materials in my graduate-level course Building Information Modeling (BIM) Applications for Construction Management.*
- *I would consider integrating the UML section when teaching system modeling or workflows in BIM-enabled project delivery. The gbXML content would be especially useful when covering energy modeling or sustainable design topics in my course LEED & GREEN Construction Principles in Construction Management.*
- *Yes, the COBie module is directly applicable to my BIM course and can be used in a course on Facilities Management.*
- *I will consider using the developed materials for my graduate level course, Computer Application in Construction.*

In addition to positive comments on the value of these modules, the reviewers suggested several changes for improvement. The suggestions are mainly related to two aspects:

- Formats such as the use of uniform template across all slides, inactive URLs, and font sizes.
- Making the slides more receivable and digestible by providing examples, in-class exercises, and case studies.

Based on the review comments, the project team improved the slides. Due to resource constraints, we did not perform the 2^{nd} round review of the lecture materials.

6. Project Sustainability

Higher education plays a critical role in satisfying the increasing industry demand for engineers with BIM skills. We plan to continue this work after the project ends with the team's own resources.

- We plan to adopt the education modules in our own curriculum if opportunities arise. The good news is that the College of Engineering at UNC Charlotte has created a new B.S. in Construction Engineering degree program, a joint program between the Department of Civil and Environmental Engineering and the Department of Engineering Technology and Construction Management. The new program will be accepting students in Fall 2026. This means that the internal need for BIM courses will become higher. We are optimistic that education modules will be adopted by a BIM course at UNC Charlotte in near future.
- We plan to improve the existing modules and develop new ones. Once the education modules are adopted at UNC Charlotte, we can obtain feedback from our students and improve the lecture slides accordingly. Regarding new materials, we are interested in completing the ASHRAE Standard 223P "Designation and Classification of Semantic Tags for Building Data", which is still under development by ASHRAE.
- We plan to continue maintaining the project website by uploading new materials whenever available and performing website analytics.
- We plan to disseminate the developed education modules on BIM to more universities through our professional networking.

7. Lessons Learned

Developing standards-based education modules needs strategic planning, risk mitigation, and careful resource management. We came across a few challenges when implementing the project:

- Curriculum planning subject to external factors. At the project proposal stage, we anticipated trying out the education modules in a new graduate course on Advanced Building Information Modeling. At that time, the department was strongly supportive to develop that new graduate course. However, the department received different opinions from the Industry Advisory Board of the Construction Management Program. As a result, the plan to include the new graduate course on Advanced Building Information Modeling in the curriculum was not implemented.
- Challenges to introduce cross disciplinary materials to undergraduate courses. The education modules are more about information technology than construction engineering and management. Based on our prior experience of teaching other courses, we have the concern that many undergraduate students in Civil and Construction Engineering may regard such cross-disciplinary materials irrelevant to their career development. Effective strategies to motivate students to learn cross-disciplinary materials are needed.
- Significant efforts are needed to "decipher" technical standards into curriculum materials. When developing the education materials of Module 3 and Module 4, we faced the

challenge of lack of updated reference books and publications. For example, COBie Version 3 was released at the end of 2023 but most reference materials were based on earlier versions. ASHRAE Standard 201 has more than 800 pages and there are few references to help decipher the technical standard to understandable education materials.

- Including a standard under development unlikely works. At the project proposal stage, we planned to include The ASHRAE Standard 223P "Designation and Classification of Semantic Tags for Building Data", which was under development by ASHRAE. This new standard aims to harmonize existing metadata schema [e.g., Project Haystack (2025) and Brick (Fierro et al. 2020)] to enable interoperability on semantic information across the building industry, particularly in building automation. However, developing a new standard is a long process. It was not until June 2025 when the draft standard was out for public review. Therefore, we could not include it in Module 4.

Acknowledgements

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