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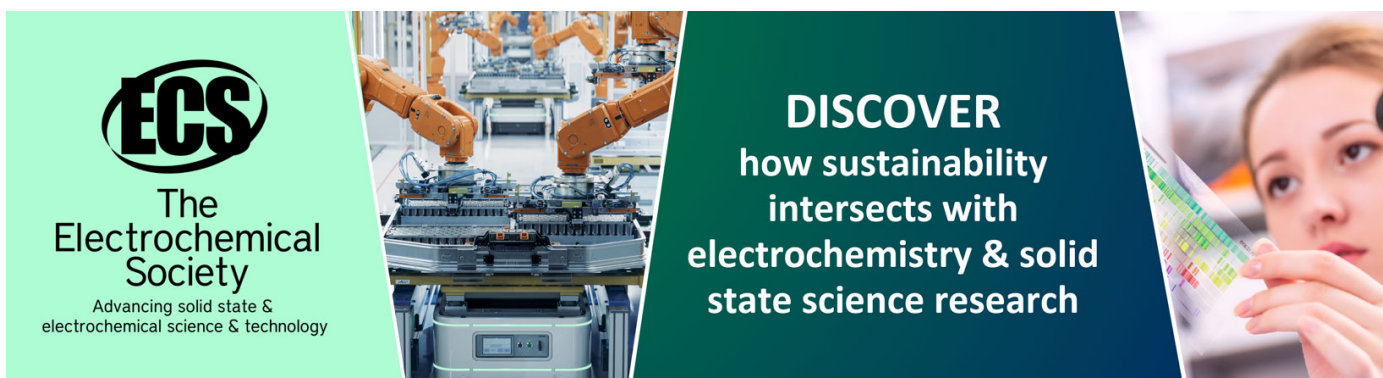
Building Information Modelling Usage in Federal Hydropower Design and Construction Management

To cite this article: Jacob West and Junshan Liu 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1203** 032027

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Building Information Modelling Usage in Federal Hydropower Design and Construction Management

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Abstract. The use of Building Information Modeling (BIM) is widespread within the engineering and construction industry, with huge strides in both usage and technological advances in the past two decades. The benefits of design collaboration, communication, visualization, and risk mitigation are untold. The U.S. Army Corps of Engineers foresaw the benefits of BIM and began to write policy for its mandatory use across the enterprise in the early 2000s. As BIM technology evolved, the U.S. Army Corps of Engineers has struggled to keep pace with the speed of industry but continue to make improvements to policy and more widespread usage across the enterprise. The MILCON program sees widespread use in the planning and design phases using BIM for visualization, communication, creation of 2D construction drawings, and rough estimating. BIM usage stops short in two major areas of the U.S. Army Corps of Engineers work: hydropower rehabilitation and construction management. Professionals from the U.S. Army Corps of Engineers in design management, hydropower engineering, and construction management all agreed that BIM, utilized and implemented properly, can have a very strong impact in each major field that would improve efficiencies, aid stakeholders in better understanding of complicated design concepts, and realize a more streamlined construction management process for complicated hydropower work. Through literature review and interviews with construction professionals, this research studied how BIM is being used within the U.S. Army Corps of Engineers, specifically within hydropower rehabilitation programs, for design and construction management. This research also focused on how private industry has been and is currently using BIM in construction management, and to correlate how processes used in private industry may be used on hydropower generation unit rehabilitation projects at USACE-owned facilities.

1. Introduction

The use of Building Information Modeling (BIM) systems has taken a large foothold in the design and construction industry in the last twenty years [1]. The industry has seen an increased usage of BIM systems by contractors from 28 percent in 2007 to 71 percent in 2012. Usage has proven the benefits of the design model being tied to a relational database as being incredibly valuable. Having seen this first-hand, contractors began to significantly drive for the usage of BIM earlier in this decade. Major construction projects utilize BIM systems in the planning, design, and estimating/bidding of the work however BIM usage is stopped short, at times, during the construction phase of the project to aid in management and quality control of the work. Researchers agree that BIM can be helpful to improve project quality and that more projects are likely to use BIM in the future to pass information from the design phase to the construction trades [2].



Private industry continues to evolve as new technology presents cost effective and demonstrated improvements to design, process, and schedule. Similarly, the U.S. Army Corps of Engineers has strived to be on the leading edge with BIM and its implementation across the enterprise. In 2006, the U.S. Army Corps of Engineers developed a BIM Roadmap that focused BIM usage for military construction (MILCON) only. This roadmap was updated in 2012 with the publication of ERDC SR-12-2, The U.S. Army Corps of Engineers Roadmap to Life-Cycle Building Information Modeling (BIM). This paper directs that “All applicable Civil Works (CW) and Army MILCON projects (new construction and renovation/expansion) in the continental United States (CONUS) shall use BIM technology for design and construction.” [3].. It was found that today BIM is widely used in the MILCON program for design, cost estimating, clash detection, and two-dimensional drawing production however benefits akin to using the model during construction are not widely taken advantage of. Research conducted did not indicate that BIM was used in any form in the CW program, including hydropower rehabilitation.

Building information modeling is widely used and implemented in the United States, and a broader set of construction companies have committed resources toward the adoption of BIM for projects due to the rapid growth and popularity of the technology [2].. Benefits to the widespread adoption for project stakeholders include proper balance among the project management factors of scope, cost, and time. These key aspects of a project can be managed and assessed in real time with the model development which imparts more control into executive stakeholders of the projects. Negative aspects, however, can prevent an even wider use of BIM; these barriers include high initial cost, lack of expertise in-house, resistance to change, lack of subcontractor usage of BIM, security risks (losing intellectual property), and lack of industry standards, among others.

Research for this paper included interviews with U.S. Army Corps of Engineers employees regarding level of BIM usage to perform required responsibilities and, if BIM is used, how it is applied. The interviews indicated that BIM is used primarily in MILCON design but not used for Civil Works or Hydropower design nor used post-award by construction contractors or the U.S. Army Corps of Engineers construction managers during the construction phase of the project.

Building information modeling systems are beginning to see an increased use in the hydropower design and construction sectors in recent years. Due to the increase in complexity, variability, and uncertainty in hydropower engineering, project participants and stakeholders are increasingly cooperating in a collaboration network, which enables them to share risks, information, and resources, as well as explore new experiences to jointly participate in the management of the large-scale projects [4].. The BIM 4D model can serve at this collaboration network to communicate key project aspects and risks to stakeholders. Within the U.S. Army Corps of Engineers hydropower design, operation, maintenance, and rehabilitation sector, BIM is not used in any facet despite being mandated by policy. Positive results may be revealed should BIM be introduced on future projects to aid in the review, visualization, and communication of the complicated drawings; as well as in the field during construction to ensure correct and quality work is being performed.

2. Background

2.1. Advantages and Disadvantages of BIM Utilization

The value of BIM in construction comes in many shapes and sizes. Whether it is the ability to save time through automated functions, eliminate the need to travel to a meeting, or save money because better information is available earlier to make cost effective decisions, all items have the same focus - results [5].

Traditional methods of the engineer or consultant providing design information through two-dimensional paper drawings continue to be the prominent way that substantial amounts of information

are conveyed in a succinct manner however reviewers and readers of the drawings require certain technical knowledge to interpret the information. It can be surmised that non-professionals may have difficulty understanding technical 2D drawings, which could prove virtually impossible without professional input [6]. Next, couple the complications with sequencing the activities of construction using the common Critical Path Method or network diagram on a Gantt Chart often completed by Project Managers that may not have the required technical expertise.

Building information modeling and its work-streams such as 4D planning has been an area of interest and discussion for the past decade in both industry and academia-oriented literature, and are considered among the major drivers for change in the construction industry [7]. 4D planning combines the 3D graphical perspective of a model with the time dimension of a construction schedule which allows for construction operations to be viewed sequentially as a virtual simulation, with the model containing logical, temporal, and spatial aspects [8].

The fundamental transformation of the industry standard 2D and 3D drawings to BIM and 4D planning has advantages and disadvantages that industry participants must all consider. Some advantages are improved communication of design through graphical representation; improved efficiencies with the operation and maintenance of modeled facilities through material identification and tracking; improved management of the project team by providing all information in model form to all personnel in real time; and quality management improvements through better organization and visualization of the work by all parties. Some disadvantages shared across industry have been the considerable startup costs and investments in software, training, and maintenance of hardware; non-use of BIM or 4D planning by stakeholders or subcontractors; basic resistance to change; and potential loss of proprietary information through open sharing between disciplines.

2.2. BIM for Construction Management and Quality Management

Building information modeling continues to redefine the way the construction sector builds and works together. The core value of BIM that the construction industry should be aware of is the ability to take model information and extend its use by giving it meaning for other related workflows and processes. These workflows include impacts to basic functionality such as estimating, scheduling, logistics, and safety. These new capabilities have opened doors for faster population of data into these systems to deliver work earlier, safer, and with better quality [5]. BIM is not only a three-dimensional model of the building or subassembly – it is much more. BIM serves as an information rich database that links the model pieces or components, often referred to as parametric modeling. BIM systems have the ability to edit, sort, and compile data for parts, assemblies, and other model components to make decisions on logistics, develop plans for installation, allow for accurate quantity tabulation, and to store component data, such as pipe and fitting material, in the model for recall later in the field.

Communication and visualization of risk constitutes the additional benefits of the BIM 4D model during construction. It is key on large construction projects that decision makers understand the risks very well. Traditionally, risks are communicated in a tabular form as a risk inventory and communicated via Gantt charts and reports. 4D BIM based applications combine the three-dimensional representation of the construction design with the construction schedule. This aids key leadership to visualize all stages of the construction process in both time and space [9]. The case study referenced in the Hartman et al paper indicated that project management did not see a benefit of the 4D model to the risk analysis of the project until the model was properly configured in a way that puts focus on a particular risk location and the time it may occur. The model provides visualization so risks can be clearly communicated.

2.3. BIM Utilization within Hydropower Rehabilitation Programs

Within the hydropower rehabilitation sector of the U.S. Army Corps of Engineers, the use of BIM is non-existent. Power plants owned and operated by the U.S. Army Corps of Engineers were designed

and constructed many decades ago in an era spanning hand drafting to the early phases of computer aided drafting and design. Drawings from the original equipment manufacturer (OEM) may not exist anymore and digitizing drawings has not been a priority. These issues, common to many existing facilities, could be improved through utilization of a BIM system when major rehabilitation of the facility begins. The USACE Roadmap for the Life-Cycle BIM special report describes a decision-making process for leaders to take with respect to initiating BIM creation for an existing facility.

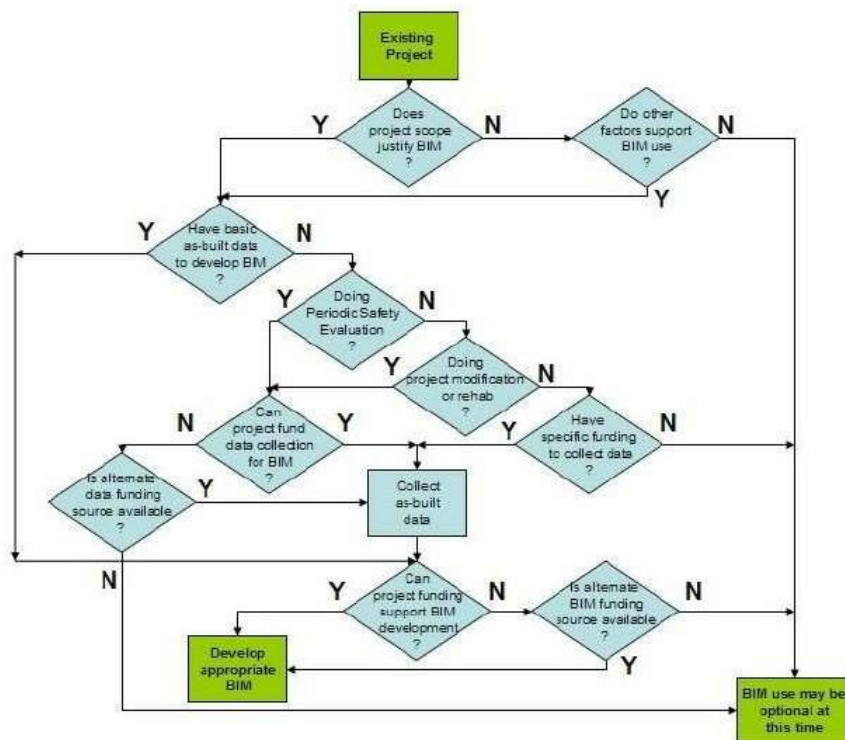


Figure 1. BIM Decision Flowchart for Renovation/Expansion Projects [3]

In the case of major rehabilitation projects for hydropower generation units, there are not many cases where the funding necessary for BIM development of existing facilities could not be justified. Based on the decision flowchart in Figure 1, most, if not all, hydropower rehabilitation projects could be candidates for new BIM being created for the existing generation units and power plant facility. Also, based on the previously referenced USACE Roadmap document, for all projects, BIM usage is mandatory for design authoring, design progress reviews, design interface management (3D coordination), construction interference management (3D coordination), and construction record modeling. All the mandatory items could have a large positive impact to the design and execution of a hydropower rehabilitation project.

Hydropower plants consist of complicated mechanical and electrical systems installed with exacting tolerances, sometimes in very tight or hard to access areas. The following figures aim to depict excerpts of two-dimensional construction plans for rehabbed systems that are prime examples of the type of work that would benefit from BIM integration. In a BIM model, individual components of the piping system could be selected and the embedded properties of that component can be annotated with the material, size, and other intrinsic data for the component that can be used by construction management personnel to ensure proper installation without having to cross reference with a separate bill of materials on other digital or paper pages.

Likewise, the mechanical two-dimensional drawing listed below for a typical wicket gate mechanism with its reference part numbers could be rendered into a BIM database with similar material properties entered as listed above to aid in the installation and quality checking.

Hydropower projects executed within the U.S. Army Corps of Engineer typically use the EPC delivery strategy (Engineering, Procurement, Construction), one of the most popular in the energy sector. EPC projects offer outstanding advantages of resource allocation, reduction of project costs, effective control of progress, and reduction of project risks [4]. Adequate communication and collaboration are deemed a substantial precondition of successful project delivery and BIM and 4D planning is becoming the best platform for the collaborative management of projects and data.

2.4. Applications of BIM in U.S. Army Corps of Engineers Construction and Quality Management

The focus of BIM implementation within USACE was for the Military Construction program (MILCON), with the Civil Works program (CW) lagging by approximately four years from the start of BIM usage implementation. This is counterintuitive as USACE has a more comprehensive role in the life cycle of CW projects as compared to MILCON projects. In MILCON, the USACE serves as the design and construction agent with handoff of the project to the Army, Air Force, or other customer upon completion of construction whereas the USACE role in CW projects typically covers the entire facility lifecycle. This strongly implies that USACE would derive enhanced benefits by formally implementing BIM for Civil Works [3]. Hydropower rehabilitation programs within the USACE fall inside the Civil Works purview and would thusly benefit from BIM implementation of the hydropower facilities during major rehabilitations.

Traditional construction management typically consists of inefficient exchange of construction information through conversation, excel spreadsheets, email, and redline drawings. In contrast, BIM-based construction management emphasizes the use of information and the transfer of that information through the integrated model to the entire project team. The integrated model contains not only material properties, detailing on specialized connections, but procurement tracing, schedule data, clash detection, the ability to make as built or design changes in real-time with collaboration, among other significant benefits.

With respect to quality control, should field engineers detect quality issues, the problems can be described with related components using photos, panoramic photos or videos, and proposed solutions for corrective action annotated to the BIM integrated model. The solutions are transferred to all necessary parties and stakeholders within the BIM collaborative system, then transferred back to the field engineers with approvals to begin the corrections. Corrective actions are taken by the field engineers and the entire quality issue is resolved in real time within the model with all documentation and communication saved to the model for future recall if necessary. This real-world example outlines the future of BIM usage in the field to streamline quality control.

2.5. Purpose of the Study

The purpose of this study was to research how Building Information Modeling is being used within the U.S. Army Corps of Engineers, specifically within hydropower rehabilitation programs, for design and construction management. Research also focused on how private industry has been and is currently using BIM in construction management, and to correlate how processes used in private industry may be used on hydropower generation unit rehabilitation projects at USACE-owned facilities.

3. Research Methodology

In addition to the literature review conducted and discussed in the Background section of this paper, interviews with key U.S. Army Corps of Engineers personnel involved in design management of military and civil works projects, hydropower design, and construction and quality management with a focus on

hydropower rehabilitation projects were conducted. The interview questions were designed to illicit the interviewee's direct experience with BIM in their respective fields, how that experience aligns with current U.S. Army Corps of Engineers policy on BIM usage, and their overall feelings on the usage of BIM in their field and how it could help or hinder the work. Questions for the interviews touched on three major areas:

- Utilization and training.
- How the interviewee feels about the utility of the BIM systems for their particular role in project delivery.
- The interviewee's opinion on how BIM could be used in other methods within the U.S. Army Corps of Engineers mission set to better deliver projects and programs.

4. Data Analysis and Findings

The following paragraphs outline the interview questions and responses received from each of the interviewees.

1. *In your line of work, do you utilize any form of building information modeling (BIM) software to design, review, and/or manage MILCON and/or CW projects for the USACE? If so, in what capacity and provide an estimate of the amount of use of a BIM system.*

This question, regarding utilization of BIM in the interviewee's respective role, returned results as expected with heavy BIM usage and training from the design manager responsible for MILCON construction projects and little to no exposure for the hydropower design engineer or the field construction manager. This result indicates BIM usage only with MILCON program work in the design phase. The design manager indicates that BIM is used for all MILCON projects as a basis for developing design drawings, generating quantities, running structural analyses, and clash detection.

2. *What has been your training within the USACE on the implementation and use of BIM systems?*

The design manager was the only to respond that training was provided by the USACE to properly utilize BIM systems. He indicates that the USACE has a contract with Bentley to provide training and support the Bentley AecoSim software, as well as technical support from Bentley. This response indicates that the USACE is making a considerable investment in the BIM technology and its employees.

3. *Were you aware of the document: ERDC SR-12-2 The US Army Corps of Engineers Roadmap for Life- Cycle Building Information Modeling (BIM) published in Nov 2012? If so, to what extent and do you utilize the policies and directives in this document? Have there been any roadblocks to this policy implementation? If so, explain.*

None of the persons interviewed were privy to the ERDC SR-12-2 document mandating usage of BIM systems for all USACE projects. This could be due to the age of the document or it possibly being superseded by a new document. Nevertheless, the "BIM Roadmap" directing specific usage of BIM does not appear to be widely known or referenced currently.

4. *What do you see as the USACE's biggest difficulty to widespread utilization of BIM in the design, management, and construction of MILCON and CW projects?*

The design manager reiterated that BIM is used widely for MILCON projects however IT support internal to USACE is the largest hindrance to optimal usage. For example, updates for the software suites are issued yearly however USACE G6 continues to be very slow in approving the software update to be installed onto USACE computers. This causes issues with version conflicts as our contracted AE partners may use a newer software version for models the Government needs to review, however

USACE G6 has not approved the install yet. So, while BIM systems are required to be used it appears that USACE values network security over software modernization which hinders the overall efficiency and communication benefits of the software implementation.

5. *Do you believe BIM would be a helpful tool in the (design/project management) of (new construction/hydropower rehabilitation) within the USACE mission? If yes, how so? What are the direct and indirect advantages in your opinion?*

All respondents indicated that BIM and the associated necessary training on use of the systems would be directly beneficial to their work. The design manager indicated that BIM is essential to his work and it is the only time- effective means to produce construction drawings for a vertical construction project. He continued that the greatest benefit is being able to generate the model based on the designer's intent and having the sheets generated automatically. He also noted that the USACE is not at the stage to just provide the BIM to the contractor for construction, but the BIM is used as a visual tool for the effective communication between the USACE, AE designer, contractor, and stakeholders.

The hydropower engineer believes that BIM of the power plant and its various mechanical and electrical systems would be very beneficial to both his line of work and the operations and maintenance of the plant. Having detailed systems model of water-cooling systems or electrical bus ducts would greatly aid his work designing rehabbed or replacement systems inside existing plants.

The construction manager thought that BIM is appropriate for select CW projects. While modeling of an entire power plant including existing mechanical, electrical, piping, and structure, would be ideal, he did not think it would ever be undertaken by the USACE due to cost. BIM for new improvements or rehabbed systems should be required and would be a very helpful tool to better understand complicated designs, assemblies, and systems. Also, having material data on hand in the model and being able to access it in real time would be a game changer in terms of inspection.

6. *What are the disadvantages to BIM utilization for (design management/hydropower rehab design/hydropower rehab construction management)?*

The design manager indicated that too much trust and reliance can be put on BIM in the design phase of work. He indicates that the software can only produce a model based on the data that is put into the system – it's not a replacement for design, only a compliment. He has seen young engineers want to use BIM to complete the design but forget the need to run calculations to verify and backcheck the program. Another disadvantage mentioned was clash detection. By this he means that on rare occasions clashes are found in the field and the construction contractors push the engineer to make corrections in the model before fixing in the field. Prior to BIM when clashes were found, contractors made the field changes and redlined the as-built prints which was a faster fix then making the engineering make the model change first.

The hydropower engineer opined that BIM may not be powerful enough to capture the complicated hydraulic performance of the turbine-generator system, i.e. cavitation modeling, pressure pulsations, water hammer, etc.

The construction manager believes that resistance to change and lack of training are the two biggest disadvantages to BIM implementation in the field for construction management. So many of the USACE construction managers have been performing quality assurance by 2D plans and specifications for so long that use of a new technology may not be widely adopted. Additionally, he was wary about sending all field personnel to specialized training in order to be able to use the program being cost effective.

7. *Do you perceive other advantages to BIM utilization within the USACE mission set outside of your expertise besides design and the benefits that come from having a three-dimensional model?*

The design manager reiterated previous benefits including quick production of construction plan sheets, rough quantity generation – this feature is not trusted yet, clash detection, and use of the model a communication tool to stakeholders. The hydropower engineer and construction manager had no other input to this question.

This question was aimed to illicit some deeper thought on the future of BIM systems to other aspects of the USACE mission set. For instance, hydropower operations and maintenance personnel utilize an antiquated computer system that tracks maintenance hours and work activities in the power plants through work orders. If new materials or parts are required, one would have to search in unorganized purchase request files stored in a separate database to ascertain basic information to place orders. I can foresee a BIM of the plant where mechanics or electricians can select individual system components and enter work history, find part numbers and past procurement data, and track hours worked on systems.

8. *Consider remodeling or rehabbing existing USACE facilities that do not have BIM data: in your opinion would the added cost to develop a BIM file for the existing facility in conjunction with the project be value added?*

The interviewees were split on this question with the design manager not seeing the benefit to spending money and time to model an existing building/structure, while the hydropower engineer and construction manager believe it would be value added since making more information readily available can be seen as a cost savings over the lifespan of the project. The responses being split as they were is interesting; the design manager role who typically deals with new construction sees no benefit to modeling existing buildings however the two others who work hydropower rehabilitation projects see the benefit likely due to the reoccurring trend of not having adequate as-built data at pretty much all power plants.

9. *Do you have any final thoughts or opinions on the usage of BIM with respect to your specific job duties and responsibilities?*

The design manager reiterated that he mostly uses BIM as a communication tool and the designers use it as a document production tool. BIM should be treated appropriately and not be used as a replacement for hand calculations. He adds that the USACE MILCON customers are not using the BIM to conduct design reviews, they only look at the 2D drawings typically.

The hydropower engineer indicates that BIM systems would be highly beneficial to him outside his focused discipline of turbine-generator rehabilitation and replacement but indicates that BIM should be more heavily utilized for the power plants to model complicated mechanical and electrical systems as well as the building and structure.

The construction manager indicated that the sooner BIM systems are introduced for hydropower rehabilitation projects, the better. He discussed having the ability to have the plant model with the newly designed components on a laptop or tablet that he could take in the field and use it to inspect work-in-place and document deficient conditions. The model, being interactive, could be used for the contractor to propose repairs and visually communicate other issues. Genuine excitement for possible future uses was evident.

5. Conclusion

Building information modeling systems are incredibly powerful tools that are becoming widely used in many major sectors of engineering and construction. Collaborative design and the ability to review,

comment, and correct in real time are major improvements over traditional computer aided drafting systems. Utilization of BIM for geometry (3D), timeline/scheduling (4D), cost estimation/budget analysis (5D), sustainability (6D), and facility management (7D) and the inherent benefits to efficiency and communication cannot be replicated by other systems on the market today.

For almost two decades, BIM has grown in popularity and use across the globe. The U.S. Army Corps of Engineers recognized early in the first decade of the 21st century that BIM would be the advanced modeling process that supports collaboration among the project delivery team members and stakeholders; and that a design generated through the use of advanced modeling tools virtually represents the physical and functional features of the project while embedding important life-cycle information and data specific to the design is the future to collaborative design and communication (USACE ECB 2018-7 Advanced Modeling Requirements on USACE Projects -- Category: Directive and Policy | WBDG - Whole Building Design Guide, n.d.).

Building information modeling systems are widely used by the U.S. Army Corps of Engineers in the MILCON program and required to be used by policy. BIM is used heavily for visualizing the design and creating 2D plan sheets rapidly and efficiently. BIM is also used for rough quantity tabulation for cost estimates. Perhaps the most value that BIM brings currently is the ability to use the model to effectively communicate complicated project design between the engineers and the project stakeholders and owners.

Perhaps the most untapped use of BIM is within the U.S. Army Corps of Engineers hydropower rehabilitation program. The capabilities of BIM in modeling complicated mechanical and electrical systems that exist in a hydroelectric facility, as well as the ability to store untold amounts of data on each mechanical or electrical component for future operations and maintenance use is an immense untapped resource. Although modeling existing power plants that range in age from 50 to 100 years old would be daunting, the benefits of the model in the capable hands of power plant engineers would open doors to new methods for modern operations and maintenance management.

References

- [1] A Brief History of BIM. ArchDaily. [Online] 2012. Available at: <https://www.archdaily.com/302490/a-brief-history-of-bim>.
- [2] L. Chen, and H. Luo. "A BIM-based construction quality management model and its applications" *Automation in Construction*, 46, 64–73, 2014. doi.org/10.1016/j.autcon.2014.05.009
- [3] Engineers, U. S. A. C. of. [Online] 2012. "The US Army Corps of Engineers roadmap for life-cycle building information modeling (BIM)," In D.W.M. Chan, T.O. Olawumi, and A.M.L. Ho. "Perceived benefits of and barriers to Building Information Modelling (BIM) implementation in construction: The case of Hong Kong," *Journal of Building Engineering*, 25, 100764, doi.org/10.1016/j.jobbe.2019.100764, 2019.
- [4] S. Zhang, F. Pan, C. Wang, Y. Sun, & H. Wang. "BIM-Based Collaboration Platform for the Management of EPC Projects in Hydropower Engineering," *Journal of Construction Engineering and Management*, 143(12), 04017087. doi.org/10.1061/(ASCE)CO.1943-7862.0001403, 2017.
- [5] B. Hardin, and D. McCool. *BIM and Construction Management: Proven Tools, Methods, and Workflows*, 2015.
- [6] M Fischer, and C. Kam. "Product Model & 4D CAD-Final Report. Project Micromanagement: Practical Site Planning and Management of Workflow." IGLC-12, *12th Conference, Center for Integrated Facility Engineering*, 2002.
- [7] M. Kassem, T. Brogden, and N. Dawood. "BIM and 4D planning: A holistic study of the barriers and drivers to widespread adoption," *Journal of Construction Engineering and Project*

- Management*, 2(4), 1–10, 2012. doi.org/10.6106/JCEPM.2012.2.4.001.
- [8] J. Kunz, and M. Fischer. *Virtual Design and Construction: Themes, Case Studies and Implementation Suggestions*, Stanford University, Stanford, CA, 2012.
- [9] T. Hartmann, H. van Meerveld, N. Vossebeld, and A. Adriaanse. “Aligning building information model tools and construction management methods,” *Automation in Construction*, 22, 605–613. doi.org/10.1016/j.autcon.2011.12.011, 2012.