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Integrated BIM and Design Review for Safer, Better Buildings

How project teams using collaborative design reduce risk, creating better health and safety in projects

June 2007

Educational Advertising Section Provided by NavisWorks

By C.C. Sullivan

Most architecture, engineering, and construction professionals agree it's a foregone conclusion: building information modeling (BIM) heralds a new era in project delivery. Yet what's most significant today is the expanding power and benefit of BIM—the collaboration tools that enhance and integrate these database-driven, 3-D-capable applications. And the benefits of these BIM-driven solutions now accrue directly to facility end-users and occupants.

"BIM has moved from if to when, and from when to how, which is what people are focused on now: Establishing a common understanding of what has to go into the model when it moves from the design team to the construction team," says Rick Lowe, a partner in the Philadelphia law firm Duane Morris LLP.

On the one hand, BIM applications and add-ons allow project teams to enhance the sustainability and safety of their buildings. On the other hand there are design-review tools that allow disparate BIM platforms to communicate seamlessly, furthering and ensuring the same goals. These graphically explicit applications also support strong teaming environments and help ensure that the project vision is shared among all stakeholders. The result includes less risk for the team, the client, and the authorities having jurisdiction (AHJs), as well as safer, more effective structures for the owners and occupants.

Imagine the integrated delivery of a project. The architect has a BIM model; the mechanical/electrical/plumbing (MEP) engineers have a BIM model; and the structural engineer and other consultants may use BIM as well. Then the contractor has a model for use in phasing and sequencing the work, and major suppliers—the structural steel fabricator, for example—use a 3-D environment to detail and fabricate building components. Ideally, these "authoring tools" should interconnect: they should either be created with the same applications or "flow" from the originating architect/engineer's or owner's BIM model.

Continuing Education

Use the following learning objectives to focus your study while reading this month's ARCHITECTURAL RECORD / AIA Continuing Education article.

Learning Objective - After reading this article, you should be able to:

1. Apply the productivity and safety benefits of operating in a collaborative design process.

2. Communicate the use of 3-D graphic design tools across multiple organizations using diverse technology platforms, resulting in better, safer outcomes.

3. Evaluate the use of integrated design tools, BIM and design review for reducing project uncertainties, waste, risk, and creating safer projects for owners and developers.

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In reality, however, there may be four different BIM solutions used by these various "authors." So design review, or a collaborative production environment, is critical to ensuring successful project resolution: greater efficiencies and greater profits. "Without design review there would be no BIM coordination process as we know it today," says Mieczyslaw (Mitch) Boryslawski, Assoc. AIA, of View By View Inc., a BIM consulting firm based in San Francisco. "There are off-the-shelf display technologies available in which one can assemble such a large amount of 3-D data into a single model," says Boryslawski. "The compression technology and the ability to assemble large and complex 3-D models from almost any CAD application makes this application a must in the project-management tool box."

BIM was used extensively to design and coordinate the new Frederic C. Hamilton Building at the Denver Art Museum. The results helped to improve safety on the job site as well as improve the safety and health of building occupants and visitors.

Denver Art Musuem, Frederic C. Hamilton Building, CO, USA
Courtesy of Arup, New York, NY

As BIM authoring tools have become easier for design and construction firms to adopt and for professionals to learn to use, so has coordination become more accessible. "A design-review tool is easier to use than a BIM authoring tool," says Matthew Jogan, AIA, an architect with New York City's H3 Hardy Collaboration Architecture, "allowing team members who may not be literate with a BIM authoring tool to engage the model data and participate in the project workflow." One significant benefit is the large reduction in field changes reported by teams using the technologies.

Structural Engineers Report Benefits of BIM
(2006 survey of 1,266 structural engineers)

Significant overall benefits:	77%
Improved schedule/workflow:	59%
Internal production cost cuts:	36%
Project cost reductions:	29%

(Source: Structural Engineer/gostructural.com)

An additional challenge addressed through collaborative design review: “Through integration software, it appears as if it’s in one model, but that doesn’t mean that you can go in and change the model right there,” Lowe explains. “If someone recognizes that a change has to be made, you send that back to the discipline who is responsible for it. In other words, you don’t have the general contractor changing the structural steel design.”

With such improvements in productivity, quality, liability and overall safety, those A/E/C professionals not using BIM are faced with a question: Why not?

Even the marketplace seems to demand BIM. The U.S. General Services Administration (GSA) requires certain BIM deliverables. At a meeting hosted by the National Institute of Building Sciences last year, the GSA’s Steven Smith reported that poorly coordinated A/E drawings result in field difficulties —“inefficiencies, mistakes and delays” that account for billions in waste and a negative impact on facility life-cycle.

In a 2006 survey of 1,266 structural engineers, 77 percent of the respondents reported significant benefits from the use of the technology. About 60 percent listed improvements to schedule/workflow benefits, while just over a third described more efficient production within their firms. Overall project cost benefits accrued to about 30 percent of the engineers, too. The GSA’s Smith noted that interoperable BIM data sharing stands to improve project delivery and ensure facility qualities that better meet occupant needs and make for “safer workplaces.”

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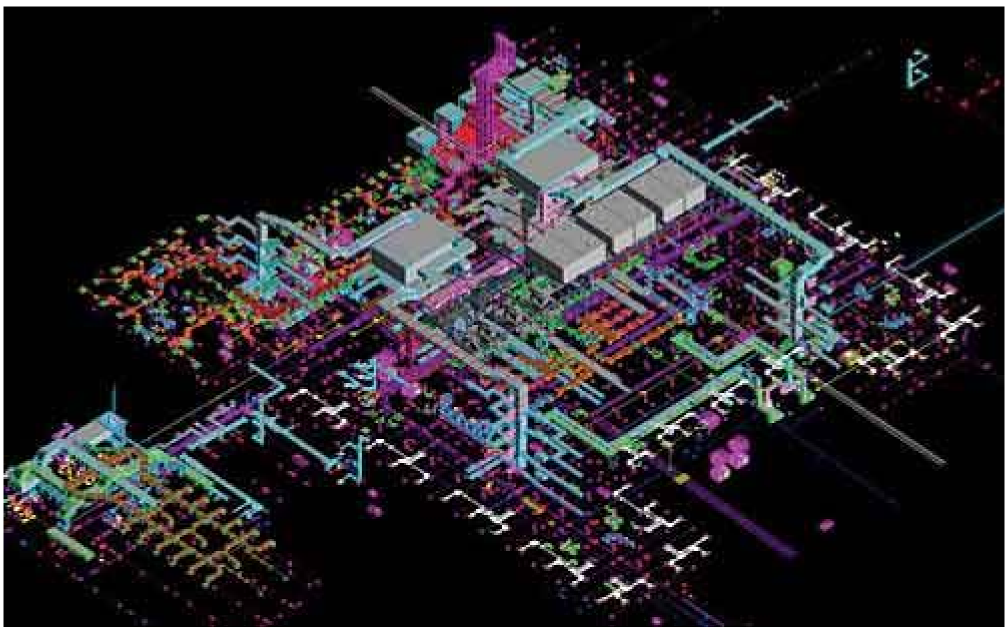
From Productivity to Safety

The rationale for using BIM, therefore, goes well beyond the ease of use of the models. Other reasons include productivity gains, project controls, rapid visualization capabilities, and downstream uses of the database built into the model, such as for facility management and operations.



MEP coordination using BIM and design-review technology can improve designs, system efficiency, job site scheduling and operational safety.

Letterman Digital Arts Center MEP integrated model Courtesy of View By View, Inc., San Francisco, CA.

More recently, however, project teams are leveraging BIM and integrated design review to enhance the health, safety and welfare (HSW) performance of their projects. Such HSW advantages include enhanced building occupant safety. For instance, BIM can be used to analyze and compare fire-rated egress enclosures, automatic sprinkler system designs, and alternate stair layouts. Even finely grained details, such as stair width, rail height, and door swing can be evaluated with BIM to simulate real-world emergency evacuations. Similarly, building accessibility and amenity for occupants tend to be better understood and executed, such as analyzing provisions for users with disabilities.

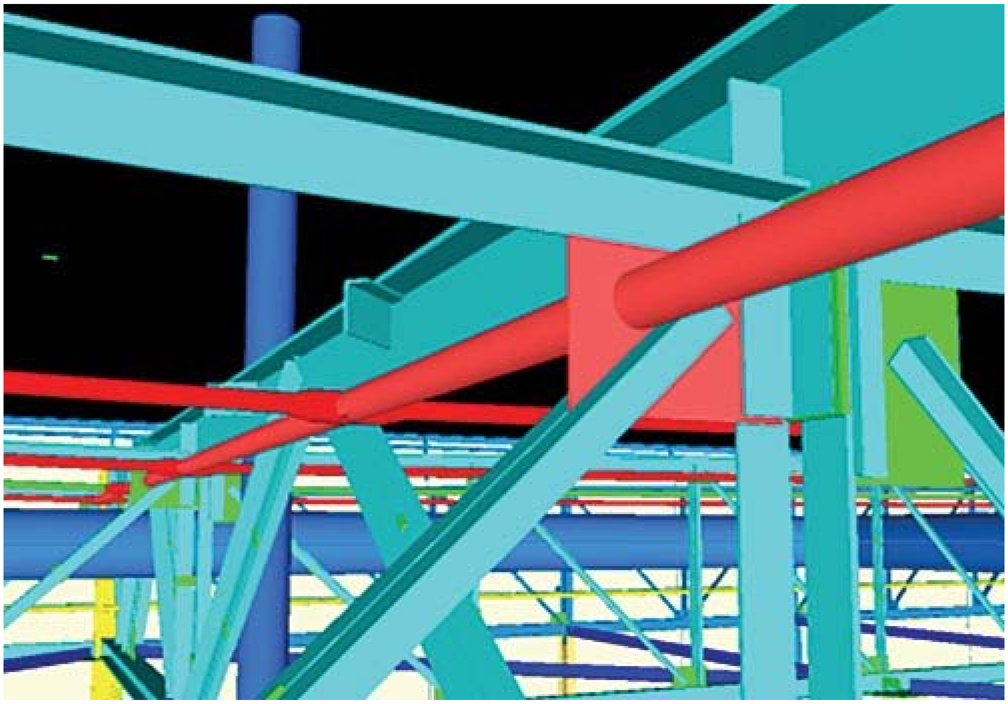
A more commonly lauded quality of integrated BIM is its use in ensuring proper and safe building operations. For example, the proper layout of MEP and fire systems can be verified before mistakes are built in. Called variously “clash detection” or “conflict resolution,” this capability proves effective in holding proper clearances and spacing between various utilities—steam pipes to electrical busway, for example.

For the Letterman Digital Arts Center in San Francisco, CA, BIM and design review were used to simulate clearances for emergency vehicles.

Courtesy of View By View, Inc., San Francisco, CA

Another emerging HSW arena exploits BIM design review to boost project sustainability, energy efficiency, and overall building performance. For instance, BIM can be used to automatically compare engineer and architect schemes, analyze energy profiles, or compare material specifications. These green-building approaches can also have a direct impact on the emotional well-being of occupants, such as by simulating interior daylighting and view corridors to determine optimal availability. Visualization of planned workspaces also allows the direct involvement of owner and occupants, bringing their input on what increases “user comfort” to the design and construction team.

“On some projects the owner has invited maintenance staff to review the model to comment on equipment accessibility and maintenance considerations,” notes Robert Mauck, AIA, P.E., vice president of Advanced Technology with Ghafari in Dearborn, Michigan.



The ability to identify, visualize and resolve conflicts among various building systems is a significant benefit of a collaborative BIM environment.

GM plant structural BIM drawing Courtesy of Ghafari Associates, Dearborn, Mich.

The 2007 American Institute of Architects (AIA) convention highlighted these benefits in a session sponsored by the AIA's Technology in Architectural Practice group. Titled "BIM Best Practices, Best Results," the session covered the use of BIM in analyzing alternatives for building performance optimization, such as minimizing material waste, optimizing equipment use, and creating a safer construction site. The presentation concluded that BIM analysis tools in several categories contribute to sustainable, high-performance buildings.

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Constructability and Coordination

Another place demanding safety is the construction site itself, where the coordination and completeness of the integrated BIM data helps ensure proper scheduling and staging of construction tasks. Some general contractors and construction managers (CMs) also use BIM to reduce the amount of waste on site—an important part of sustainable construction practice—as well as loose material that can be a theft target. Additional uses include facilitating movement on the site and reducing the number of workers needed: the bottom line, fewer human and material resources to complete the tasks at hand.

Less activity on the job site also contributes to a safer construction process, as well as a better liability picture, say some. “The more the team understands what’s going on, the liability issues tend to be reduced,” says Dan Gonzales, corporate manager of Virtual Design and Construction at Swinerton Construction. “In a paper-based, 2-D environment, everyone only understands their piece; but with 3-D, everyone is looking at the same model. And the design-review tool reads so many different models that everyone still has responsibility for their own model, so there is no change in liabilities,” he says. “From that standpoint, I think design review keeps liabilities clear.”

According to The Contractor’s Guide to BIM, published by Associated General Contractors (AGC), the advantages of using BIM include: identifying collisions, such as where piping may run into structural steel; studying what will be built in a safe, simulated environment; reducing errors and corrections in the field; having more reliable expectations of field conditions; being able to incorporate more prefabricated components and assemblies; and comparing of “what if” scenarios for logistics, sequencing, hoisting and other major moves. The AGC also writes that BIM can reduce callbacks and warranty costs.

With its early design review, the BIM process essentially shifts project coordination to much earlier in cycle, says Boryslawski. “The numbers of trades working in a tight area is minimized, and some parts of MEP are assembled off site from the BIM 3-D shop models, also contributing to safety due to fewer people on site during the installation process,” he explains. “And the trades have a clear understanding as to the position of all the items within the confined space.”

Swinerton, for one, reports frequent uses of the BIM model in the field. “We use BIM to plan equipment placement, storage, and on-site conditions, and to tie into our sequencing to really look at how a building is going to built,” says Gonzales. “For example, we use BIM to make sure lower areas are cleared away when you’re placing steel.”

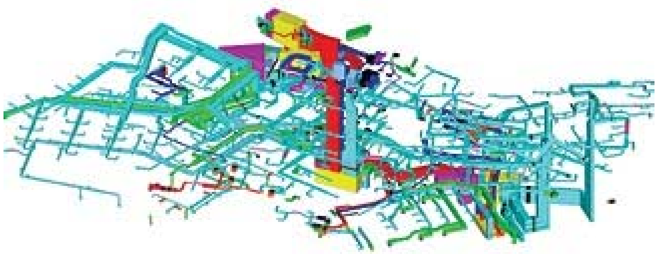
Risk Reduction

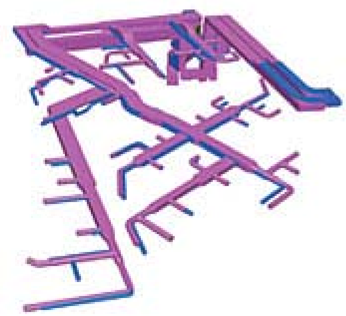
With such significant health and safety benefits in both design and construction phases, it follows that overall project liability, as well as project team risk, can be reduced, too. Issues of design coordination, conflicts, and code compliance can be addressed during design, rather than construction. Projects should have less variability in cost and construction time, along with fewer claims.

“Architects, as well as their consultants, working with a building information model, reduce risk because the model makes the relation of design information explicit within the same virtual space,” says Jogan. “The ambiguity between the architect’s design intent and the ‘fit’ of a consultant’s building system is practically eliminated.”

Denver Art Museum, Denver, CO.

Interior view (left); Isometric view of ductwork (below left); Superimposed isometric view of sheet metal shop drawing vs. design drawing (below)





During the development of the project, strict rules can be applied to police the model, restricting access rights and allowing changes only by authorized project team members, according to Lachmi Khemlani, editor of AECbytes. When versions of the model fall out of date, they can be automatically destroyed or archived, with a precise audit trail. Responsibility for the various models can also be clearly assigned. “For instance, quantity take-offs is not something that the design team should be responsible for any more in 3-D than in 2-D, even though the model itself can generate this,” Lowe explains. “Shop drawings, as well, remain on the contractor side.”

In some recent cases, the BIM model has remained contractually subordinate to 2-D documents, as was the case for work on the Denver Art Museum. In the future, more design teams will rely more on electronic data so that construction pricing, scheduling and detailing can be generated without duplicating 2-D documents. One of the reasons is that BIM tools are becoming available for more construction specialties and vendors. For the Denver museum, according to Engineering News-Record, the model specifically designed for steel fabrication was used to procure other building systems.

http://www.construction.com/ce/articles/0706navis-3.asp

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Such challenges again open the door for BIM design-review and collaboration tools, says Jogan. “They enable architects and their consultants to focus on the work—the design and coordination of a building—instead of focusing on issues about the use of specific authoring tools and limitations with interoperability,” he explains. “In this way, the potential to collaborate with different engineers, contractors, and subcontractors via a model-based process does not get derailed by limitations of various authoring tools to interoperate with each other. BIM is about enabling a model-based process.”

Furthermore, Jogan adds, the collaboration tools are easier to use than BIM authoring tools, opening the doors to more use across the building teams. And the original design information is protected, says Lowe, even as it is accessible through the design review.

All this functionality and explicit information translates into reduced risk. “When this is combined with a workflow process that coordinates and documents directly from the model, there is inherent and immediate coordination between systems within the design documentation,” Jogan observes. “The risk of delivering a design intent that has unaddressed coordination issues between building systems is greatly reduced.”

Healthcare Project Benefits

In certain markets driven by complexity and liability, BIM has been more quickly adopted. One of those markets is healthcare. “I don't know how you'd design and build a medical facility today without using BIM,” said Douglas Fitzpatrick, P.E., LEED® AP, managing member of Fitzpatrick Engineering Group at a national roundtable on BIM. “The need for collaboration among the disciplines is tremendous.”

The use of collaborative BIM signals better outcomes, say experienced project teams. “In the health industry most of the problems occur in MEP construction coordination, and about 45 percent to 55 percent of the total costs of hospital construction projects are in the MEP systems,” says Boryslawski. “Having a fully design-coordinated BIM for MEP will reduce most of the risks associated with healthcare industry projects.”

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GM Pulls Up with BIM
Case Study: General Motors Flint V6 Engine Assembly Plant, Flint, Michigan

GM plant aerial view
Courtesy of Ghafari Associates, Dearborn, Mich.

How is it possible to deliver a project 25 percent faster and 15 percent under budget, with virtually no change orders? The answer is through the utilization of 3-D modeling to promote optimal building team collaboration.

Such was the case with the recent design and construction of a 442,000-square-foot engine manufacturing plant for General Motors. By replacing 2-D drawings with 3-D modeling, the team was able to capitalize on building information modeling (BIM) for design integration, automated "collision detection," construction visualization, shop drawing and constructability reviews and maintenance analysis.

As a matter fact, via BIM's weekly automated collision-detection sessions (review meant to see whether building elements in the design interfere with each other), literally thousands of potential conflicts were detected and avoided throughout the project.

According to Robert Mauck, AIA, P.E., vice president of Advanced Technology for Ghafari in Dearborn, Michigan, the use of 3-D modeling "eliminated rework caused by field interferences, allowing the team to adopt a build-to-the-model approach using increasingly off-site fabrication and just-in-time delivery and construction, which further enhanced quality and site-safety."

One such example where BIM really proved its value was when it came time to order 4,500 tons of steel from the mill. Typically, it takes eight to 12 weeks to issue the mill order to the fabricator, but in this case, the team would have missed the mill-rolling schedule, further delaying steel delivery.

However, since a 3-D model was available, the steel fabricator was able to extract steel quantities directly from the model created by the architecture/engineering firm, Ghafari. This way the mill order was delivered within three weeks of the start of the design, assisting the team to deliver this fast-tracked project in just nine months. In addition, the early availability of this information enabled the fabricator to provide valuable information regarding steel members, leading to additional project savings.

Contractors have also documented specific advantages of using BIM for healthcare work. Steve Mynsberge, a senior vice president for the healthcare segment at McCarthy Building Companies, credits BIM for better handling the complex MEP systems required for hospitals, especially as teams rely more on off-site prefabrication. By using BIM, Mynsberge has seen “better-facilitated outside fabrication” and “better results on coordinating design documents and shop drawings for all the different systems.” Another company, DPR Construction in Redwood City, California, employs BIM design review to consolidate and coordinate 3-D and 2-D hospital project information from fire-protection and plumbing engineers, as well as from the electrical and mechanical trades. In addition to life-safety benefits, DPR expects to realize an average savings of 15 percent or more on installed costs for their fire-protection systems.

But the advantage goes beyond MEP coordination and cost. The Dallas-based A/E firm HKS has used fully integrated BIM to simulate process and material distribution, patient and staff flow, and MEP activities. Detroit’s A/E firm, SmithGroup, and Seattle’s NBBJ have employed 3-D coordinated BIM to check for patient and equipment visibility and access, in some cases in meetings with doctors and nurses who will use the facilities. Such information on clearances and mobility has a direct impact on patient health outcomes as well as the safety and security of hospital operations, say these teams. NBBJ has also demonstrated the efficacy of modeling natural light for the patients and the families.

Then there’s the “virtual treatment room”: realistic 3-D models of patient rooms or surgical suites, to compare patient services and treatment regimens. Considering the rapid changes in medical technology, A/E firms such as Leo A. Daly, Omaha, Nebraska, employ BIM to simulate treatment room design. Using static views and animated walk-throughs, the designers verify clearances and utilities needed to operate the major types of equipment, such as MRIs, as well as the access and accommodations needed for attending healthcare staff.

In a recent article, Graham Condit of Seattle-based Sellen Construction described the application of BIM for “building out interior spaces in an occupied medical facility.” Major safety benefits Condit details include the evaluation of alternate phasing sequences based on ingress and egress routes, infection-control procedures, required operational downtime, and need for temporary spaces. Another phasing consideration is the use of prefab components. On a recent project, according to Condit, the contractor had utilidor racks produced off site, and then installed to connect such services as emergency power, medical gases and chilled water to the new building. The approach reduced labor time on site, maintaining the schedule and ensuring quality.

Beyond helping with long-lead items, Condit details major safety benefits. including the use of BIM to determine access routes for equipment, as well as to mock up treatment areas. “Moving a 30,000-pound MRI machine through a corridor requires advanced planning,” Condit said. “BIM can be used to find the precise date in the construction schedule and the optimal ingress route to ensure successful installation.” Also, as key MEP fittings are often located in the ceiling, BIM allows contractors to pinpoint the locations while maintaining required infection-control protocols.

Last, because healthcare projects tend to include national design teams and remotely located consultants, BIM design-review tools have been used to facilitate long-distance coordination. Boryslawski describes a $450 million hospital project near San Diego taking advantage of the high level of compression in its BIM collaboration technology: The data can be shared over high-speed Internet. “Any changes during the design process are automatically updated within the BIM, then streamlined to the recipients,” he says.

“This design-coordination BIM process will reduce the number of future RFIs [requests for information] normally issued by the general contractor,” Boryslawski predicts. “Once taken over by the general contractor, more intelligent 3-D data can be added to the BIM for their coordination and fabrication processes, so there is only one main source of information coming from the BIM.”

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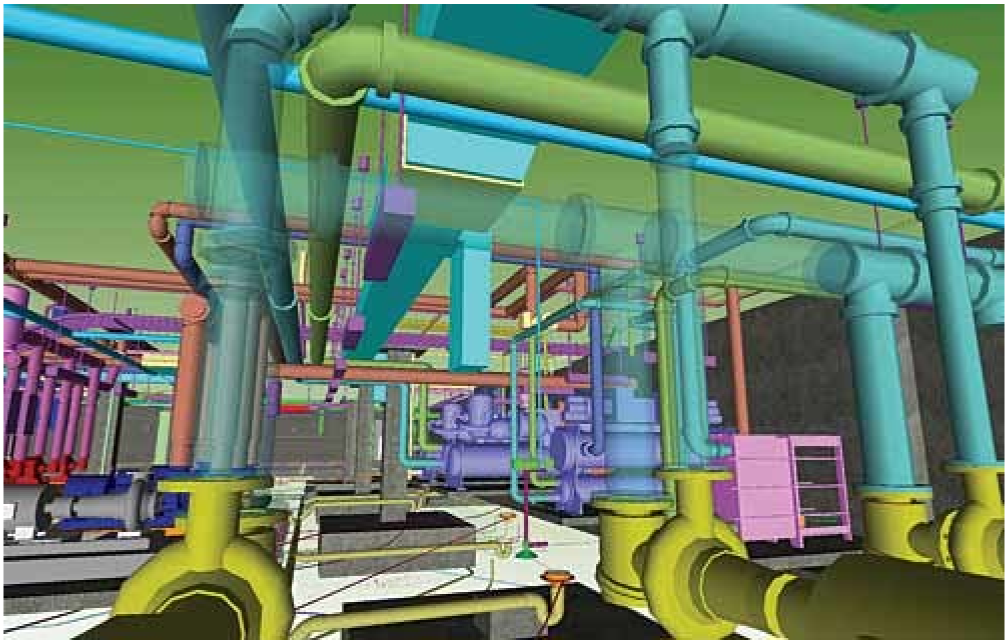
Field Experience on Safety and Sustainability

The focus on HSW considerations has led to some unique advances in the field. Among many authorities having jurisdiction (AHJs), for example, BIM and integrated design review are improving how codes officials handle building inspections, permitting processes, and design and zoning reviews. The Singapore government, for example, now requires all building permit applications to be submitted in a software format that allows for automatic code checking.

The idea is nascent in the United States, with serious attention from the International Code Council (ICC). The group's "SMARTcodes" initiative envisages instant plan reviews and reduced approval cycles. According to ICC, an "automated code-compliance check" employs BIM data and model-checking software. Codes officials may print the results or view the building design in 3-D, with any noncompliant elements highlighted with explanations of the violations. David Conover, ICC senior advisor, adds that the technology allows "interoperable building regulations" to be cross-referenced through BIM, showing whether the designs meet all life-safety and ADA rules. The output could include "redlining" of, for example, non-fire-rated penetrations in fire-resistive walls.



The GSA requires the use of BIM on many projects, as at the new federal courthouse in Eugene, Oregon.

GSA's US Courthouse, Eugene, OR Courtesy of Jeet Mahal, CMG

Another benefit would be instant public availability of information on the building, site access, and any storage of hazardous materials for use by the fire service in disaster planning and response.

Based on interoperable BIM technology, SMARTcodes is similar to the collaborative design review tools. Many of the benefits are alike, too, says the ICC: “By automating and sharing data, building departments can reduce the time it takes to review plans and increase code compliance, allowing staff resources to be shifted to the field to perform enhanced building inspections. Designers and others in the building community can also address code-related issues more completely and accurately prior to permit submittal,” said a recent statement by the group.

While few U.S. jurisdictions have adopted such a process, more AHJs are conducting automated energy analyses, such as with REScheck or COMcheck. Building project teams are much farther along, using BIM for simulations of building performance — for example, ensuring ample daylight and view corridors, analyzing provisions for users with disabilities, or studying life-safety egress.

Another growing trend is the use of BIM to boost building performance and sustainability. In the BIM models, design features and specifications describe quantitative performance attributes, such as for VOC content, energy consumption, reflectivity or solar gain. This gives the A/E team insights into the best orientation and enclosure strategies, as well as layouts and materials that best support occupant health and welfare.

At the end of design, BIM supports A/E firms in the submittal of required drawings and documentation for LEED® certification. Quantification of recycled or recyclable material contents, determination of life-cycle costing, as well as the modeling of energy and daylighting effects can all be accomplished more quickly. According to architect Jim Gleeson, AIA, BIM can be used to “link project information directly to a Web-based MasterSpec LEED specification” or to quantify material content or the recycled content in fixtures and furnishings. The design model can also be linked to such energy-modeling programs as the Lawrence Berkeley National Laboratory’s DOE-2.

According to Martin Fischer, director of Stanford University’s Center for Integrated Facility Engineering, building owners and users can expect improved life-cycle performance when a model is shared among mechanical engineers and others. Fischer has shown that research labs designed using this process have heating energy requirements as low as 20-25 kilowatt-hours per cubic meter, compared to levels two to four times higher for facilities not using BIM.

“Building performance can be tracked within the 3-D space,” says Boryslawski. “One can calculate heat gains or losses and observe the movement of hot and cold air in a form of red and blue 3-D cloud moving” in a BIM model simulation, he explains.

In some cases, collaborative BIM has been effective in evaluating specific user health targets as desired by owners or by LEED® project certification. For the Georgia State University Library, for example, BIM load calculators and design tools enabled the study of shading, shadow locations, and daylight penetration within occupied spaces. (The construction manager also used the data to do cost takeoffs for proposed design alternatives.) BIM was also effective in the team’s elevation studies, undertaken to describe views of the plaza from the interior based on various fenestration designs.

Similarly, simulations for the GSA’s Herbert C. Hoover Building in Washington, D.C., helped redesign an infill structure within the building’s courtyard. The solution included the effects of a green roof and skylight, showing where daylight and cooling or heating needs would change. For the nearby White House Visitor Center and Law Library, BIM modeling allowed the project team to keep ceilings as high as possible, introduce maximum daylight, and integrate new supply-air distribution, all enhancing the indoor environmental quality, or IEQ. The model also helped to determine the needed life-safety egress and to reduce the project’s impact on historic facilities.

For the Eisenhower Executive Office Building, Washington, D.C., in order to address historic guidelines, as well as to ensure security objectives were met, the project team used BIM and a digitized video file to ensure compliance for a rehabilitation introducing new glazing. The results demonstrated the quantity and quality of daylight as well as the impact of shadows, while ensuring preservation and security objectives.

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BIM Case Study

One example of a project team that came to incorporate BIM as part of its best practice involved a new four-building campus and theater called the Letterman Digital Arts Center, or LDAC, to house LucasFilm Ltd. In that case, the use of BIM proved invaluable, credited with saving more than $10 million on the $350 million, 865,000-square-foot project.

By creating a 3-D structural model and then importing the architectural and MEP systems through the utilization of a integrated design-review tool, literally hundreds of design and construction discrepancies were found and corrected throughout delivery of the project, which was built on the grounds of San Francisco's Presidio National Park. "By incorporating the contractor's shop drawings as another layer in this process, additional errors were found which, left unchecked, would have resulted in considerable costs to the contractor and delays in the construction schedule," recalls View By View's Boryslawski.

One compelling example of such a near-miss was caught when a daily round of on-site photography, routinely conducted to compare actual building construction with the digital building model, discovered incorrectly positioned concrete formwork. With three more floors to be built above the floor in question, the error about to be made would have been a serious and costly one. Fortunately, the BIM model confirmed the impending mistake and the contractor's team was alerted, literally minutes before the concrete was poured. Yet another case of BIM providing an important safety check was the discovery of a steel truss penetrating an aluminum curtain wall, during a regular visual conflict check. The error was automatically reported to the project management team, and although the steel frame had already been manufactured by the steel fabricator, it had not yet been delivered to the site, so the frame could still be modified in the shop.

BIM also enabled the owner, George Lucas himself, to actively take part in the design process. "George wanted to see everything digitally before approval, so we were providing him with digital renderings while he was finishing Star Wars in Australia," relates Boryslawski.

Key to the whole BIM process for LDAC was a highly compressed technology to consolidate large amounts of 3-D data from different applications into one model. This design-review tool "reads all the major BIM applications file formats," according to Boryslawski. "Without it, there would be no BIM coordination process." The software's "clash detector" module also came in handy when the team wanted to make sure that the mechanical piping systems installed in the parking levels met the Presidio fire department's height requirement. Similarly, the owner also has the option to perform other emergency simulations such as emergency egress routes.

At the end of the day, utilizing BIM as a virtual design-and-construction tool for the LDAC project did more than identify design conflicts and clashes early, providing cost-effective means to resolve them. BIM also led to better design solutions with “what-if scenarios” developed at an early stage and tested for constructability. Cost estimating was also found to be more accurate than expected. Plus, digital mock-ups of critical areas meant that complex details and assembly methods could be better understood.

In terms of CM, the approach led to lower costs from the subcontractors by providing them with the virtual model and information for their scope of work. Schedule performance was optimized by simulating the best sequences and maximizing the labor crew sizes. The number of change orders and requests for information were modest, too.

Last, George Lucas and his team got 3-D as-built models both for review and for use in facilities management, including all of the MEP and equipment object libraries.

C.C. Sullivan is an author and consultant specializing in architecture and technology.

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