The USC BIM Symposium

# PRACTICAL BIM 2012

## Management, Implementation, Coordination, and Evaluation

July 2012

School of Architecture
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# PRACTICAL BIM 2012:
# Management, Implementation Coordination and Evaluation

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Proceedings of PRACTICAL BIM 2012:
The Sixth Annual USC Symposium on
Building Information Modeling – Management, Implementation, Coordination and Evaluation

*Karen M. Kensek*
*Editor*

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*There's a way to do it better - find it*

– Thomas A. Edison (1973)

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The event could not have happened without the tireless work and dedication of Douglas Noble; he was instrumental in organizing the symposia, creating the handouts and posters, and collecting the conference proceedings. A special thanks to Tamar Partamian and Jinhua Peng for their help in editing this volume.

Thank you!
Karen M. Kensek

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# FORWARD

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The USC School of Architecture has a long and distinguished record of bonds to the building industry, a solid professional orientation in the academic programs, and a spirit of inquiry into all aspects of architecture education. More than two decades ago, the faculty of the USC School of Architecture established digital media as a priority in their research and educational mission. This commitment led to the establishment of the first annual USC BIM Symposium in 2007. Since then, each summer there has been a BIM symposium focusing on a different aspect of building information modeling:

- BIM 2007: Sustainable Design and Education
- BIM BOP 2008: BIM + Sustainable Design
- BIM CON!FAB 2009: BIM + Construction and Fabrication
- BIM Analytics 2010: Performance Based Design
- Extreme BIM 2011: Parametric and Customization
- PRACTICAL BIM 2012: Management, Implementation, Coordination, and Evaluation

The annual USC BIM Symposia attract speakers and participants that represent a cross-section of academics, professionals, software manufacturers, and industry. As BIM requires collaboration across all disciplines involved in the design, delivery, and ownership of the built environment, we have encouraged non-academics to become heavily involved and submit papers for presentation.

The papers in "PRACTICAL BIM: Management, Implementation, Coordination, and Evaluation" demonstrate that building information modeling is not simply a question of specific software training, but that BIM effects the process of design and construction both directly and subtly. Authors have given considerable thought as to how the software tools affect the way we work and communicate. A goal of the symposium this year was to uncover practical advice that the BIM community can put to use immediately. The papers in this collection are deliberately oriented towards functional and directly useful knowledge. Authors were asked to get straight to the point, to avoid hyperbole, and to describe direct experience. Many of the most important voices in advancing BIM come from those who are not skilled academic writers or orators. Evidence from past BIM symposia reveals that those attending have a deep appreciation for these voices and viewpoints. The USC BIM Symposia will continue to be unapologetically pluralistic in its commitment to cross-disciplinary interaction, software agnostic, and optimistic of the role of digital computing in the design profession.

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# BIM TOOLS AND DESIGN INTENT:
## Limitations and Opportunities

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*Dr. Simone Garagnani, Ph.D, University of Bologna, Italy*
*Visiting Scholar, University of California, Berkeley*
*Prof. Roberto Mingucci, Ph.D., University of Bologna, Italy*

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### Abstract

BIM, new design paradigm in the AEC world, is a methodology supported by sophisticated computer tools. At the ending of the 80's in the last century, a family of software products has been developed in order to gradually cover many requirements proper of the BIM approach. Nevertheless some fundamental aspects, although managed by current tools, still show limitations if compared to an ideal perfect world.

After a short summary of the most remarkable items, the paper focuses on the aspects connected with the editing possibilities of a BIM model, which are related to its parametric nature.
Following themes will be discussed:

- nature of BIM objects, used to build/describe the building, including their configuration functions and the possibility to create new object classes;
- methods to define and manage relative positions between objects;
- techniques that allow to record the user's design intent, keeping model consistency after modifications too;
- impact of the above items on users' activity and interaction with BIM systems.

### Introduction

After Interactive Computer Graphics was born in the 60's of the last century (Sutherland 1963), CAD tools started to spread in the AEC professional organizations beginning from the 80's, replacing traditional paper drawings with digital ones (Bermudez and King, 2000). The revolution affected tools, but left unchanged the design methodology, still based on two-dimensional building representations where parametric contribution were primarily intended as a ''solution for reuse of existing designs" (Shah and Mantyla, 1995).

The real revolution in methodology was actually prepared in the academic field since the 70's (Eastman, 1976) and materialized with commercial software at the end of 80's (1); it was based on few basic assumptions:

- design had to be developed making a 3D building model, able to describe the object to build up in a complete way;
- it should have been simulating the building behaviors on different aspects (architectural, structural, energetic, ...) as soon as possible along the design path, in order to make evaluations more comprehensive and effective;
- it should have been unique, consistent and always up to date, in order to avoid any possible misinterpretation;
- all documents needed for design review meetings, design presentation and design approval had to be easily retrieved from the model.

Other goals have been added later, such as the support for team-working in a structured way, the support extended to all aspects related to the entire building lifecycle (construction, management, disposal, ...) and other minor ones not related to the topic of this paper.

This working process, known as BIM (Building Information Modeling)(2), is strongly supported by software tools that allow its adoption. Starting with the very first software presented on the market, many developments have come and brought to users a rich set of functions that allowed the design activity improvement in several ways: quality, reliability in communications, optimized scheduling, error reduction, document management and cost reduction.

But some basic features, even if their effectiveness allows good usage, are still limited or difficult to use. The most important ones that deserve further improvements are:

- the capability to model any geometry with objects supplied by the system or added by the user, keeping all the benefits connected with a complete relations management among building's components, in order to guarantee model consistency during the design process;
- the ability to develop projects since their initial conceptual definition phase, taking advantage of BIM systems. Current software products, too much oriented toward the execution phase, force users to define detailed information since the beginning, so a real top-down approach is still not viable;
- the BIM process application to existing buildings, for renovation, restoration or maintenance activities (Gaiani, Benedetti and Apollonio, 2009). Because of these, the integration between 3d scanning operations and model data should be improved. Bare geometrical data produced by scanning operations are very limited when compared to BIM smart objects, so the only way to get a complete model is to rebuild it, component by component. Very often this takes too long and it is hard to justify;
- the possibility to modify decisions (also in a late stage of the design development or even during the construction phase) assuring the respect of the design intent (Rundell, 2005). This is a very basic concept of the BIM approach, but today's tools are often not suitable for a good trade-off between editing ease on one side, and reliability of the model consistency together with respect of the design intent on the other part.

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Focusing on this last issue, it can be observed that design activity, which follows an iterative path, is hardly dependent from editing functions in order to change, locally or globally, aspects that can be improved (Zisko-Aksamija, 2008). Therefore these functions should be the base of the modeling technology. So it is worthwhile to analyze what are the basic aspects of the technology needed to reach these goals and their impact on practical operations.

### BIM systems parametric structure

Parametric functions, subsequently added to systems whose basic technology was based on solid modeling paradigm, were developed using different approaches (Eastman, Teicholz, Sacks and Liston 2011).

The first aspect is related to the nature of smart objects, used to represent base components of buildings (such as walls, columns, roofs, stairs, beams, ...). Normally these components are supplied with the application (Garagnani, Cinti Luciani and Mingucci, 2011). The system guarantees not only the possibility to control their geometric dimensions, but also their specific attributes and rules to be used when interacting with other components. Each instance of these objects used to build up the model are driven by a set of parameters (for instance dimensions and sill height for windows) end it is easy and natural to change these parameters in any moment obtaining an updated object. It is obvious that components supplied with the system are not able to cover all specific needs, so they must be customized, changing or adding specific features. In some cases user needs are so far from the base component description, that it is needed to define a new class of objects. This can be achieved using specific tools supplied by the system (3) or developing real software applications through specific libraries that allow the interaction with system features and the other objects in the model (API: Application Programming Interface) (4).

A second aspect is related to the positioning of these objects. This implies the generation of a relation chain that the systems can manage in different ways:

1. One approach could be called *parametric-procedural* (Eastman, Teicholz, Sacks, and Liston, 2011, p. 35): it is based on the capture of the relations along the object placement operations. In any moment the system allows the editing of these relations *post facto* and regenerates the model geometry. This approach is generally used for building object models like doors and windows (Figure 1), but it can be used also for generic components. It is very easy and natural to use and it can be presented to the user also through the standard dimensioning features. But there is a limitation: the component placement can be changed only according to the methods allowed by the system. For instance, a window can be placed defining the distance by one of the two ending edges of the wall it belongs to or by another window on the same wall, but not referring to another generic entity in the model.

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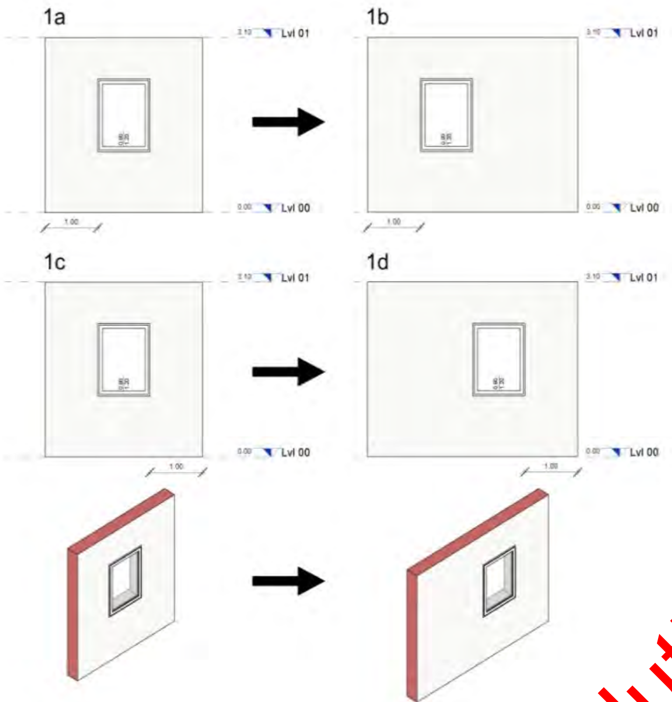


Figure 1. Example of design intent related to the window placement on a generic wall. The system infers rules that control the behavior of the window position even changing the wall dimensions, referring to the annotation mode selected by user. If the annotation that specifies the position is related to the wall left edge (1a), it becomes the constraint, which remains unmodified editing wall dimensions (1b). The opposite happens if the dimension is referred to the right edge (1c, 1d).

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2. Another is called *variational* and it is based on the concept that every component has a specific number of degrees of freedom that can be locked by constraints. Until a component has degrees of freedom, its position is undefined. To make the position of a component known, each of its degrees of freedom must be blocked (5). Constraints can be dimensional or geometric (coincidence, parallelism, alignment, ...) and they can be defined explicitly, by the user, or implicitly, by the system. The number and the type of constraints must be consistent with the degrees of freedom of involved components. This approach is more powerful and in theory allows to reconfigure the model with no limitations. However there are rules that has to deal with the consistency between constraints and degrees of freedom but this knowledge is not part of the typical culture of an architectural designer. Moreover, situations can happen where the complexity is so high that even an expert can find it hard to define the appropriate set of constraints needed to achieve a particular result.

3. In any case, the reciprocal placement of components can also affect their dimensional properties (like a wall limited by other walls or a sloped ceiling). So a network of relations between positions and dimensions of all the components must be managed. Systems generally represent these facts with a *directed graph* (Eastman, Teicholz, Sacks, and Liston 2011, p.37, 38). These kinds of relations, generally managed for components supplied by the system and coded inside it, are not always managed for user created components. In this case the consistency between all components in the model is not completely

guaranteed after modifications. So the user, after a change, must ask himself whether this kind of objects were involved, check them and, if necessary, fix them directly. This can take a lot of time, but, even more important, it can be a source of dangerous mistakes (Roller, 2001).

4. A few systems, in some situations, do not allow to use parametric positioning. Even in this case the user can obtain a modification, using direct editing functions (like move or stretch) instead of changing a dimension. But in this way a complete model consistency is not guaranteed, with the same consequences described above.

5. In other cases, the placement is tied to abstract geometric structures, like parametric grids. Once the grid is placed and dimensioned, the user can place components with respect to it, and changes to the grid affect all the components (Figure 2). Problems can arise if the user wants to move some components individually after the placement referred to the grid. If the system does not allow this operation it should be considered too rigid. If the operation is allowed, what should happen after another modification of the grid? Even more complex situations can arise using complex surfaces as reference, like in free form façades.

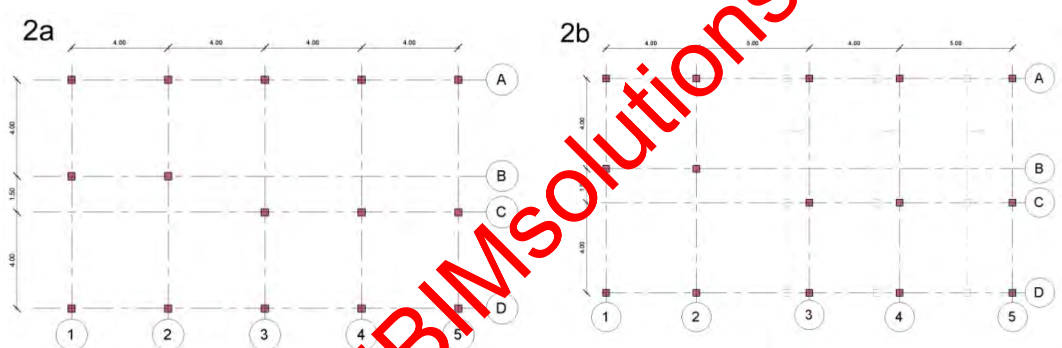


Figure 2. Grid used to place pillars in a building plan (2a). Once grid is defined as parametric, components can easily be placed snapping to the axes intersection: this way they are bound to the grid layout and they will follow all the related changes (2b).

Referring to the above considerations, each BIM system has its own approach, adopting different techniques in different situations, presenting them more or less explicitly in the user documentation (Anderl and Mendgen, 1998). In particular, while some BIM tools show very clearly the constraints structure and supply to the user all tools to manage them (like Gehry Technologies' Digital Project, figure 3), others try to present a simpler environment to the user, hiding this structure (like Autodesk's Revit Architecture, Garagnani and Cinti Luciani, 2011). In the first case the user must know very well the conceptual foundation of the parametric environment; in the second one, everything is simple until the system correctly infers user's intentions; but there can be cases where this doesn't happen and the model doesn't behave like expected; then it can be very difficult to understand what is the issue inside the parametric environment and what must be done to get the desired result. Operations by which the system infers constraints and relations are, for instance, dimensioning functions and connection to specific model points through the snapping functions.

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Figure 3. A refined geometric constraints management avoids interferences and discontinuities, even if models are highly complex as often occurs along the building process. Digital Project for example, software developed by Gehry Technologies Inc. and based on Dassault Systèmes products, allows the constraints definition in order to define elaborate geometries: in this picture the Disney Concert Hall by Frank O. Gehry in Los Angeles (image by Simone Garagnani) and the related HVAC model produced in Digital Project environment (courtesy of Martin Riese, Gehry Technologies Inc.).

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Other systems, allow parametric management for a limited number of situations, the simple ones, leaving to the user full control on the other situations (Monedero, 2000); this way, modifications are supported by direct editing functions (like stretch) even if the system cannot guarantee full respect of the model consistency and design intent. It's up to the user taking responsibility of these aspects.

### Impact of parameterization over design activity

From what presented, it is evident that a correct parametric model set up produces the following advantages:

- design modifications along project development are possible, minimizing the number of operations and focusing the attention locally to the area to be modified (Figure 4);
- models are guaranteed to be consistent; in other words, every modification will not generate unexpected situations (like the detachment of a floor from the external wall or the disappearing of a window, ...)

In some situations these advantages can be achieved only due to a substantial increase in time spent into design structuring, starting from the preliminary phase. It must be noted that, even if the design structuring process outguesses many possible evolutions, modifications needed later along the development reveal themselves not compatible with the previous model organization; in these cases an extra effort is needed to rearrange the whole model.

As a result, if the parametric nature of the model is not correctly represented, or absent, the following facts can occur:

- the design is changed in a specific part, and other parts modify themselves in an unexpected manner;
- a dimension is changed and the geometric change is different from what expected;
- a dimension is changed or something is moved and the system warns that the operation cannot be completed because incompatible with the parametric configuration of the model;
- a user defined component does not behave like expected about its connections with other components within the model.

## Conclusion

As described above, BIM systems employ a set of different parametric techniques (explicit or hidden, mandatory, optional or partially absent). In every case, the knowledge needed to master the parametric aspects in BIM modeling is not easy to gain.

Looking at the future, we can expect improvements in BIM systems in order to minimize information needed to control parametric aspects and more natural and effective tools will be developed, even relating them to existing buildings (Christensen, 2009). On the other hand, the culture of design operators, thanks to a more deep education, will improve. So it will be more natural to manage the concepts of a geometry that is not static and will be easier to take advantage of more and more smarter design aiding systems.

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Figure 4. One of the most noticeable BIM modeler features is the ability to modify a project under its development. In this picture, a "railing" component modeled in detail with Autodesk Revit: parametric constraints introduced by the software are not always sequentially satisfied with the project progress, in this case their subsequent editing and customization is sometimes compromised once inserted (railing do not follow floor in its modification).

## Notes

(1) Radar CH (then become ArchiCAD) by Graphisoft (Hungary, 1984, V1.0) it is considered the first commercial BIM product on the market, followed by AllPlan by Nemetschek (Germany, 1984, first commercial edition)

(2) The BIM term was introduced since 2002. In that year Autodesk, after the use of “Single 3D Building Model Technology (SBM)”, started using BIM talking about its strategy for the AEC market. The same term is mentioned in a white paper of the same year by Cyon Research about ArchiCAD by Graphisoft, that until that moment was referring to “Virtual Building”

(http://wbh.com/WhitePapers/Graphisoft_Virtual_Building_Model–a_Cyon_Research_White_Paper_030102.pdf). In the December 2002 issue of his newsletter, Jerry Laiserin suggests to adopt universally the term BIM for this technology (http://www.laiserin.com/features/issue15/feature01.php).

(3) For instance Nemetschek in 2012, with AllPlan 2012, makes available a language to build user defined Smart Parts (Allplan SmartParts Script)

(4) For instance, Autodesk makes available in 2005, with Revit Building 8.1, its first official API library.

(5) The problem is similar to those related to solve isostatic structures. Every constraint can be represented by an equation. Unknown quantities are the components' degrees of freedom. To get the solutions a number of equations equal to the number of degrees of freedom is needed.

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# BIM LEADERSHIP: Getting Beyond the Technology

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Architectural firms of all sizes from around the world are adopting BIM as both a technology and process with varying degrees of success. There are several reasons why BIM Implementations could succeed or fail on specific projects including buy-in from upper management, previous experience, client expectation, etc. At the same time a common thread throughout successful firms has been leadership. BIM has allowed for new leadership roles to develop within innovative architectural design firms. Focused on digital design technologies the "BIM Manager" (also known as the Director of BIM, Digital Design Leader and many other titles) has evolved as a critical component to the success of a firm's transition to and continued growth with BIM.

In Randy Deutsch's recent book *BIM and Integrated Design: Strategies for Architectural Practice,* he focuses on the idea that BIM has significant social implications that are far more than just technology; he places more importance on leadership. He also goes on to say one's success and progress with BIM occurs where technology, culture and business intersect. This may be a much broader statement than most are accustom to associating with BIM, but it is one that is often true. While design technologies might be one's initial focus, and are undoubtedly critical, there needs to be a solid understanding to the implications this transformation will have on how firms practice architecture.

The BIM Manager, will almost always embody a "T-shaped" personality providing a tremendousadvantage to any firm. In *The Ten Faces of Innovation* Tom Kelley describes T-shaped people as those who "enjoy a breadth of knowledge in many fields, but also have a depth in at least one area of expertise." In today's practice a successful BIM Manager must be able to combine a depth of knowledge in digital design technologies with a breadth of knowledge in: architectural design, professional practice, project management, sustainability, IT management, marketing, project contracts and delivery methods, constructions methods, engineering, collaborative workflows, and many more.
While this ability to merge technology and practice will certainly create a leadership opportunity capable of driving the continued evolution of BIM within a firm, the BIM Manager should also be

developing strategic and competitive advantages that help their firm to win work and produce new revenue generating business opportunities outside of their traditional project scope.

Four case studies will be used to described how DesignGroup was able to build on the leadership of its Director of BIM to not only work more efficiently to create higher quality designs and better project documentation, but also to re-invent what design information is produced and delivered to better inform the clients' decision making process. DesignGroup is a 40 person architectural design firm in Columbus, Ohio serving a diverse range of markets including: Healthcare, Education, Workplace, Civic and Libraries. Additionally, the firm brings a strong emphasis on sustainable design (as seen in their adoption of the 2030 Challenge) to all of its projects as well as an innovative approach to integrating BIM to support these outcomes which has evolved over the past seven years.

One of the ways DesignGroup has evolved their application of BIM beyond the traditional design and delivery process is to push the creation of the model earlier and earlier in the design process. Having the model available during the planning and programming phase achieves a better understanding of the design earlier and stronger communication with the clients.

It has also acted as a catalyst to explore the sustainability of a project and better understand how energy can serve as a formgiver for design. On the recent Battelle Darby Creek Metro Park Nature Center project, the team adopted this workflow and was able to further the development of design by capturing intelligent information about the buildings form, massing, envelope conditions, window to wall ratio, and orientation in Autodesk's Revit Architecture.

| Option A | |
|---|---|
| Exterior Wall Area | 9,473 sf |
| Window Area | 2,635 sf |
| Window to Wall Ratio (WWR) | 28% |

| Option B | |
|---|---|
| Exterior Wall Area | 8,418 sf |
| Window Area | 3,881 sf |
| Window to Wall Ratio (WWR) | 46% |

*Figure 1: Final planning study models and schedules in Revit.*

As the team worked through multiple design iterations, they ultimately developed two final planning study designs. While the programmatic outcomes were similar, they had contrasting site orientations and glazing amounts. Both options were converted to gbXML models and exported to Autodesk's Green Building Studio to run whole building energy simulations where quantifiable feedback on the overall energy performance of the two design options were simulated. While Option B had a much greater amount of glazing, it's massing, window distribution and more favorable solar orientation

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allowed it to outperform Option A by almost 10% (Figure 1).

While Option B helped to direct the overall form of the building in schematic design (Figure 2), more analysis was necessary to further understand how the building would perform and react in its specific climate. The project had specific requirements including expansive views to the outside which lead to a building design with an abundance of south-facing glass. Reacting to this and a desire to optimize daylighting opportunities, the team looked to simulate the qualitative aspects of the design by studying the impacts of different daylight harvesting options in the project.

| Final Schematic Design | |
|---|---|
| Exterior Wall Area | 7,698 sf |
| Window Area | 3,406 sf |
| Window to Wall Ratio (WWR) | 44% |

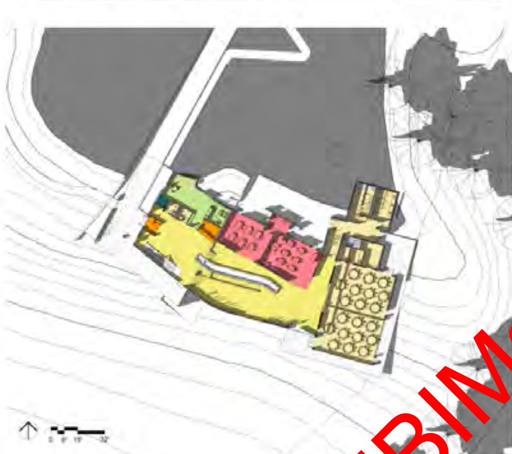

*Figure 2: Final optimized schematic design model in Revit.*

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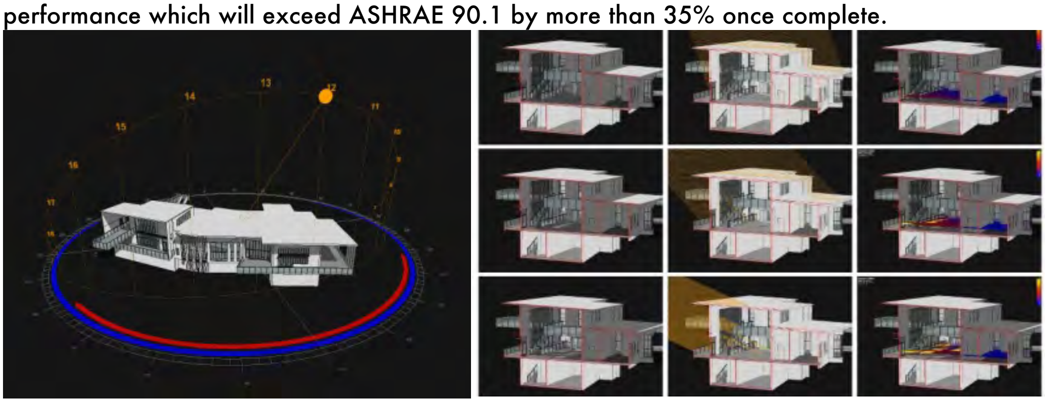
Autodesk's Ecotect Analysis, was used to simulate these qualitative aspects by optimizing shading devices and roof overhangs providing a better understanding of how to best maintain a high level of daylight in the building spaces (Figure 3). This also allowed the design team to validate how their design decisions would maximize and minimize solar gains to have the most positive impact on the building's overall energy consumption throughout the year. Sharing this information in a collaborative BIM environment with the engineers contributed to the design's anticipated energy performance which will exceed ASHRAE 90.1 by more than 35% once complete.



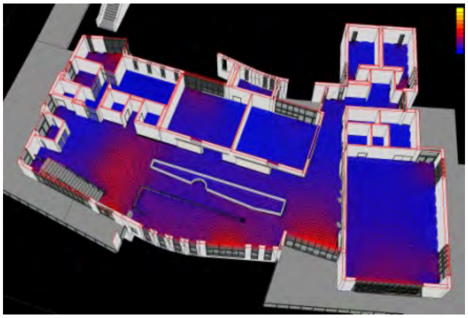


*Figure 3: Daylighting studies and analysis results in Ecotect Analysis.*

This first case study highlights how the "BIM Manager" takes on a research role to better understand what technologies are available in the industry and how they can provide the most value to one's firm. This combined with the ability to quickly learn a design technology and define a series of best practices is an important trait to the position. At the same time it should not be a limiting factor to the BIM Manager's collaborative participation, which may a cause a BIM implementation to not realize its full potential.

The Battelle Darby Creek Metro Park Nature Center project allowed for the Director of BIM's close collaboration with the team to perform and validate these workflows. While the process needed to be adjusted moving forward, it was more important to impart this knowledge on the design team so it could be integrated into their design workflows instead of it being a separate isolated effort.

A second case study, the Alum Crest/Clearbrook Middle/High School project, provided the next step in leveraging BIM during the programming stage when the design team used Revit to define an early visual Program of Requirements (PoR). This was important as the client not only had specific programmatic requirements for their school projects, but they also had prototypical room layouts that would need to be incorporated. Able to embed the owner's required information into the model geometry, the team leveraged Revit, rather than their historic raster based methods, to study spatial relationships and adjacencies. Creating a BIM they blocked out major spaces such as the classrooms, gym, cafeteria, etc., color coding these room objects to create a visual program of space which could be quantified/scheduled and validated against the clients PoR (Figure 4).


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*Figure 4: Visual Program of Requirements (PoR) of the first floor.*

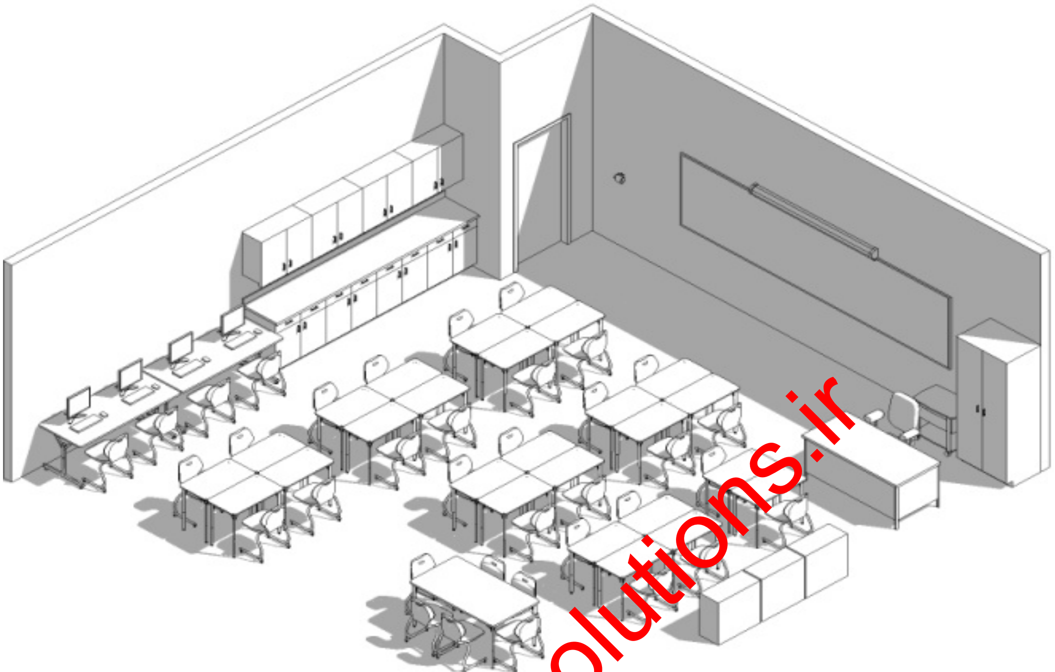

*Figure 5: Prototypical middle school classroom.*

As the design team moved forward with this visual programming effort, the BIM Leadership team created the prototypical rooms that were defined by the client. These 3D building blocks replicated the 2D drawings and schedules of predefined programmatic elements that demonstrated how classroom spaces should be laid out per their size, the number of students, the type of equipment and furniture needed. These prototypical room objects allowed the team to quickly and accurately build out the model evolving from the original visual program elements as they transitioned from programming to schematic design and accelerated the decision making process for the owner (Figure 5).

Having a more fully detailed model at this stage of the project also allowed the design team to focus on some of the larger integrated design and sustainability strategies they were seeking to achieve, including daylighting in the academic core and circulation spaces. While this was an important aspect of the building's overall passive solar design strategy, it was also an important feature that needed to be understood for the optimization of the learning environment for the emotionally disturbed students this school was being designed for. This included additional spaces such as sensory rooms that students use to center their emotions, extended learning areas located within the academic core to allow for more individualized teaching spaces, and sensory gardens that students use to naturally calm themselves.

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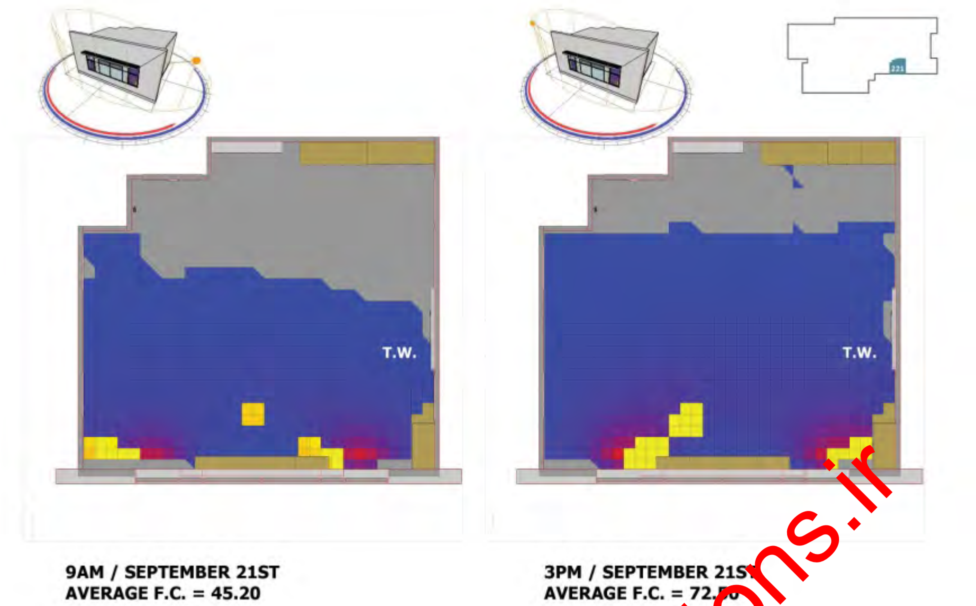


*Figure 6: Typical classroom daylight analysis.*

As the design development phase began, the architectural team exported the Revit model into Ecotect and began to run a series of daylight simulation in conjunction with Radiance to study if the project in its initial design state would meet the illuminance level criteria defined in LEED EQc8.1: Daylighting & Views (Figure 6). Specifically, size and location of window openings, illuminance values, and impact on the building's energy performance were studied and provided yet another opportunity where the firm's BIM Leadership was able to integrate technology into the design process to bringing value to the project's outcomes.

This early model development and analysis proved extremely valuable as the team uncovered that they were only partially meeting the owner's design criteria, but since the project was still early in the design development phase they had the opportunity to revise the design. Able to modify the design and reanalyze the space allowed the team to bring this aspect of the design back into alignment with the project's expectations, which would have probably not been found so early in a traditional design process. This effort also created a more collaborative and integrated design environment with the MEP consultants. Overall the building's design is anticipated to achieve a 12% energy savings from daylight harvesting in the gymnasium, dining and media center. In addition, this effort reduced the amount of lighting fixtures in the classrooms, providing a lighting power density that is 50% less than the 1.4 w/sf baseline requirement.

While clients and designs benefit from the integration of analytical tools with BIM, this new expertise is becoming a competitive advantage and firm differentiator for future projects. In addition, to providing this internal leadership with design technologies, the marketing and business development of this expertise has become a growing and exciting part of the BIM Manager's responsibilities. These responsibilities extend to leadership outside of the office, such as presenting and authoring articles on the value of BIM; both of which further develop the T-shaped personality.

The outcome of this external leadership has been the opportunity to translate BIM expertise into developing new business opportunities creating innovative projects for existing and new clients that



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would have not been possible with traditional technologies. BIM expertise is not only being integrated into the early stages of the design process, but also in the post occupancy stage of the building's lifecycle that include a much deeper understanding of how clients operate and manage facilities.

One such project for DesignGroup was an energy modeling project for Nationwide Mutual Insurance Company. While collaborating with Energent Solutions, who was analyzing Nationwide's carbon footprint, the client expressed a desire to be able to run energy models of their existing corporate facilities. Since there were no digital models of their existing buildings they initially found it to be too time restrictive to retroactively build those models for the desired outcomes. In response, DesignGroup's Director of BIM proposed a more comprehensive idea: create a building information model for their existing corporate headquarters that could not only be used as an energy model but could serve as a foundation for other facility management uses such as, space and lease management as well as other future renovation projects. This would enable them to stay ahead of the industry's rapid transition to BIM from traditional 2D methodologies.

The result was a unique project where DesignGroup was hired to construct building information models for the nearly 2 million square feet of Nationwide's corporate office towers (Plaza 1 and 3; Figure 7) in Revit. Once the models were complete, they were shared with the client via gbXML and .inp files for use in either Green Building Studio or eQUEST enabling them to run various simulations. From these simulations, opportunities could identified for operational improvements and strategies for future capital planning projects that would allow the client to reduce their overall energy consumption.

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*Figure 7: Rendering of Nationwide's Plaza 1 and 3 buildings.*

Due to the highly regarded "firm's reputation for BIM leadership in Columbus," DesignGroup was chosen as the lead consultant for the Facilities Information and Technology Services team at The Ohio State University Wexner Medical Center during their BIM implementation project. It provided a unique opportunity for partnership and collaboration between the firm's BIM Leadership and Ohio State.

The team developed a well-defined multi-phased approach to transitioning the Medical Center's 53 existing buildings, totaling more than six million square feet, of 2D CAD information into a BIM environment (Figure 8). While the first phase focused on the development of standards/templates, process/workflow integrations, and the development of a series of customized training sessions, the ultimate value of this implementation was the focus on the entire staff which included a diverse range of users at the Medical Center who would take full advantage of the building information models once created.

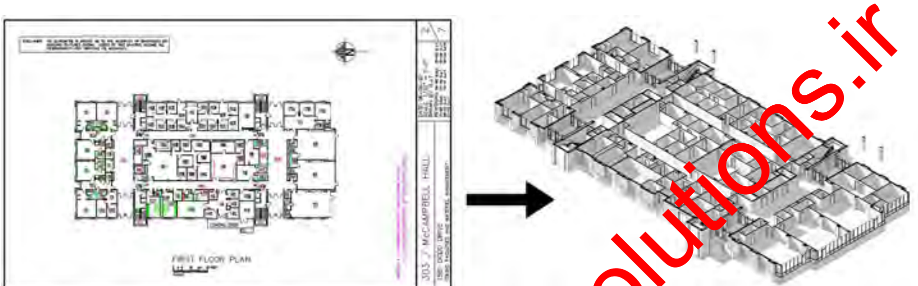


*Figure 8: Sample conversion from AutoCAD to Revit Architecture.*

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The overall project goal was to have the models enhance space planning and communications. This would result in improved quality and increased speed of the decision making process regarding: facility use, building renovations, maintenance, wayfinding and energy consumption. While these goals are currently being realized through this collaboration, there have also been a series of unexpected and positive outcomes for the client. This project has provided an additional level of improved accuracy to the Medical Center's existing building documentation and allowed a higher quality of data and visualization opportunities to be available especially for project funding and donor recognition opportunities (Figure 9).

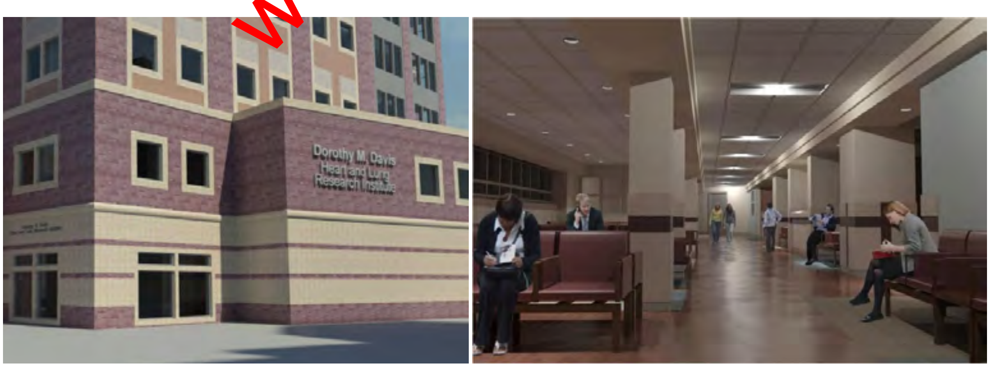


*Figure 9: Renderings for project funding and donor recognition renderings opportunities.*

BIM is providing the opportunity to transform a firm's design process for the better, but shouldn't be limited to designing and documenting projects in a new technology. While the case studies in this paper highlight the continued development of BIM and the BIM Leadership at DesignGroup it should be noted that it has not only been an anecdotal evolution. Through the continued leadership of DesignGroup's Director of BIM new processes capable of providing quantifiable building performance improvements on projects that were not accessible with previous workflows have been integrated into the project's design process.

In addition, a unique external leadership role has emerged providing business development outlets for the firm to be recognized as an industry leader in the application of BIM which is opening the doors to winning new work and creating new revenue generating opportunities.

While the technology is readily available for architects to take advantage of, leadership will remain a critical step to ensure its success within any organization. Empowering the right person to manage all of the complexities that come with the application of any new technology is important but having a T-shaped "BIM Manager" in place who can merge that technology with practice will enable a truly innovative and successful environment within a firm.

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# BIM FORWARD:
# From 'Push' to 'Pull'- Best Practices for BIM Integration

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## The Elephant

There's a digital elephant in the room. And it's a big one. (Both the room and the elephant.) The elephant is the growing gap between the extreme digital prowess and knowledge among BIMerati and the real life, applied, practical uses of Building Information Modeling (BIM) in design, construction and owner organizations. The room is the entire playing field of digital software, hardware, and infrastructure as they are being implemented, sold, used, trained and proselytized across the broad AEC and Owner industries in the context of the full spectrum of use, interoperability, and potential benefits they could have.

## The BIM Gap

The BIM gap is real. It's big and getting bigger. And I think that many of us who know and love BIM experience it far more frequently than we admit. If we are truly in search of 'practical' BIM – that which transcends theory and can be used by many for real value, we must confront the reality of the BIM gap and learn to behave differently. If we are serious about advancing BIM integration in our own organizations and to partners and the industry, we've got to learn to make it simple, accessible, understandable and usable. This paper outlines a few simple best practices for how we have made small inroads doing that at Holder Construction Company, a national construction management company and early BIM adopter, in the hope that our best practices might accelerate BIM integration in your organization.

## BIM's Bleeding Edge

As an observer and participant in the design and construction industry since 1968, I have witnessed many epochs, angsts, movements, media and technologies form and migrate across our professions. These include design movements such as modernism, post modernism, community-based design, and evidence-based design, and technologies such as pencil, ink, mylar, pin bar overlay drafting, CAD, and now BIM. Except perhaps for the renewed interest in green and sustainable design, no other issue has grown so quickly and been championed as fervently as has Building Information Modeling. Because of its long gestation period, momentum, and the convergence of available technologies and market conditions, BIM is ripe. And it is this very condition of being ready to eat that has brought out so many cooks, experts and knowledgeable BIM researchers, users, professors and vendors. The fire that burns within these BIM fanatics burns brightly. So much so that in many cases it screens the believer's own ability to see clearly and to bring about real, practical uses. The BIM evangelists, self-included, are often hindered by their own BIM intellect- they know too much. It is this condition of being at the bleeding edge that limits our ability to talk and interact with the BIM-unwashed: We are not practical.

## Being Practical

If practical is defined as "put into practice", then it should be a simple matter to advance BIM in our companies. But it's not. In our eight years of BIM awakening and adoption at Holder to date, we have only just begun to move to the Integration phase, and have yet to achieve Transformation. But in the spirit of being practical I'll share some of the things that we have learned.

## Best Practices for BIM Integration: Things We've Learned

### 1. There is No 'Wrong' Implementation Strategy - There Are Just Different Paces.

The most important thing we've learned about the practical application and integration of BIM in our organization is that without true leadership commitment from the top, you will move very slowly. Our company's initial implementation strategy was one of tolerance, humoring us, and allowing and observing the BIM experiments and trials from afar. This hybrid approach – which involved some aspects of Bottom Up, Parallel Pilot, and Top Down approaches, was successful for us. It allowed us to get an earlier start than we would have if we had adopted an 'all-in, top-down' change mandate. For us, such a Top Down, company-wide change (in 2003 when we bought our first software) would not have been possible. It simply would have required too much capital investment. Organizationally, we weren't yet mentally ready. We didn't understand BIM enough. We weren't hungry enough. And despite the efforts of several key colleagues, we didn't have enough effective, persuasive visionary leadership (or feel enough competitor or peer pressure) to make the "big" move. Things were good. Why change radically?

Instead, we were "practical." We did the best we could with what we had. We hired a few good people, supplemented missing skillsets with a growing, diverse, strong team and tried a wide range of services and software on real company work for real customers. We celebrated and publicized successes. Because we weren't under transformation deadlines we were able to perform without pressure and amazingly – have had no failures. An advantage of our gradual BIM migration was that it allowed an earlier start. We were doing <u>something</u>- trying software, providing applied BIM

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services on real projects earlier than many. This slower ramp up also offered the advantage of having less risk, less investment, and more time to evaluate the technology, people and process changes associated with BIM.

Now, eight years later, after a successful BIM 'adoption' stage, we have officially crossed over into the 'Integration' stage. And the thing most responsible for bringing about that change is the understanding, acceptance and "pull" for BIM by the company mainstream management and production core - our Preconstruction and Operations associates. But what will propel us even farther, faster, is the recent realization of BIM's potential by the company's Chief Executives. Since BIM has grown to be a significant investment and is now an expected part of our business, company leaders have begun to survey BIM's consistent application and integration on all project sites. Finding consistency lacking, they have now shifted emphasis to focus on consistent BIM integration across all projects. Only you can decide which implementation approach will suit you best, and where you are in your timeline, but whichever option you choose, know this: it won't be taken seriously nor be as effective as it could be until it's driven in all senses (financially, verbally, spiritually, and in words and in actions) by those at the top.

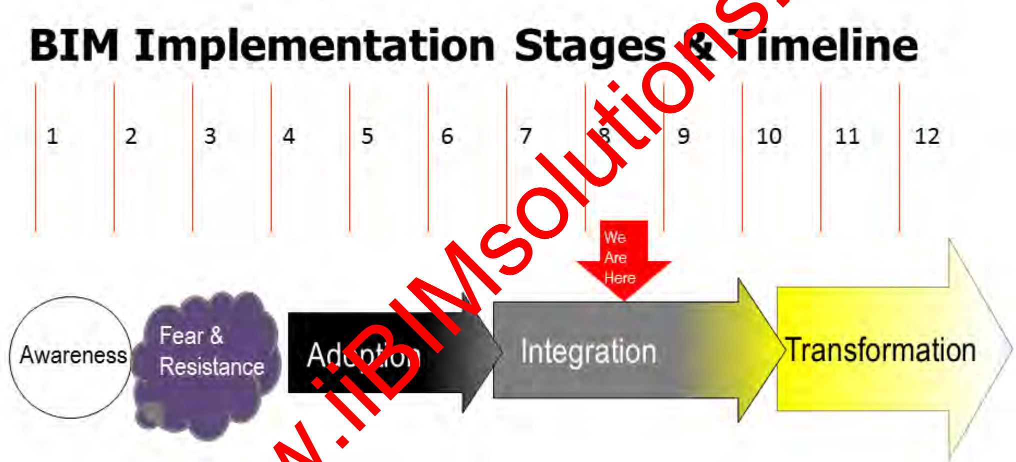


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Figure 1: BIM Implementation Timeline
Stages: Awareness, Fear / Resistance, Adoption, Integration, Transformation, M. LeFevre 2008

2. How to Speak BIM

A second lesson that may be helpful to you is that it is not productive to try to impress your team with your vast knowledge and mastery of arcane BIM technical terms in an attempt to demonstrate your BIM superiority. As obvious as this may seem, I find on many occasions, that BIM change agents (buoyed by their hard-won technical proficiency) do just that. On many occasions while seemingly attempting to help or persuade others to adopt a new technology, the initiator sets about proving just how smart they are - and how dumb the person they are talking to is – when it comes to technology. I do it myself. On occasion I have the urge to share some BIM knowledge and frequently catch myself doing it in a corrective, pedantic – dare I say pejorative- way. In these instances, while my intent is not to obstruct progress or understanding, that is often the result. Surely we who are so passionate about computing in design and construction do not intend to slow adoption? Why then do we insist on speaking like BIM Martians or computer Klingons? On many occasions I have heard people arguing about terms, philosophy and BIM issues which serve only to kill conversations stifle the interest and turn people off. To solve these problems of the 'BIM haves' turning off the 'BIM have nots' in their interactions, in 2008 we implemented a series of classes called "How to Speak BIM." Our target audience was the construction professionals in our company: Managers, Construction Engineers, Superintendents, and Preconstruction staff who were not familiar with BIM. Our initial strategy was simple. Like any new language, we first taught the ABC's and words. We followed with applied BIM uses, structures and syntaxes. This first round was focused on "us", (i.e. BIM.) What was it? What were the proper terms for things? What was the difference between 2D, 3D, 4D, and 5D, between CAD and BIM, a rendering and an animation, and so on? In parallel with this class we developed the 'BIM Value Menu' – a McDonald's style sheet (complete with yellow background and numbers.) It was an attempt to help people know what to ask for, what was available and what to use it for in doing their services via quick, easy, standardized ordering. It did have some initial success in developing awareness, data compression and standard branding, naming and packaging of emerging services and products. But it failed in one respect.

Because of its quick transactional nature, e.g. "Gimme a Number 1 Collision Detection Special." it shortened and disconnected real dialogue. It lost opportunities for one-on-one learning and discussion that would have resulted in deeper, more meaningful exchange. It missed opportunities for slow learning, realization of other potential uses and 'lightbulb moments' by adoptees.

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Figure 2: How To Speak BIM
Early Classes Targeted Basic Vocabulary, Products, Services and Use Cases, M. LeFevre 2008

After two years of 'How to Speak BIM' V1.0, and reflecting on feedback, we re-tooled our thinking and content. After realizing that mutual BIM understanding and real applied use was not about us, we revamped 'How to Speak BIM' to be about listening, caring, asking and speaking the other person's language! In 'How to Speak BIM' V2.0, our focus shifted to asking about our customers' problems and concerns*. After starting with their issues we translated them into our language and toolset and provided solutions and options to solve their problems. Along the way, some dialogue occurred: They learned more about BIM and how it can be used to help their work. We learned more about their work. Today we use a hybrid of these two techniques to integrate BIM into our organization - ongoing teaching of basic BIM terms and principles and a renewed focus on speaking our customer's language and serving them. By working hard not to scare people off we have gone a long way to remove the fear and to 'practicing' BIM across the company.

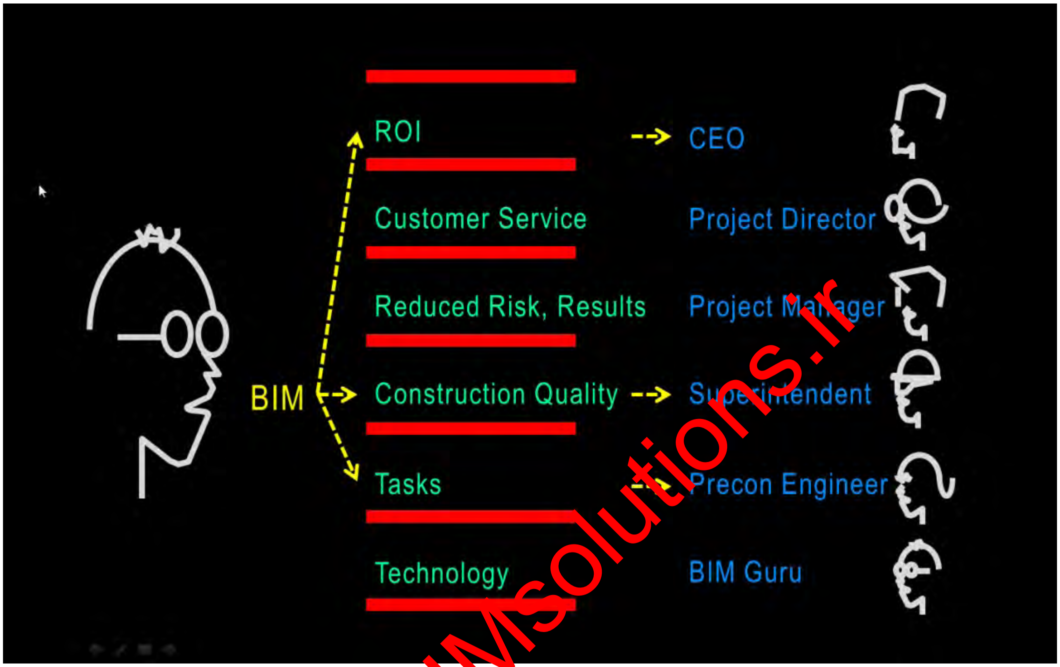


Figure 3: Translate Tech Language to Audience Needs
To Integrate Technology- Empathize, Immerse, Exchange Mutual Trust and Value, M. LeFevre 2011

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3. It's Not About Us: (Relate, Empathize, Immerse, Translate and Communicate)

The next big thing we're learning, despite our passion for BIM, is that BIM does not exist to serve itself. In our organization at least, BIM exists to support our core business - construction. While this too might seem obvious, it has taken time to get this concept to sink in to those of us who spend our days consumed with using software, connecting hardware, re-inventing processes and training related to BIM. Because we're immersed in the BIM toolset and mindset we're less attuned to our 'real' business, and to our role in leveraging BIM to enhance our performance as a construction company.

While in the early days we used awareness campaigns to gain exposure and proudly showed our work, we stopped short of using hats, t-shirts and banners to show how cool we were. Yes, BIM's graphical 3D output and information reuse is visual, sexy, new and often dazzling. But, rather than BIM because it's cool, fun or new, we realized that we were (and always will be) a support function, not the main event.

To this end, and in evolving our classes on 'How to Speak BIM', as we continue to integrate BIM services into mainstream company functions, we now strive to use existing, proven process and product names where possible. Rather than continuing to talk about "collision detection", "Navisworks", and "IFC files" we make conscious decisions to call this process "coordination" or "quality", as we always have. We just happen to use some new tools, software and processes to do it. By shifting our emphasis to be about usefulness (to our customers) first, we have a better chance.

4. Training Is Everything

After eight years, we're now in our third generation of BIM training. And whatever you have devoted to BIM training - it's wrong. No matter how big your BIM training scope, it's not big enough.

Our first BIM training attempts were to train ourselves – the BIM 'producers'. After taking some external industry classwork we quickly focused on self-training and sharing to build basic BIM skills within the BIM department. This has evolved and remained strong due to our company training culture: 'seek, learn, share.'

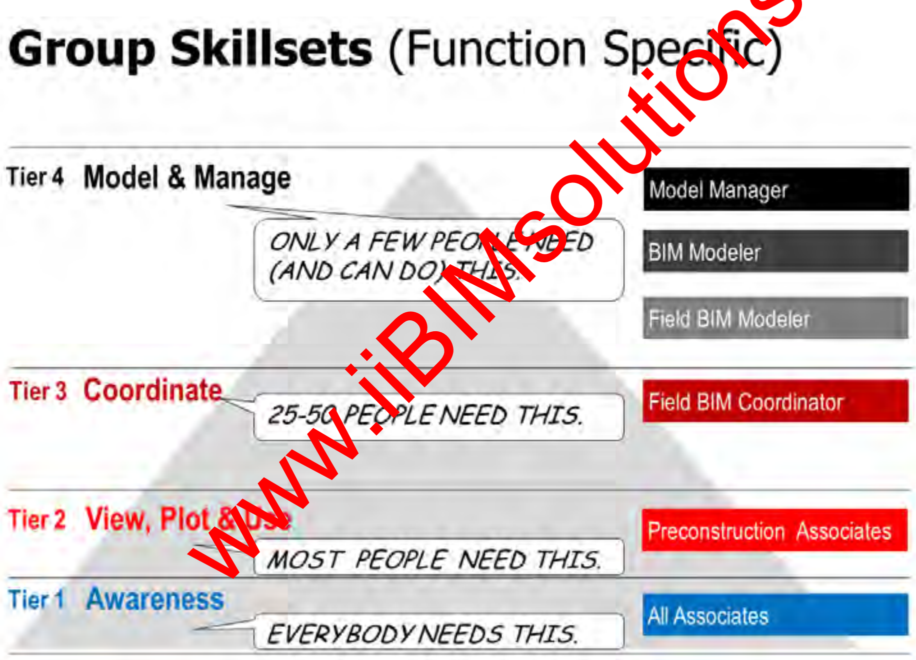


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Figure 4: Function-Specific Tiered BIM Training
Aggregate and Deliver BIM Skills Per Task and Functional Need (vs. Mass Learning), M. LeFevre 2010

For company BIM training, our approach has been more storied. After early awareness and consciousness-raising sessions, we started with a blanket approach at company conferences to give all associates the ability to open view and Navisworks Freedom Viewer since it could open most model file formats. It was a "we build 'em, you use 'em" mentality. This met with some success, but we soon realized that we had much foundational work to do and that each of our associates – in different roles doing different jobs- needed to learn (and be able to) something quite different in the world of BIM.

Our response to this was a re-directed, audience-targeted, segmented approach. We borrowed a branding and graphics shortcut for our BIM audience targeting campaign. We called it "BIM4". It gave us the ability to tailor BIM training (in name and content) e.g. BIM4 Superintendents, BIM4 Owners, etc.  This audience targeting has added complexity to our BIM training but has increased its effectiveness many times over.

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Figure 4: Function-Specific Tiered BIM Training
Aggregate and Deliver BIM Skills Per Task and Functional Need (vs. Mass Learning), M. LeFevre 2010

After starting with conventional classroom style BIM training in hour long sessions we learned several things. First, classroom settings and hour long time blocks suggest large groups and broad horizontal content. Based on our earlier audience targeting lesson, the challenge for project teams to devote multiple hour long sessions to learning BIM skills, and low-cost technology, we quickly evolved to mini-modules available 24/7 via short video clips on our company intranet. These on-demand learning chunks are now available to all, anytime, anywhere.

We continue to offer formal classroom training mixed with on-demand, customized training in multiple modes and formalities. In addition, our longstanding BIM industry and partner outreach education program BEAMUP (BIM Education Awareness Momentum and Use by Partners) continues to give introductory presentations to industry groups, owners, designers, and universities to boot strap those who make up our supply network.

I repeat: Do not underestimate the time, effort and cost of BIM training. It is required for all staff levels in your organization and for 'hard' as well as 'soft' issues such as cultural and process change. Find, retain and develop lots of BIM presenters and trainers. You'll be glad you did.


Figure 5: Audience Targeted Training & Awareness Programs
Ongoing Education, Awareness and Training in Customized Assemblies Yields Results, M. LeFevre 2005

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5. If You Want To Know, Just Ask

After our initial 'guesses' at BIM training content (i.e. what we thought people needed), we had the radical idea that if we really wanted to know what they needed, we should ask them. As a result, after six months of weekly work sessions we redefined the BIM training needs and content. In response to customer demand, we revamped our primary format and developed over 70 BIM training videos in four tiers, and have dramatically increased the interest in and effectiveness of BIM training as a result. With a better understanding of what they do and what they need, we were able to deliver it, and they were much more motivated to learn it and use it when they were done. We don't always ask (because sometime they don't know) but we've found it to be a good thing to try first.


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6. Dialogue Is Difficult When You Don't Speak the Same Language: Enable It

For the first seven years of BIM adoption in our organization, we saw it as our mission to "push" BIM onto the rest of the company. Because they didn't know BIM (and we did), our daily modus operandi was to teach, preach, sell and show. We used our passion and BIM's new capabilities as persuasion. In doing so we frequently lamented the lack of Operational involvement in BIM. There was no real "pull." It was the company leadership who saw this gap first. Those of us within the BIM department could not see this 'forest and trees' conundrum. Because of their perspective and clarity of vision, company leadership suggested forming an interdisciplinary workgroup to focus on BIM integration. "BIMForward" was the name the group coined for themselves. Their mission was clear:

- *accelerate BIM integration into the company's mainstream operations*
- *open two-way dialogue between BIM and the company to bring BIM understanding, services and applied use to the field while bringing valuable construction feedback to BIM*
- *serve as a prioritizing body for emerging technologies and R&D for applied use*
- *be a temporary initiative, not a permanent structure, department or layer*

## BIMForward


Figure 6: BIMForward Initiative
Preconstruction/Operations–based Initiative Enables Dialogue, Demand, "Pull", BIM Awareness, Use, M. LeFevre 2012

To date, after one year of existence, the BIMForward initiative has accomplished:

- *Identified training needs and created 70+ online BIM training videos*
- *Delivered training (100% of associates complete through Tier 3)*
- *Development and update of key BIM processes for consistent application across the company*
- *Opened Dialogue. Accelerated BIM site visits and established monthly BIMForward Forum Meetings in which on-project BIM 'show and tell sessions share valuable BIM use case testimonials by Operations associates. These are virtual meetings with no physical, face-to-face conference room in which 30 to 40 people regularly share applied BIM practices, leverage BIM peer pressure and advance the BIM integration mission. And the best part is that the BIM experts don't do the talking about BIM- the builders do.*

The value of the BIM Forward group as a middle ground, translating, mapping and dialogue-and-momentum-generating mechanism has been clear. Without it, company BIM integration would still be slow – 'separated' by a common language (English) spoken by two different cultures using two different dialects: BIM and construction.

7. Be Patient. Be Moderate. Be Flexible. (Evolution <u>and</u> Revolution.)

The last lesson is simple. BIM has been well documented as a "disruptive technology." Despite its

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rapid progression past the tipping point in recent years, much development remains. While impassioned BIM disciples just don't 'get' why 'they' don't get it, a bit of patience, moderation and flexibility are in order. We have had many occasions in which we were frustrated by our inability to get our point across, convince a user to change, get funding, get software to be interoperable, or any other of the top recurring BIM frustrations. But in each case, when we kept the faith, carried on and believed in our company, our team and our "plan", eventually the roadblock or frustration was removed. Examples include

- *company leadership shifting from tolerance to expectation and mandate*
- *company management finally beginning to exhibit the "pull" for BIM*
- *industry partners and owners catching up and participating in BIM*
- *software versions becoming more interoperable, less expensive and easier to use with each new release*
- *growing tolerance for increased resources (hardware, software, infrastructure and staff) with increased understanding of BIM's value*
- *many other examples of where being practical, making do and carrying on were the right approach. ( i.e. evolution alternated with revolution can be o.k.)*

BIM Forward

In our experience, BIM, and BIM integration are broadly defined - still early in their life cycle. We hope that sharing these lessons (mostly organizational, sociological, and psychological) serves to fast forward your BIM integration and helps you find more opportunities for 'Practical' BIM. In the meantime we'll continue to carry on, listen better, speak the language of others, try to remain calm and (occasionally) temper our BIM fever in the spirit of doing what we love and in recognition that we exist to support our customers. We hope that you do too.

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# CONCRETE CONSTRUCTION BIM:
## Shop Drawings and Logistics

***Reginald Jackson, AIA; Vice President, Morley Builders***
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### SUMMARY

As a concrete subcontractor, we have been producing Revit models for MEP 3D coordination and concrete shop drawing since 2005. As of today we have completely transitioned from AutoCAD to Revit to create our concrete construction models. This presentation will primarily focus on the levels of detail that is needed within the concrete model for use with concrete shop drawing, MEP coordination, & Sequencing. Beyond the actuals details required, the idea of "planning ahead" runs throughout the model building process.

### CONCRETE CONSTRUCTION MODEL

A construction model is a coordinated model that has horn
 level of detail, precision, & tolerance needed for construction. This criterion has to be discussed early on depending on the uses of the model. An estimating model will not need as much detail as a model for concrete construction. This is not to say that the details cannot be added at a later time. Knowing the intended use of the model will allow modeler to make provision for information required.

Here are some common uses of a concrete construction model:

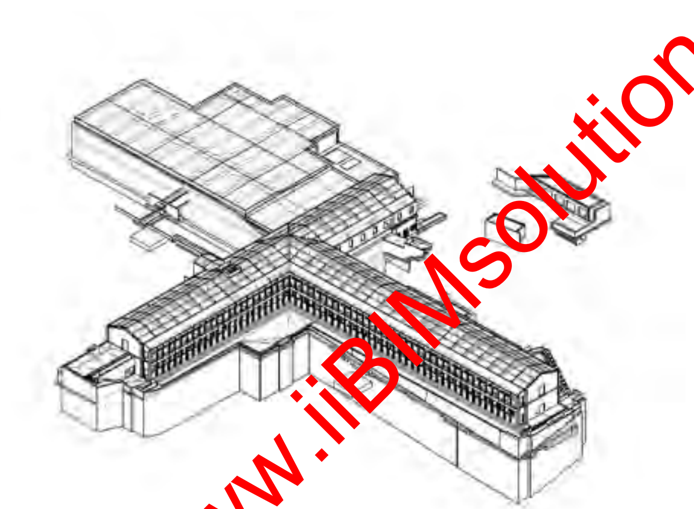
- Concrete Shop Drawing
- MEP Coordination – Clash Detection
- Concrete Formwork
- Construction Planning – Site Logistics, Sequencing
- Estimating - Quantity Takeoff
- Rebar Detailing Support

## LEVEL OF DETAIL

Depending on the use(s) of a model, the level of detail could be significantly different. A model used for quantity takeoff is most likely not "good enough" for concrete shop drawing. Accuracy in model's elements is not as important in a takeoff model where formulas in schedules and reports may provide sufficient resource and cost information. In order to get the "right" information from the model for quantity, modeling elements in a certain way is needed.

Our construction models serve three main purposes; concrete shop drawings, MEP coordination, & sequencing. Most of the time, we start building a construction model from scratch using CAD backgrounds. If there is a design model available, we will evaluate whether we can make use of it.

There is a lot of validation involve throughout the modeling process when using a design model. It is crucial to understand how the design model is build. In the following we will illustrate how we used the design model as a basis for our construction model.



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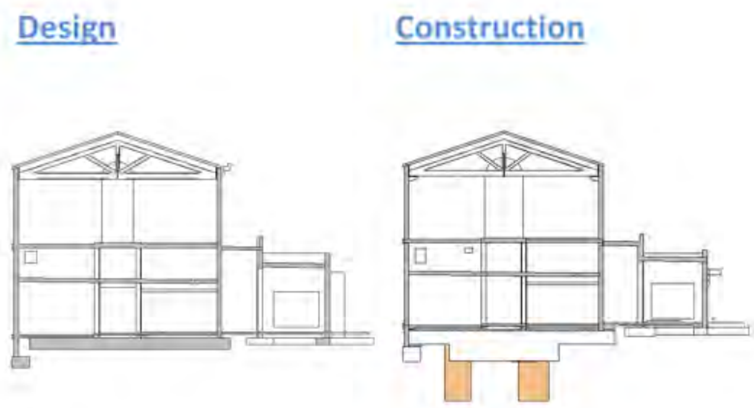
Sample Project




## Design Model and Concrete Model Comparison

At a glance, the design model has most of the elements we need for a concrete model. Let's take a closer look by putting color on the different model elements.

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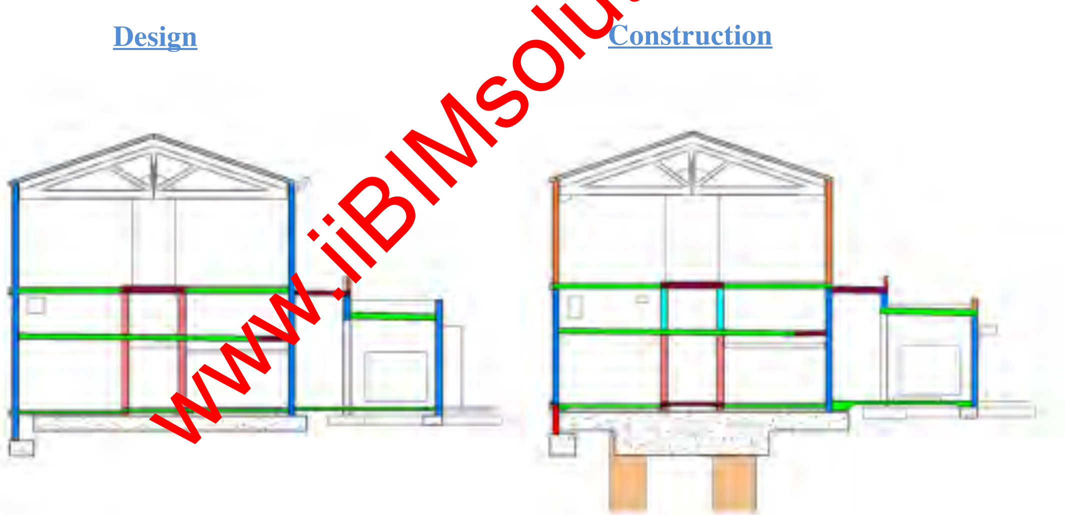
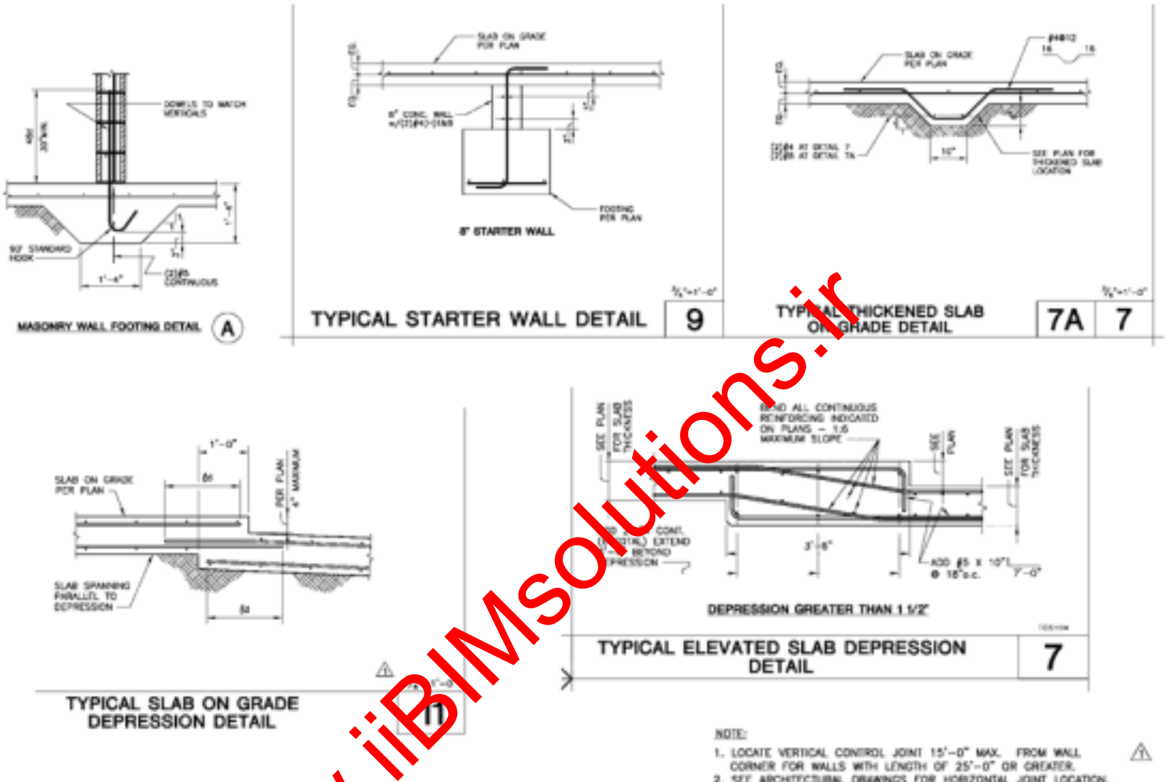



## Design and Concrete Model Elements Comparison

The concrete model reflects the methods and sequences of how the structure will be built. Walls and columns are split for different pours. Decks pour to the top of wall instead of stopping at the face of wall. Beam pouring with another group stops on the upper face of floor. Slab edges are modeled for accurate concrete volume and MEP clash detection.

To understand how we model our concrete, we must look in to the typical details. These will need to be included in the model where the detail applies. Whereas the design model had all major elements, these typical details are not included. In order for us to create a precise model for concrete shop drawings, MEP coordination, & sequencing, we need all the typical details in the concrete model.

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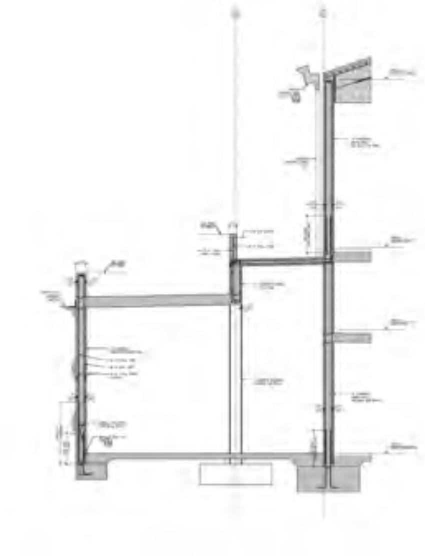
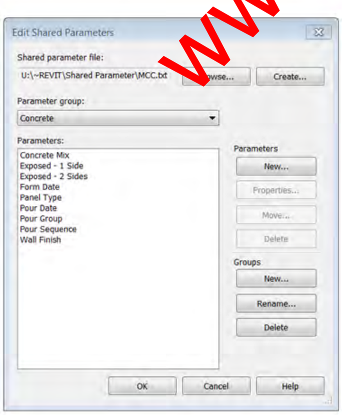
Typical Concrete Detail

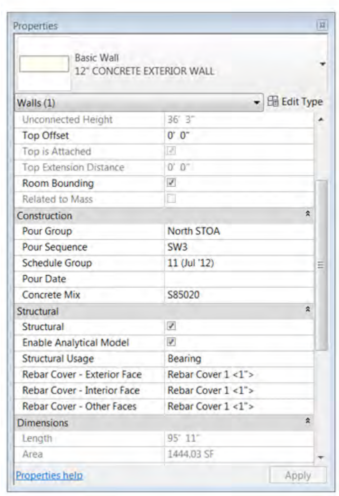


## Concrete Wall Detail

Planning ahead is the key for a well-developed concrete construction model. A well-developed model is one that you have control over and gives the information that you are looking for. The goal is to have a concrete model that resembles that actual construction methods and sequence. Deciding what and how to model certain elements will help in the process to resolve constructability issues.

Sequencing for concrete elements is achieved by using Shared Parameters, View Template and Filters.

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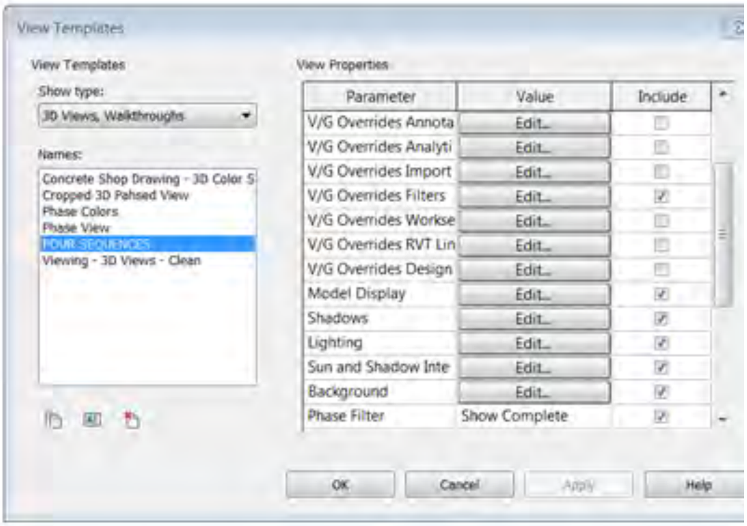
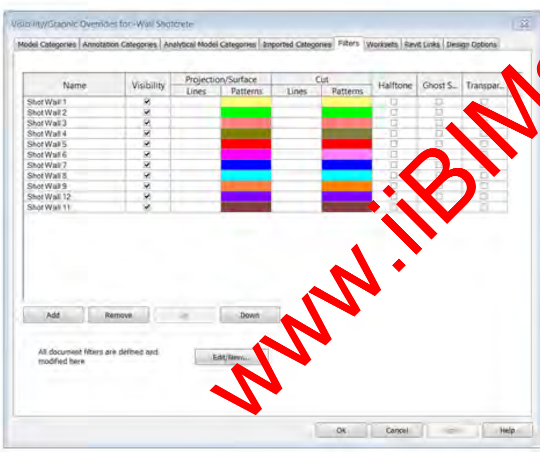
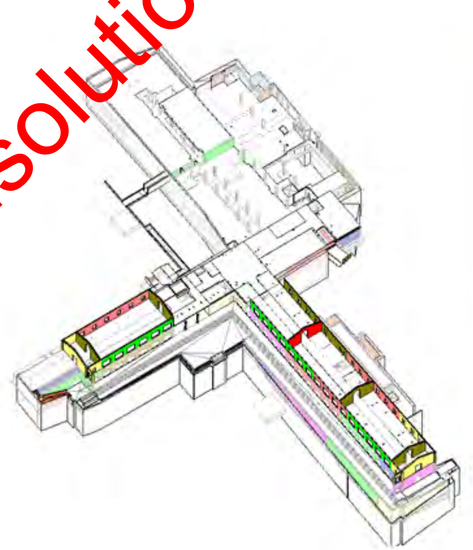
## Shared Parameter





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## View Template and Filters

## Concrete Modeling Guidelines

I. Concrete Shop Drawing

A. Model Elements

- Structural Concrete - Footings (Keyways), Floors, Walls, Columns, Thickened Slab Edges, Slab Steps, Rough Opening, Thickened Slab for CMU wall, CMU Walls,

- Architectural Concrete - Tie Holes, Panel Joints, Recessed Light Fixtures, Recessed Outlets, Window/ Door Recess

*Tips:*

- Avoid using "In Place" Family as much as you can
- Use components under "Structure" tab
- Make use of custom "View Templates"

II. MEP Coordination

A. Model Elements

- Sleeves, Blockouts, Equipment Pads
- Structural Opening Boundary Elements

*Tips:*

- Create blockout and sleeves as "Families" not "Openings"
- Equipment Pad as separate "Family Type"
- Setup Coordinates for File Export

III. Sequencing

- Set up reporting "Shared Parameters" that can be reused on other projects
- Use "Filters" to group, sort, and filter elements

*Tips:*

- Model floor by "smaller pieces" instead of using one "big" slab.
- Split walls into "smaller pieces" both vertically and horizontally
- Look into all "Error" when splitting elements.

There is a lot of decision making in the process to ensure the validity and availability of information from the model. Due to the parametric nature of Revit, tracking changes on drawing sheets still requires another set of eyes. As changes occur throughout construction, the model will need to be updated. There is correct or incorrect way of modeling. To get the best use of information, it is important to decide what element should be model and how it should be model.

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# (UN)REAL BIM:
# Providing a Unique BIM Experience In Virtual Reality

*Vaughn Horn, AIA, NOMA, LEED AP*

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We as architects inherently occupy virtual environments in our heads: clients look to us for our ideas to make their dreams become reality. Yet an exponentially growing market niche in which these ideas, and the manner in which they are exchanged, renounce the traditional means of printing design documents and flying half-way across the world to "shake on it." Instead, more companies are coping "with travel budgets deeply slashed across corporate America [and] more companies are turning to virtual [reality]" (Yu, 2010).

While the push toward sustainable design encourages creative approaches to minimize environmental degradation, virtual reality provides a unique building information modeling experience, with zero carbon foot print. As of 2010, the market for technology companies that develop virtual [environments] was about $100 million, estimates Sharat Sharan, CEO of the company ON24 that developed about 300 virtual [environments] in 2009 (Yu, 2010). Therefore "virtual" architectural companies are transforming buildings, cities and geography that is easily accessible, and can be embedded on websites, or displayed on tablet devices.[1]

As a result of partnering with video game developers and technology companies like Tipodean Technologies, devices such as the ArchTech Engine (Arch Virtual) provide user-friendly approaches to customized virtual environments. According to Chris Collins, manager of Linden Lab, "what you've got with a virtual environment is that it's completely immersive." (Wagner, 2009). On that same note, the ability to transform architectural drawings and 3D models of almost any format (including Auto CAD and Revit) into information-rich applications that are perfect for architectural visualization, and city planning, is re-shaping the perception of architecture.
Praised by video game designers for its high performance, video game engines like Unity 3D (by Unity Technologies) yield high quality renderings, and produce animations without chops or jumps, which in the video game world, is a "demonstration of a system's power and efficiency."[i] In addition, Unity 3D offers a free licensing package for novices to become acquainted with basic features and "the complete toolset, intuitive workspace and rapid, productive workflows help users to drastically reduce the time, effort and cost of making games."[2] In fact "before Unity 3D [came along], organizations were constantly challenged by issues related to the scalability, usability, and

the cost of implementing large virtual world rollouts. Unity 3D [now] puts the immersive experience into the hands of users."[3]

Establishing an architectural practice within a virtual environment challenges traditional business development and project acquisition methods, allowing clients to walk through their buildings, and literally (and figuratively) run into people. For instance, in 1997, Pat Carmichael of HKS Architects, based in Dallas, Texas, sought to improve the immersive experience for clients who were eager to walk-through their buildings before they were built. At that point, building information modeling (BIM) was integrated into the practice through ARCHICAD, and many traditional fixed-path fly-through perspectives aided in visualization. However, virtual environments were at the time un-conventional. Yet he saw an opportunity for clients to become instantly engaged, in a role-playing game format with their building proposals in the foreground.

Mr. Carmichael and his design team developed a first-person perspective for the Camden Yards Project in Baltimore, Maryland, and successfully navigated a virtual character through the scene in a schematic design meeting. Upon operating simple mouse-guided controls like opening and closing doors, running up and down stairs, and picking up objects in the scene, the client was sold on the project direction. Ultimately, an opportunity to increase the amount of successful project acquisitions using virtual environments had materialized. Furthermore, Mr. Carmichael explained how "so far [at HKS] he has seen a 93% success rate for projects that include the [virtual reality] show, and a 50% success rate without it."[5] This testimony underscores the effectiveness of virtual reality within architecture, and could stimulate more widespread uses among architecture firms practicing today.
Producing virtual environments requires a cross-platform approach that at its root serves the singular purpose of immersion, and "people are in the virtual world for an experience," explains Paul Messigner, a business professor at the University of Alberta (Noyes, 2009). Utilizing Unity 3D, which currently carries a $1500 licensing fee, produces a unique visualization experience, achieved with one-click publishing of executable files (.exe) that are easily displayed on the web in Flash format, computers, mobile devices (iOS and Android platforms), and video game consoles (Nintendo, Sony, Microsoft). The display of 3D models as game objects allows them to be assigned scripts to that affect kinematics, such as collision detection, gravity, and first-person controls that allow users to pan or walk through the scene. Thus, the virtual world in the architect's head, including materiality, lighting, and points of view, are seamlessly integrated from the virtual environment to reality with greater ease.

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Furthermore, making concepts more tangible for prospective clients has grown beyond static imagery toward utilizing interactive, cross-referenced, and portable content, setting a new par for the course in building design in virtual reality. Hence, it is important for architectural firms to embrace multi-platform "unreal" building information modeling in order to remain competitive in lean economic times that calls upon us as architects to develop more ingenious approaches to provide immersive experiences.

FOOTNOTES

[1] http://www.archvirtual.com/archengine.
[2] http://www.En.wikipedia.org/wiki/Frame_rate: Frame rates in video games.
[3] http://www.untiy3d.com/create-games/: What is Unity and what can I do with it?
[4] http://www.tipodean.com/service/unity3D.html
[5] Excerpts from a phone interview with Pat Carmichael (HKS). April 2012.

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# BIMSCORE: GPS FOR BIM NAVIGATION:
## From Aspirations to Quantitative Measures of Success

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### ABSTRACT

The adoption of Building Information Modeling (BIM) and Virtual Design and Construction (VDC) is accelerating as owners, builders, and the broad spectrum of design consultants recognize its value in improving productivity, reducing costs, and enhancing project quality. Although these benefits are known, there is no proactive, objective mechanism to evaluate the VDC planning and BIM maturity necessary to achieve these benefits, and accurately quantify their value to projects and enterprises. BIMSCORE fills this void by facilitating a shift from subjective, notional assessments to objective, quantitative evaluations of BIM and VDC implementation. Relying on the VDC Scorecard framework developed at Stanford University's Center for Integrated Facility Engineering (CIFE), BIMSCORE evaluates BIM adoption using scientific measures to verify efforts are on course and progressing at the correct pace to achieve the full potential of BIM and VDC investments. The motivation behind the BIMSCORE methodology will be discussed, as well as the evaluation framework in terms of the four areas of assessment. Special attention will be given to the evaluation scope and measures, the value assessment results bring to a project team or enterprise, and the questions and challenge the BIMSCORE framework intends to answer.

### 1.0 MOTIVATION

Global investment in capital projects is growing at a rate that will soon outpace GDP growth, with a projected 67% growth in construction globally by 2020 (Betts *et al*, 2011). Although volume is growing, construction productivity improvement has been marginal or negative over the past two decades. The adoption of Building Information Modeling (BIM) is accelerating in reaction to this problem, and is expected to reach 80% in some sectors this decade as public agencies and private owners mandate BIM for their construction programs (Young *et al*, 2008). BIM is a sub-practice of Virtual Design and Construction (VDC), which is the use of integrated multi-disciplinary performance models of design-construction projects to support explicit public and business objectives. Despite the high stakes for successful BIM and VDC adoption, there is no proactive, objective mechanism to evaluate BIM maturity and its contribution to construction value.



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BIMSCORE fills this void by facilitating a shift from subjective, notional assessments to objective, quantitative evaluations of BIM and VDC implementation. BIMSCORE's vision is to optimize the value of the global built environment through continuous improvement in business decision-making, processes, and technologies, empowering quantifiable and actionable improvements in BIM planning, execution, performance and return on investment from capital projects and portfolios. Owners, builders, and the broad spectrum of design consultants can benefit from objective, scientific measures to verify efforts are on course and progressing at the correct pace to achieve the full potential of BIM and VDC investments.

Successful BIM adoption on an enterprise level requires careful attention to strategies, tactics and performance tracking. Even the most experienced and successful firms and project teams have opportunities for improvement in this rapidly advancing field. In addition to BIM, interdisciplinary collaboration is widely acknowledged as an essential element in solving complex performance requirements of architectural projects, broader social and environmental concerns, and proper operation and management of facilities. Useful collaboration depends on establishing strong, reliable connections between team members, and establishing similar connections between their use of BIM and VDC tools. Achieving these connections requires thinking beyond the tools to be used, in order to focus on developing collaborative processes and protocols. The objective measures of BIMSCORE framework help project teams develop a clear picture of their collaborative approach, and then compare their plan with those of other projects. This allows decision makers and managers to compare their expectations for their current practices to their actual level of practice in the context of the global market, motivating improvements in efficiency, productivity, BIM and VDC investments, and overall marketability to progressively sophisticated clients and owners.

## 2.0 FRAMEWORK AND METHODOLOGY

BIMSCORE assessments rely on the VDC Scorecard framework developed at Stanford University's Center for Integrated Facility Engineering (CIFE). Several evaluation frameworks have been developed to assess BIM maturity, though they vary in their focus, applicability, and comprehensiveness. The VDC Scorecard has taken a more holistic approach by not only evaluating the maturity of models or technology applications, but also the preparation, standards, people, and processes interacting with technology throughout its implementation. As part of BIMSCORE's research and development this scorecard has been applied to over 30 case studies in industry to validate and improve its measures, demonstrate its repeatability, and create a global database of BIM and VDC maturity to benchmark project performance. Outcomes and findings of this scorecard implementation provide an accurate picture of BIM implementation in practice, ranging from typical model uses, qualitative and quantitative objectives and metrics, BIM Execution Plan contents, and how VDC responsibilities vary by stakeholder and project phase.

Evaluations are benchmarked against other current projects around the world, and the "scores," are used to identify areas of strength and weakness to inform the advisory process used to drive performance improvements. The overall BIMSCORE illustrates how the project is ranked among other projects in the global market via a 5-level innovation ranking system shown in Figure 1, with scores ranging from "Conventional Practice" to "Innovative Practice." This executive overview is useful in gaining a general understanding of BIM maturity, and can be used in making management decisions regarding the allocation and attention of resources to a project, or among a portfolio of projects.

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Figure 1: Diagram illustrating the five level industry practice percentile ranking system, providing an overview of where a project's or enterprise's BIM and VDC practices rank relative to global practices.

As illustrated in Figure 2, the BIMSCORE evaluation framework is organized by four areas (Planning, Adoption, Technology, and Performance), ten dimensions, and over 50 measures. Each area has a specific scope, yet all are interconnected and meant to collectively lead to reliable tracking and assessment of VDC implementation throughout the entire design-build- operate-reuse lifecycle. Each area, dimension, and measure has its own weight and contribution to the overall score.

As BIM and VDC industry practices and technology evolve, so does the Scorecard framework. Based on analyses of the global database of scores, trends and patterns are identified to inform the framework structure and ensure it keeps pace with rapidly progressing industry practices. This is done through adjusting scoring weights, adding or removing measures, expanding the scope of areas or dimensions, and adjusting the interrelationships between areas and dimensions to ensure scores are relative to the best practices identified in exemplary projects.

The accuracy and confidence in an evaluation and resulting advice largely depend on the length of interviews, the stakeholders involved, and the documentation reviewed; yet, a reasonably accurate assessment can be made with little time investment, ranging from 1-2 hours.

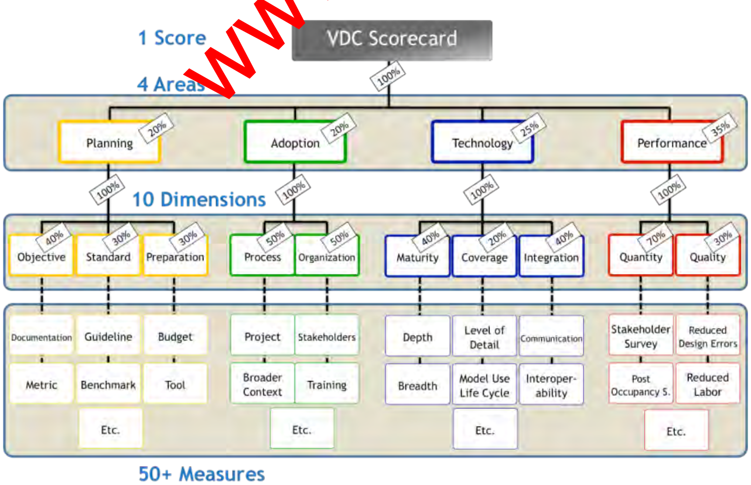


Figure 2: The VDC Scorecard Framework, showing the four areas, ten dimensions, and over 50 measures to enable a holistic evaluation of BIM and VDC adoption.

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In the following section each of the four areas will be discussed in terms of their scope, the value they bring to a project team or enterprise, the questions and challenges they intend to answer, and the measures they utilize. Again, each of these areas is meant to have interdependencies and overlaps with other areas in order enforce a system of checks and balances: strong or weak performance in one area can carry over to other areas, but no one area can dictate overall performance.

## 3.0 BIMSCORE EVALUATION AREAS

### 3.1 PLANNING AREA

VDC planning is instrumental in aligning a wide group of stakeholders and identifying the likely technologies, hardware and software resources needed for the project and the firm. Figure 3 illustrates some the metrics involved with assessing VDC planning, and an overview of a typical Planning Area evaluation result. The Planning Area is used to evaluate planning in three dimensions: Objectives, Standards, and Preparation. An objective assessment of these three dimensions helps identify the strengths and weaknesses of VDC planning, enabling directed, actionable advice grounded within any human capital or financial constraints. Successful VDC planning does not guarantee better project performance, but it does provide the foundation for improving technology adoption in current projects and in the future as tools, software applications, and the management processes to support them, evolve.


Figure 3: Typical metrics used in evaluating VDC planning, and an overview of a typical Planning Area evaluation result

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### 3.1.1 OBJECTIVE DIMENSION

Establishing and tracking both quantitative and qualitative objectives is integral to guiding, motivating, and assessing VDC performance. Without mature targets and metrics, performance cannot be accurately measured and tracked throughout a project; this situation leaves the team unsure about the value of their BIM investment and the degree to which they may have improved over more conventional practices. Furthermore, objectives help prioritize and guide implementation, as well as identifying and reducing inefficiencies and non-value adding processes. Even if the established targets are not met, they are still useful in identifying areas of poor performance and informing the correct level objective maturity for future projects. There are seven basic categories of project or enterprise objectives that will be described below in terms of the questions and potential challenges they intend to inform and solve.

[1] Communication

BIM enables vastly improved communication and collaboration, and setting communication oriented goals helps to ensure technology is being effectively leveraged to experience these improvements.

- What is the acceptable latency for RFI's, submittals, and other information exchanges?
- What means of communication will be used throughout the project? What means best serve the stakeholders involved and their VDC proficiency?
- How has design intent understanding or design review effectiveness improved? How can this be measured?
- What is the value and ROI of physical v. virtual co-location?
- What information should be shared via the project management system and with what stakeholders?
- How can improved communications be facilitated within VDC or BIM guidelines? How should communication relationships and expectations for the project team be mapped and defined?
- What level of BIM integration and access will a project need? Will multiple users create content in a concurrent manner?

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[2] Cost Performance

Improved cost control is enabled through model-based analyses as well as BIM-enabled team collaboration and coordination. Setting enterprise and project goals oriented toward cost management and performance motivates BIM implementation, and focuses its application toward reducing and managing costs.

- What cost performance targets will serve the project and firm objectives? What metrics will best measure cost performance?
- What applications and analyses can facilitate automated quantity take-offs and estimation, or cash flow and budget projections? How can BIM be used to facilitate project billings and payments?
- What is an appropriate target for change order reduction through enhanced coordination? How should the cost savings achieved through BIM-enabled coordination be quantified?
- What amount of contingency should be devoted to in coordination upon adopting BIM? How should this differ from non BIM-enabled projects?
- What financial incentives should be established to motivate VDC implementation and collaboration?

[3] Schedule Performance

Improved schedule performance can be enabled through software applications, and also through the collaboration processes supported by 4D simulations and other schedule visualizations such as flow-line scheduling. Maximizing the value of these tools is supported through establishing schedule performance targets and mapping these targets to specific BIM-based analyses.

- What applications and analyses will shorten the entire plan-build-design timeline and optimize its sequencing?
- What are mature targets for schedule variation? How can they be supported by software tools and collaboration?
- To what degree can pre-fabrication shorten construction duration?
- How can labor resources be optimized? How can a continuous workflow be achieved? How can dependencies be analyzed to optimize construction sequencing?
- How can schedule considerations be integrated into the design process? How early in a project can schedule control be implemented?
- How can BIM enable lean processes and principles and pull scheduling? What are the best collaboration practices to communicate schedule intent to the broader project team?
- What is the value of linking the schedule to the model, cost and labor resources? What tools enable this integration?
- How can BIM mitigate and reduce schedule risks and uncertainties? What is its value in terms of identifying hidden work and preventing cascading delays?

[4] Facility Performance

Many model-based analyses support improving facility performance during design, and BIM-based collaboration tools allow end-users to easily visualize designs and contribute to the decision making process to maximize operations efficiency. Setting objectives to guide these analyses and coordination will help maximize facility performance throughout design and construction, leading to higher quality end product with lower maintenance and operations costs, and increased end-user satisfaction.

- What tools support achieving an optimized design? How should competing design parameters be prioritized? How many design alternatives should be considered?
- What energy usage targets should be established? How can these targets be achieved through model-based analyses?
- What are mature tolerances for actual building performance v. predicted performance? What tools support monitoring energy performance during the O&M phase?
- What analyses should be considered to increase facility performance? These include daylighting analyses, CFD simulations, energy analyses, circulation analyses, and many others.
- What collaboration protocols should be implemented to facilitate input from O&M personnel? How can BIM enhance these interactions?
- Can operations and maintenance costs be predicted and monitored through design and construction? Can the savings in O&M costs enabled by BIM be quantified?
- How can cradle-to-grave or cradle-to-cradle lifecycle considerations be incorporated into design and construction with VDC and BIM?

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[5] Safety

Increased safety can be achieved during design, construction and operations and maintenance phases. Several model-based analyses support increased safety, and a guided application of these analyses can be facilitated through establishing mature safety objectives.

- How can the behaviors of facility users/occupants be modeled? How will they behave on a normal day, or on an overcrowded day, or when there is a fire or other emergency?
- How can the model be leveraged to assist facility operators or emergency responders in accessing different parts of the building during an emergency situation?
- How can BIM identify what design features may be hazardous to construct? How can these hazards be mitigated through revisions or improved safety planning and training?
- How early during design can safety hazards be considered? What tools support automated safety checks throughout design and construction?
- How can the model be used to enhance safety planning and training?
- What are mature safety targets, such as minimizing egress times or reducing injuries? How can safety analyses be mapped to these objectives?
- What is the value of increased safety, and how can it be quantified?

[6] Project Delivery

Project delivery objectives should be directly related to owner/client satisfaction, and increasing the overall quality of the final product. This broad category can be supported by BIM and VDC in a number of ways, including software applications, hardware and physical tools, and the contractual processes that define project team integration and collaboration. Through establishing objectives that contribute directly to quality and owner satisfaction, project teams can ensure they are focusing their application of BIM to not only achieve project objectives, but the ultimate objective of client satisfaction.

- What is the project delivery system? How will the project team adopt an integrated mindset if they are not contractually obligated to do so? What incentives are necessary to foster collaboration?
- How can owner design review effectiveness be improved with BIM?
- How can BIM enhance coordination and reduce field-initiated changes?
- How can quality control (QC) be improved? What are mature targets for BIM-enabled QC (punch lists, inspection, dimensional tolerances)?
- How will the project management system be accessed and used by owner representatives? How can VDC keep the owner apprised of the schedule and costs?
- What level of documentation is required by the owner over the project timeline? How can BIM enhance documentation productivity?

[7] Enterprise Objectives

Enterprise objectives should guide organizational achievements from project to project, whether this is through knowledge management (e.g. documented lessons learned or best practices), standards, enterprise training, or specialized BIM personnel. Therefore the application of BIM is not a direct contributor to these objectives, but rather the best practice development for employing BIM and VDC tools.

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- How should technology diffuse through an organization's hierarchy? What proportion of the staff should be considered an expert in BIM implementation?
- How many projects should have BIM deliverables? What requirements should apply to all projects? What project types should have unique requirements?
- How can human capital be optimized? How can technology be used to minimize team size while still maintaining quality, cost, and schedule control?

### 3.1.2 STANDARD DIMENSION

An integral part of proper VDC planning is establishing standards and processes to guide implementation and ensure consistency among all project stakeholders. If standards are lacking in comprehensiveness or specificity, or if they are beyond the capabilities of project stakeholders, then the potential for misguided information exchanges and rework can be significantly increased. Therefore the contents of standards, their appropriateness for the project team, and the efforts made for continuous improvement all need to be evaluated.

Standardization of BIM and VDC practices is facilitated through the use of BIM Execution Plans (BEP's) or VDC Guides, which dictate project or enterprise objectives, communication procedures, training requirements, responsibilities, software, and naming conventions, among other requirements. Several BEP's and other BIM standards are available in the public domain, and their contents will be described below. Each of these guides and their contents have been used as points of departure for developing the VDC Scorecard and BIMSCORE's evaluations, in order to provide the most comprehensive evaluation possible based on a wide variety of available resources.

[1] GSA BIM Guides

The General Services Administration (GSA) established the National 3D-4D BIM Program in 2003, and has since assessed and supported 3D, 4D, and BIM applications in over 100 projects. The goal of the National 3D-4D Program is to more effectively meet customer, design, and program requirements through incremental adoption of 3D, 4D, and BIM technologies. This goal has in part been achieved through the publication of the GSA BIM Guides, a series of eight guides that are listed below. Each guide may or may not be incorporated by reference into contracts for new construction or modernization, and are therefore of interest to not only internal GSA staff, but also other agencies and contracted parties.

- Series 01– 3D-4D-BIM Overview
- Series 02 – Spatial Program Validation
- Series 03 – 3D Laser Scanning: Supports
- Series 04 – 4D Phasing:
- Series 05 – Energy Performance and Operations
- Series 06 – Circulation and Security Validation
- Series 07 – Building Elements
- Series 08 – Facility Management

[2] National BIM Standards (NBIMS)

The goal of the NBIMS is to overcome the lack of efficiency in today's construction industry through establishing standard definitions for building information exchanges in order to enable accurate and

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efficient communication. Improving information interoperability and reliability is key to eliminating inefficiencies and non-value added work, which is currently impeding the transformation of the building industry. To overcome the challenges of interoperability, the NBIMS provides a guide to developing BIM standards in order to enable integrated life-cycle information models that improve facility performance throughout their entire life time.

[3] AIA E202

The AIA E202 Exhibit is a contractual document that establishes protocols, level of development (LOD), and authorized uses of Building Information Models for project stakeholders. The agreement also assigns responsibility for the development of specific model elements to a certain LOD at each project phase. The Contract is titled "Building Information Protocol Exhibit," and is intended to be incorporated by reference into the regular AIA contract.

[4] Autodesk BIM Deployment Plan

The Autodesk BIM Deployment Plan provides tools and BIM support for AEC professionals as well as owners to effectively implement BIM within their organizations or on specific projects. These tools and support include templates for streamlining communication, recommendations for roles and responsibilities, best business process examples, and software recommendations. This framework aims to assist BIM implementation through increasing efficiency, reducing costs, and facilitating collaborative communication.

[5] Penn State BIM Project Execution Planning Guide

This guide helps project teams create and implement a BIM Project Execution Plan in order to improve communication and collaboration among stakeholders during early project phases. The resulting plan will help project teams design a BIM strategy that establishes BIM goals and uses, information exchange requirements, team responsibilities, and the technology needs to support BIM implementation. This strategy considers all project phases, from planning to operation, and helps identify the BIM uses that will enhance performance and achieve project goals in each phase.

[6] Indiana University BIM Execution Plan

This document provides a template for a project team to establish a framework for implementing BIM and best practices. The template assists in defining roles and responsibilities for each project phase, project objectives and milestones, the detail and scope of information to be shared, and the required processes and software. In addition to this template for establishing a BEP, Indiana University also provides a BIM Proficiency Matrix, to summarize the BIM capabilities of project stakeholders, and an IPD Methodology Plan, to identify project stakeholders and define their interaction throughout a project.

### 3.1.3 PREPARATION DIMENSION

Preparation refers specifically to the VDC budget, the preliminary set of BIM tools, and any VDC management practices that may not be found within a BIM Execution Plan (BEP) or VDC Guide. Proper preparation therefore provides the foundation for successfully enacting technology standards and objectives, the other two components of VDC planning. The Preparation dimension is concerned with questions and measures such as:

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- What is the VDC budget? What software, hardware, training, and technology specialist salaries should be accounted for? What is the expected return on investment?
- What means of interaction should be used (e.g. Big Room or I-room, web conferences)? Which ones are most appropriate for the broader project team and its proficiencies?
- What capabilities should a project management system have? What information should be shared and with what stakeholders?
- What is the preliminary set of VDC tools (hardware and software)? Which will be used by what stakeholders?
- How should stakeholders be prequalified in terms of VDC capabilities and experience? What should the requirements be?

## 3.2 ADOPTION AREA

Proper VDC planning can only be successfully leveraged if the people and processes adopt the plan through establishing the appropriate roles and responsibilities, incentives, and BIM proficiency. The Adoption Area measures the performance of a project team or enterprise in deploying its human capital to properly support technology plans, and assesses multi-stakeholder teams with respect to their responsibilities in technology adoption. Of particular importance in this area is the on-boarding process for the entire group at the onset of a project, and how each new team member is incorporated as they are added throughout the project timeline. Ensuring the stakeholders remain a cohesive, collaborative team throughout many project phases is integral to successful VDC implementation. Figure 4 illustrates some the metrics involved with assessing VDC adoption, and an overview of a typical Adoption Area evaluation result. Performance in VDC adoption can be measured in terms of two dimensions: Organization, which is concerned with level of involvement and proficiency of the stakeholders in a project team, and Process, which assesses the interactions and relationships between stakeholders and their impact on project performance.

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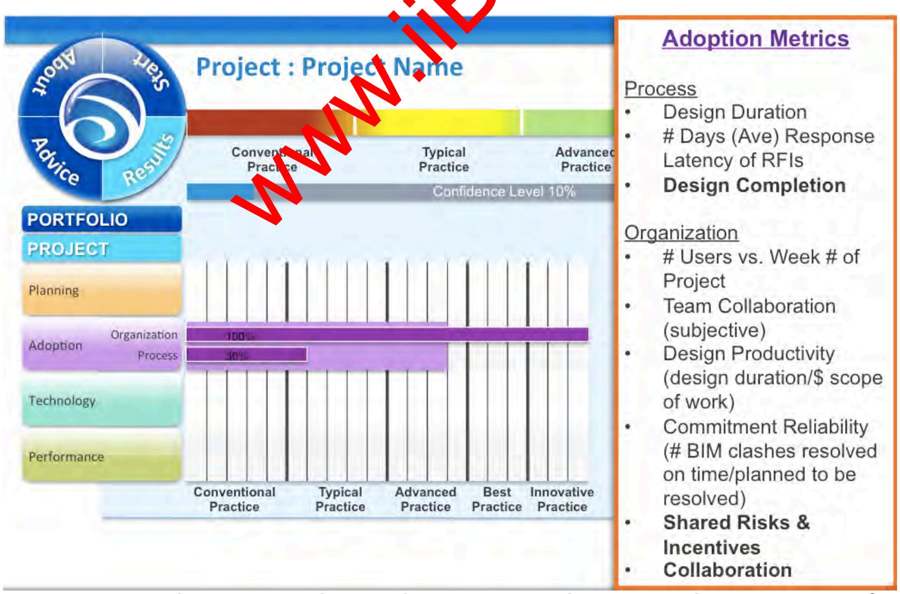


Figure 4: Typical metrics used in evaluating VDC adoption, and an overview of a typical Adoption Area evaluation result

### 3.2.1 ORGANIZATION DIMENSION

After a project team has decided upon a likely suite of VDC tools for an upcoming project, the next step is to consider the stakeholders involved, their roles and responsibilities, and their level of BIM proficiency. Technology can be an amazing tool to increase productivity, expand capabilities, and standardize and automate many tasks, but ultimately its performance depends on the practices and capabilities of its users. The organization dimension's scope includes, but is not limited to, the following questions and measures:

- How should project stakeholders be incentivized to improve VDC performance?
- How should VDC responsibilities be assigned? What stakeholders should be involved in the VDC process?
- What level of technology proficiency should each level of an organizational hierarchy possess? How should BIM be utilized at each of these levels?
- How can lean concepts be applied to technology training? Can training be "just-in-time" and "just-enough"?
- What are stakeholders' attitudes toward VDC? How can this attitude be improved?
- What are the appropriate phases to initiate each stakeholder's involvement? What are the major junctions when new stakeholders will enter a project, necessitating additional training and team alignment?

### 3.2.2 PROCESS DIMENSION

The process dimension evaluates the level of team integration, the temporal distribution of VDC implementation, and the project delivery methods. Although individual stakeholders may be very proficient with BIM tools and processes, this does not ensure high performing VDC implementation throughout all project stakeholders. This requires integrated collaboration and communication among the team to ensure models and other information is effectively shared and used throughout all project phases. The Process dimension's scope includes, but is not limited to, the following questions and measures:

- What meeting protocols are in place? How can meeting effectiveness be maximized with BIM and VDC processes (e.g. Integrated Concurrent Engineering, i-room, Big room)?
- What is an appropriate project delivery method? Should IPD or Design Build delivery methods be considered? What are their benefits and drawbacks?
- Are VDC process benefits being documented and tracked? How many more design alternatives are being evaluated? Is there a tighter synchronization between design and fabrication? Is waste being minimized as part of BIM-enabled Lean processes?
- How can BIM be leveraged in early design phases, or during closeout and O&M?

## 3.3 TECHNOLOGY AREA

In contrast to the Adoption area, which focuses on the people and processes supporting technology, the Technology area evaluates the actual tools and analyses employed throughout a project. Misguided implementation of new tools, ineffective information exchanges, and inefficient modeling practices can all contribute to poor project performance. Ensuring all tools and model uses provide direct support of project goals is essential. By considering the specific BIM tools and their information content over time, a project team can create a technology roadmap aligned with planning objectives and stakeholder interests. Figure 5 illustrates some the metrics involved with assessing VDC technology, and an overview of a typical Technology Area evaluation result. The

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Technology area divides the assessment of BIM tools and model uses among three dimensions: Maturity, Coverage, and Integration. These three dimensions provide a tiered evaluation of the technology utilized on a project, considering the analyses and models used during design, their information content and level of detail, and how well this information is exchanged with other applications.

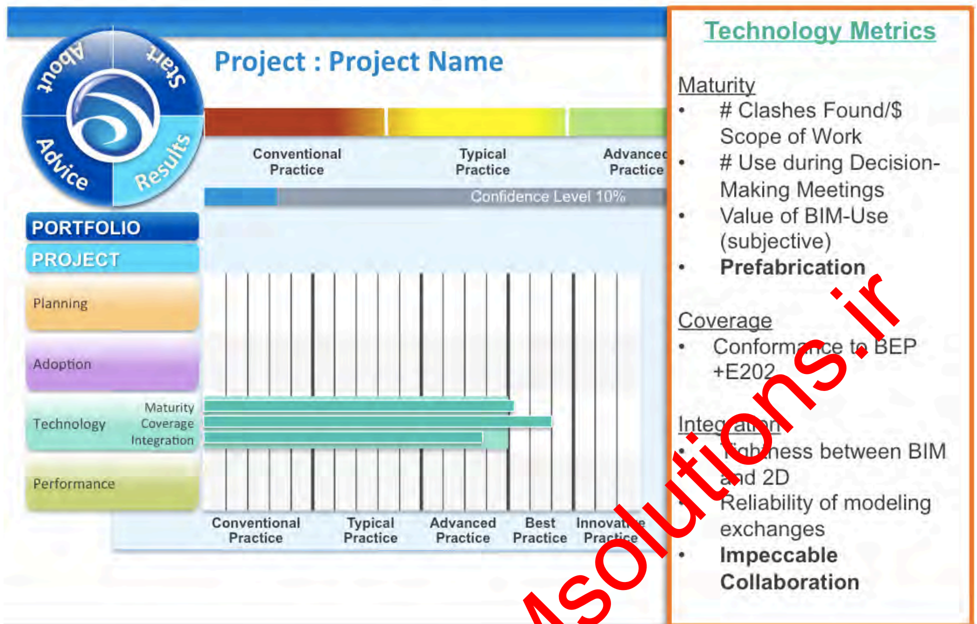


Figure 5: Typical metrics used in evaluating VDC technology, and an overview of a typical Technology Area evaluation result

### 3.3.1 MATURITY DIMENSION

Technology Maturity is based on five levels of model uses, with each level considered as more mature then the levels preceding it. Categorizing model uses in this manner makes it easy for a project team or enterprise to identify applications of BIM that will help them more effectively achieve their objectives, and ultimately deliver a higher quality project to the client and end user. Each of these levels of maturity will be discussed below, in terms of the typical applications, value-adding potential, and design productivity improvements.

[1] Visualization

Using BIM for visualization is considered the least mature model use, and although it is undoubtedly valuable, it is typical of conventional VDC implementation. Using BIM for visualization includes renderings, walkthroughs, mass model studies, and simplistic 4D animations used primarily for presentations. BIM for visualization represents a significant improvement over 2D drawings, as it provides a means to efficiently and effectively convey design intent and better inform design decisions. However, although it is powerful, BIM for visualization is only scratching the surface in terms of properly leveraging BIM.

[2] Documentation

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BIM for documentation includes generating construction documents from a BIM, incorporating product or system specifications into models for facility management, using laser scanning to verify as-built conditions, or performing quantity take-offs for estimation or historical records. This level of model use extends beyond visualization, in that it uses the model to assist with typical design and construction documentation tasks, greatly improving productivity through both enhanced efficiency and reduced rework.

[3] Model-based Analyses

Model based analyses refer to a wide range of simulations and analyses that leverage BIM to increase the accuracy of results, the efficiency in achieving them, and the overall quality of a design. Such analyses include spatial validations, structural analyses, daylighting and energy analyses, 4D simulations, and model based estimation. These are all relatively complicated tasks without BIM, but being able to reference 3D geometry and object attributes makes these analyses much more efficient and cost effective to perform.

[4] Integrated Analyses

In comparison to the preceding level, integrated analyses less trade and design specific, but instead combine multiple analyses and stakeholder interests into one analysis. Such integration is achieved in clash detection, which resolves conflicts between different systems and trades, and integrated scope-cost-schedule applications, which combine multiple construction management tasks into one platform. Other examples include supply chain management, which uses RFID tracking to better integrate fabrication, transportation, and delivery, or constructability analyses, which sequence and integrate trades to reduce field-generated changes. By integrating multiple analyses and stakeholder interests into one analysis, a project team can reduce information loss in information exchanges, consolidate data for quicker, more informed decisions, and increase overall design and construction productivity.

[5] Automation and Optimization

The most mature level of model uses, automation and optimization, refers to tools and applications that automate typical design and construction tasks. This includes software that automatically checks code requirements, such as circulation, egress, and ADA standards, or off-site pre-fabrication, which removes construction from the field to a controlled environment where efficiency and quality can be significantly increased. By automating typical tasks more design and construction alternatives can be evaluated, enabling better optimization among competing objectives and achieving higher quality designs. The increased design and construction productivity facilitated by this level of automation is integral to improving VDC performance, and will be a key factor in transforming the AEC industry.

### 3.3.2 COVERAGE DIMENSION

The Coverage dimension evaluates the level of detail and contents of models and analyses, which stakeholders control these factors, and how these map to and support the goals of the project. The level of detail included in models and analyses should change throughout project phases, reflecting the objectives of the project and the required accuracy for various stakeholders and analyses. An evaluation of coverage identifies where information content may be too detailed, or where detail is lacking, in order to improve efficiency and increase design and analysis productivity. The Coverage dimension includes the following questions and measures:

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- What components are modeled? What value does modeling these components provide? Where can model efforts be reduced?
- What is an appropriate level of detail for each phase, model type, and model-use?
- What model and analyses are being used by which stakeholders? How do competing stakeholder interests affect the model?
- What contract documents can be implemented to make coverage requirements explicit? What modifications need to be made to publicly available model progression specifications and contract exhibits?

### 3.3.3 INTEGRATION DIMENSION

The Integration dimension measures the interoperability between various technology tools and applications, and how a lack of mature information exchanges may affect project or enterprise performance. The lack of interoperability between various software platforms and stakeholder communication processes can have a significant financial impact on projects that is difficult to quantify, but a report by the National Institute of Standards and Technology (NIST) estimated the cost of inadequate interoperability in US capital facilities at $15.8 billion per year (Gallaher *et al*, 2004). These costs can be mitigated through close monitoring of information exchanges, in order to maximize their efficiency and effectiveness. To facilitate this monitoring, the Integration dimension focuses on measure and questions such as:

- Are the software and hardware adequate in supporting information exchanges?
- Is there information loss in the information exchanges? What is the business impact of this information loss? Is this impact quantified in terms of costs?
- What formats are used to transfer information? Are certain formats associated with more or less information loss or exchange inefficiencies?
- How often can models be re-used or reformatted for analyses? What is the cost impact of remodeling for certain analyses?
- Can information exchanges be mapped, indicating the stakeholders, formats, efficiency of exchange or required level of detail?
- Are best practices for information exchanges documented and shared from project to project?

### 3.4 PERFORMANCE AREA

The Performance Area is concerned with assessing the attainment and maturity of project or enterprise objectives, the performance of technology applications and uses, and the qualitative measure of satisfaction with VDC implementation. Tracking and monitoring progress toward achieving objectives is an essential part of guiding VDC adoption, ensuring actions map to project objectives, which in turn drive financial performance and client satisfaction. Of particular importance is the assessment of quantitative objectives, which provide an objective measure of performance in order to properly justify investments and VDC management decisions. An accurate measure of performance will identify problematic areas with the potential for improvement, and guide the formulation of new strategies, tools, and processes. Figure 6 illustrates some the metrics involved with assessing VDC performance, and an overview of a typical Performance Area evaluation result. The Performance area is composed of two dimensions: Qualitative, which is concerned with the assessment of non-quantitative objectives, and Quantitative, which assess the achievements and monitoring of objectives with numerical benchmarks of performance.



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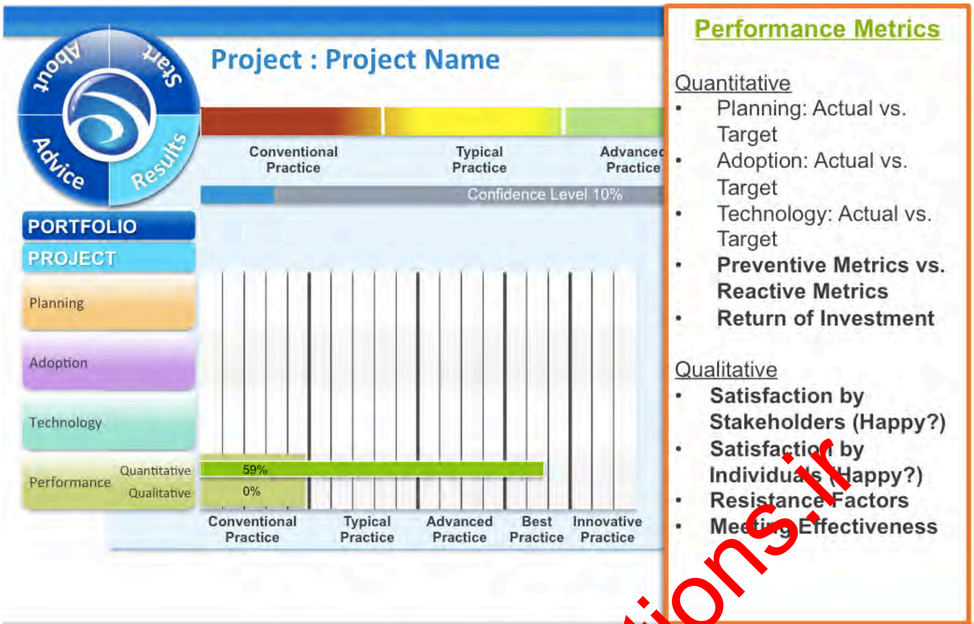


Figure 6: Typical metrics used in evaluating VDC performance, and an overview of a typical Performance Area evaluation result

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### 3.4.1 QUANTITATIVE DIMENSION

The assessment of quantitative objectives provides the most accurate and objective assessment of VDC adoption and its value. Measuring performance through metrics directly related to quantitative objectives can provide insights into the cost savings, time savings, and return on investment of BIM-enabled processes. In contrast, more generalized qualitative goals or aspirations for VDC adoption are prone to subjective assessments, with no grounding in concrete data. The assessment of quantitative objectives can solve questions and challenges such as:

- How can VDC and BIM reduce RFI latency and RFI creation time? How does this translate into cost savings over more traditional communication processes?
- What is an appropriate benchmark for the proportion of contingency used on in coordination and field initiated changes?
- What is the value of using BIM for increased prefabrication in terms of cost and time savings? Is the increased modeling effort worth the reduction in construction duration?
- Does modeling safety hazards or using BIM for safety planning reduce construction injuries? What is the value of a lower recordable incident rate enabled by BIM?
- By how much can model-based project management reduce the time to generate an estimate or revise a schedule? What is the value of this level of automation and the reduced rework?

### 3.4.2 QUALITATIVE DIMENSION

The assessment of qualitative objectives, although generally less valuable then quantitative objectives, is still merited in that it captures what numbers cannot: VDC user emotions, subjective evaluations based on human experience, and other challenges that that be described in numerical terms. Because they are not confined to objectivity, they can useful in making improvements where human emotion and opinions are the guiding factors to success. This is of particular value in answering questions such as:

- How satisfied are project team members with VDC and BIM coordination meetings? How important are these meetings, and what is their effectiveness?
- How satisfied are BIM users with certain applications, analyses, or information exchanges?
- How effective are BIM-enabled design reviews in terms of ease and quickness of understanding?
- How can BIM increase RFI and submittal clarity? How much does BIM improve communication satisfaction?
- What stakeholders are problematic with respect to VDC? Are any team members resisting VDC implementation or impeding its efficiency?
- What is the collective sense of goodness related to BIM implementation?

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## 4.0 SUMMARY

The BIMSCORE framework provides an objective mechanism to evaluate BIM/VDC planning and maturity, and to accurately quantify BIM's value to projects and enterprises. This represents a shift from typical subjective or notional assessments of BIM's value, to objective and quantitative evaluations of impact on project and enterprise performance. The BIMSCORE evaluation is informed by the four areas of Planning, Adoption, Technology, and Performance, which each have their own specific scope, dimensions, and scientific measures, yet are interdependent in terms of their assessment and contribution to the overall score. Applying this framework, managers and decision makers can easily identify strengths and potential areas for improvement, and focus their resources to generate greater value while considering any financial and human capital constraints. Therefore the BIMSCORE framework not only provides quantitative guidance in terms of VDC decisions and investments, is also focuses this guidance on specific areas and processes. The BIMSCORE framework and methodology provide quantified measures of project performance with respect to VDC/BIM, actionable advice for improvement, and mechanisms to track acquisition of quantified goals. Moreover, BIMSCORE empowers forward progress in the larger challenge of increasing the productivity of the design and construction industry in order to optimize the value of the global built environment.

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# PRACTICAL USE OF B.I.M.: In Design and Construction For An Integrated Design / Build Approach

*Marc Howell; McCarthy Building Companies*
*John Vaught; Taylor Architects*

## INTRODUCTION

While the advent of B.I.M. is not a new term or concept, the following questions are still the most commonly asked;

Why utilize B.I.M. technology?
What are the practical applications?
What value does it bring and to whom?

In a 2002 study from the U.S. Department of Commerce Technology Administration and the National Institute of Standards and Technology (NIST), they presented a conservative estimated cost for inadequate interoperability in the U.S. capital facilities industries as $15.8 billion per year. This study included design, engineering, facilities management and business processes software systems and redundant paper records management across all facility life-cycle phases. Of these costs, two-thirds are borne by the project owners and facility operators.

According to a 2004 report, titled The Scope and Role of Information in Managing Construction, from the Stanford University's Center for Integrated Facility Engineering (CIFE), the overall productivity in construction has dropped from 1964 to 1998. While the manufacturing industry's productivity, during that same time period, has risen (6X).

We will illustrate that today's technology is not simply a conceptual design tool, or 3D coordination tool for clash detection, but a valuable and practical tool to be utilized throughout the design and construction processes.

## OVERALL APPROACH

Through the creation and implementation of a B.I.M. Execution Plan, the design/build team was able to establish an open information / communication protocol utilizing Autodesk (*.dwg) file format as the basis for exchanging basic model information.

The architect employed Revit as their design platform, while other designers utilized compatible

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programs and the general contractor used Autodesk Navisworks for coordination. This cleared the way for increased efficiency and collaboration.

The first step in the execution plan was to use the design models to create room template drawings for initial user review. These drawings consisted of floor plans, ceiling plans, elevations, and 3D images of each room from the design model for the client review and comment sign-off on.

Once sign-off was achieved for the templates, the design model was updated and then used to create panoramic renderings of each room. These renderings accurately depicted the volume, finishes, furniture, equipment and devices in each room. Hotspots were added to provide relevant specification information as well. The final results were posted to a website that is accessible to all team members including the contractor, designers, owner and users. On the website, team members are able to manipulate the camera view to achieve a complete 360 degree view of each space. This was used not only as a coordination tool but to document the desired design intent.

Finally, the design model was used to prepare full size, photo-realistic virtual mockups of selected spaces. The spaces chosen were the headwalls at the patient rooms, the pre-op bays and the PACU bays. The renderings were projected full size, room boundaries were marked off with tape and samples of the equipment and furniture schedule for the room were placed in proper relation to the projection. User comments were marked up electronically in real time on the projection. A digital copy of the final marked up projection served as the record of sign-off. The process reduced the need to construct a full size physical mock-up resulting in significant savings for the project.

As the design progressed, the design/build team utilized Autodesk Navisworks for clash avoidance methodology in lieu of clash detection. Whereby, each discipline would populate the coordination model in sequence avoiding the previous trade which significantly reduced re-coordination efforts and durations.

The coordinated model was then linked to the overall project schedule utilizing Synchro where logistics planning and phasing options were reviewed and modified as conditions change. This allowed all stakeholders to visualize the upcoming work and communicate it to; the installers, hospital staff and surrounding community.

To control all of the documentation, the design/build team created an electronic plan-room, where all project documentation created was; tracked, stored and exchanged electronically. For field use, all of the data was transferred to mobile devices and utilized for field layout and verification.

## RESULTS

As part of an ongoing case study of an acute care hospital project in California, this project consists of; a 200,000 square foot acute care hospital building and 14,000 square foot central utility plant designed, coordinated, plan checked and permitted in twenty-seven (27) months.

To date, the construction is thirty-five percent (35%) complete with less than one hundred twenty (120) total requests for information (RFIs). Through the open communication protocol and exchange of electronic information, the average response time for raising and resolving a question is three (3) days. Total cost of issues caused by missed coordination between the design and construction is less than two percent (2%) of the overall project cost. Due to the level of detail contained within the model and completeness of the documents, the project is currently sixty-five (65) calendar days ahead of schedule.

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## CONCLUSION

Why utilize B.I.M. technology?
What are the practical applications?
What value does it bring and to whom?

When combined with an integrated approach, B.I.M. as a tool can be very powerful. Utilizing current technology with a focus on providing value is the key to implementing practical solutions. It allowed us to provide a much higher level of detail and completeness in the documents incorporating constructability, logistics and cost certainty to all of the stakeholders.

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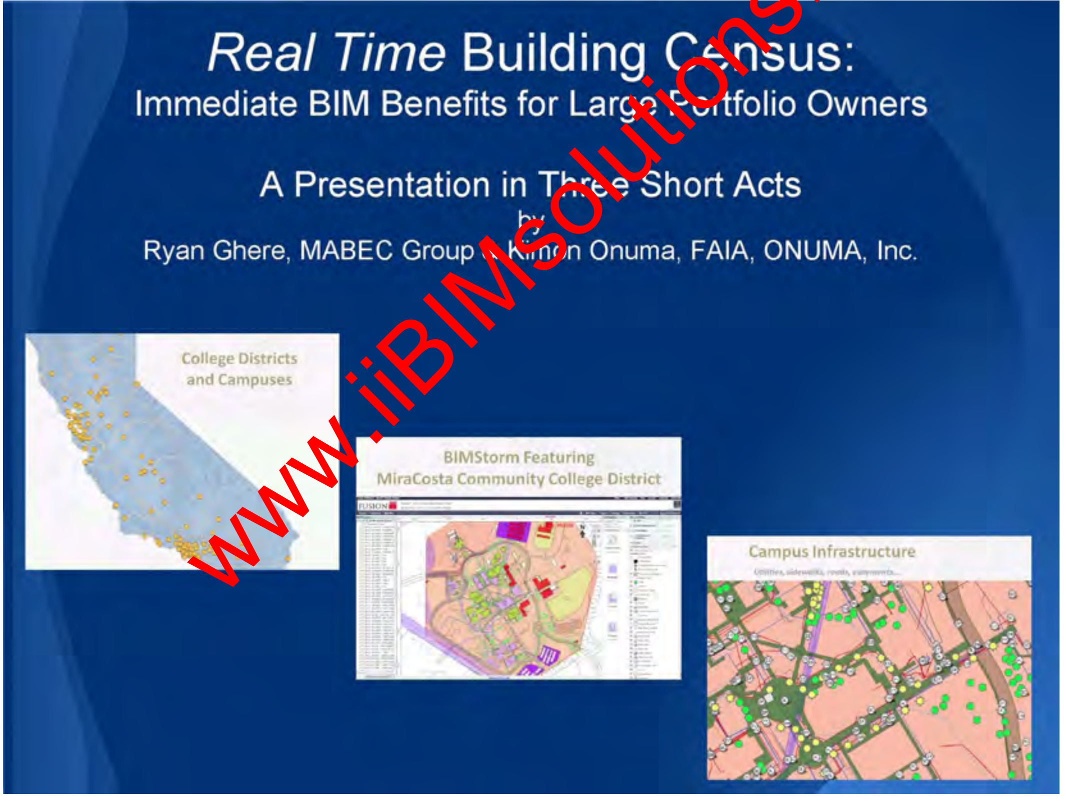
## REAL TIME BUILDING CENSUS:
## Immediate BIM Benefits for Large Portfolio Owners

*Ryan Ghere, MABEC Group*
*Kimon Onuma, FAIA, ONUMA, Inc*

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# Presentation Contributors

BIM Education Co-op members and supporters including Toby Considine, James Salmon Esq and Michael Bordenaro. Also, thanks to City of Carlsbad; California Community Colleges Foundation; Pasadena City College, Fort Thomas Board of Education, Energle; Opto22; Merlok, USC and others


Fort Thomas Board of Education, Kentucky - Highland High School Sports Facilities

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# Presentation Overview

1) Overview
 - Focus on Benefits

2) Five Case Studies
 - Online Real Estate Sales Company
 - City of Carlsbad
 - Fort Thomas Board of Education
 - California Community Colleges
 - Pasadena City College

3) Live Demonstration Q & A Session
 - Answered will be provided through a live demonstration of current capabilities

## What is a Real Time Building Census?

- It is a new way of looking at *information* you already have
- It is a way gathering *information* you never had
- It is a way to see all of this *information* mashed-up . . .
- . . . in real time . . . to gain immediate benefits


Pasadena City College Real Time Energy Report

## Benefits obtained by case study owners

*Energy management* – Pasadena Community College
*Improved sales* – Online Real Estate Sales Company
*Consensus decision support* – Fort Thomas Board of Ed.
*Visual Reports* – California Community Colleges
*Total Cost of Replacement Report* – City of Carlsbad


They gain benefits using Services Oriented Architecture to share data and increase productivity

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## Ways Attendees Can Benefit

If you are an owner:

- a company,
- an educational institution,
- a municipality, county, state of federal agency
- or any multiple building owner

. . . Real Time Building Census helps you save money <u>designing</u>, <u>building</u> and <u>***operating***</u> your facilities


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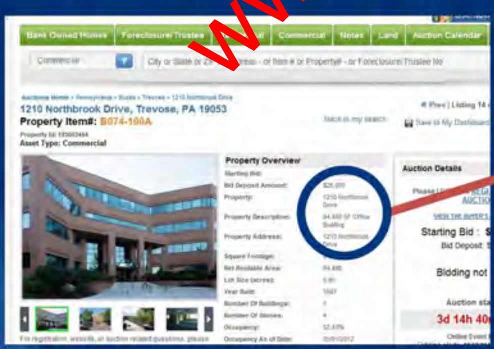
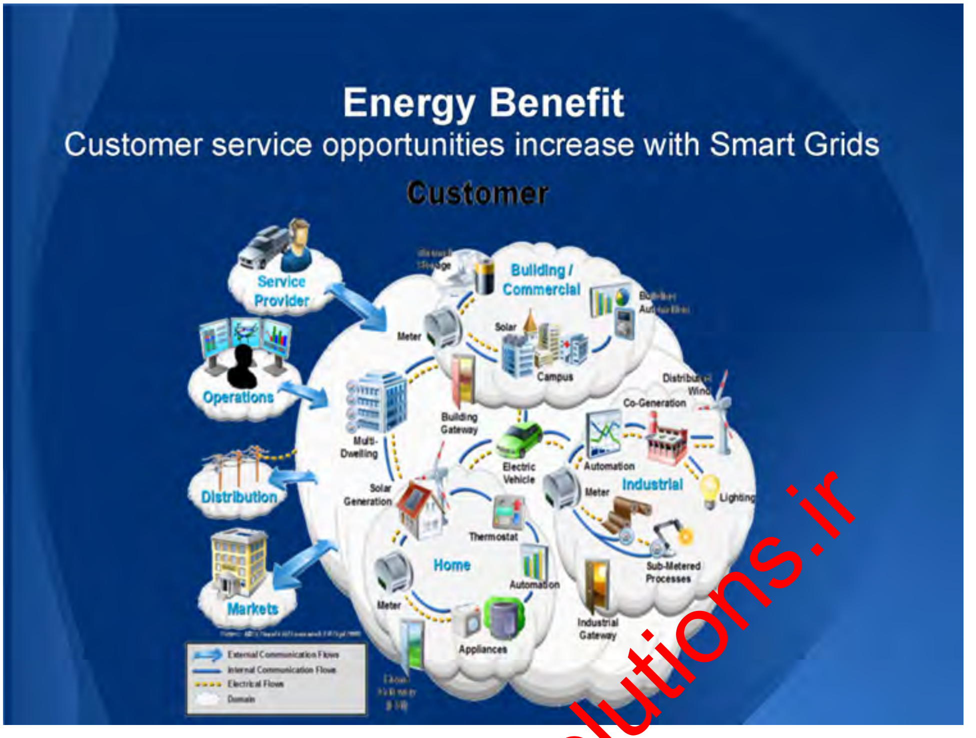
## Ways attendees can gain benefits

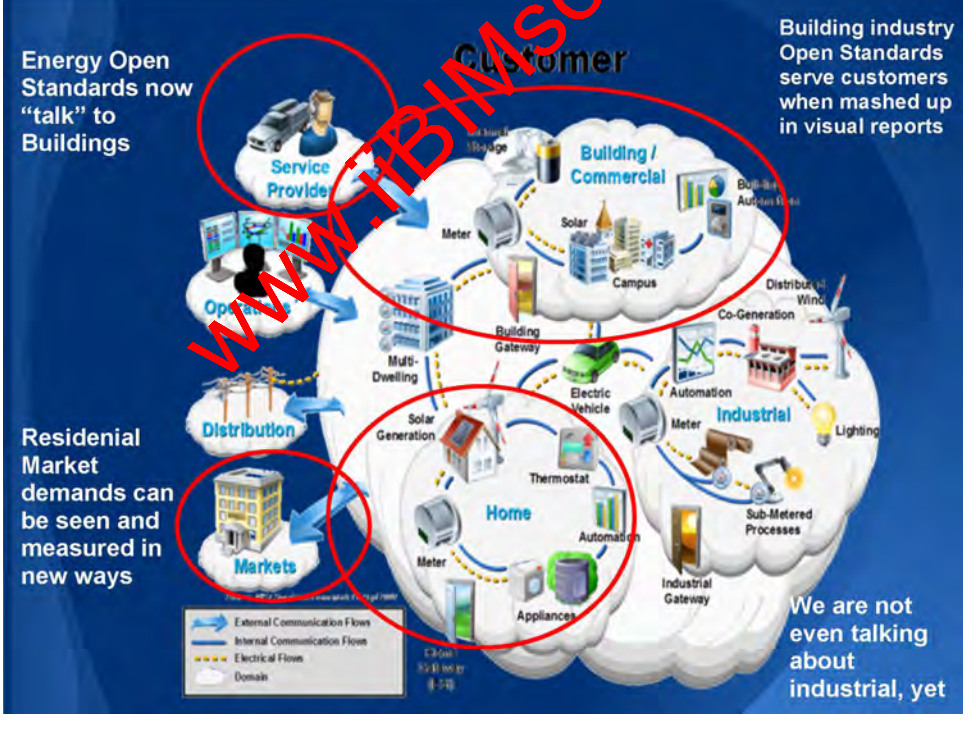
If you serve owners:

- provide clients with Real Time Building Census data that saves money and energy using any number of open standards based software programs




Property Description: 94,480 sf office building and all relevant data

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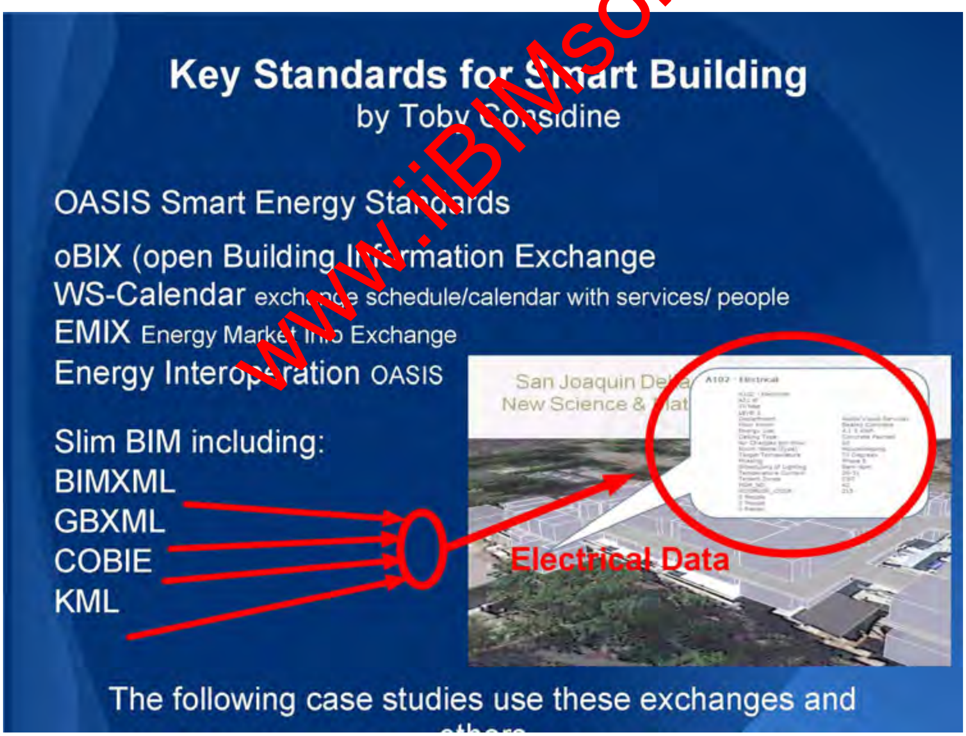


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## Case Studies

Case Study 1 – Online Real Estate Auction Company
Case Study 2 – City of Carlsbad
Case Study 3 – Fort Thomas Board of Education
Case Study 4 – California Community Colleges Foundation
Case Study 5 – Pasadena City College's IT Building



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## Online Real Estate Auction Company

Current Conditions:
- Good use of web-based processes
- Proven sales in 8 figures annually
- Open to process improvements with proven results

## Online Real Estate Auction Company

Step one

- Contextual visual model for abstract relational benefit by using Google Earth to orient customers to site

Existing, static data on the web


Dynamic, real-time data on the web

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## Online Real Estate Auction Company

Steps Two and Three

- Use SketchUp and other software to prepare model for interaction with other programs like Revit and Maximo

## Online Real Estate Auction Company

Benefits

- Develop advertising revenue based on market interests

- Increase "matching maker" sales by targeting responses to visualizations of different property types

- Increase buyer satisfaction to drive return business

- Gain empirical value from visual representation of data measured in increased sales

- Add data and value to ever improving visualizations

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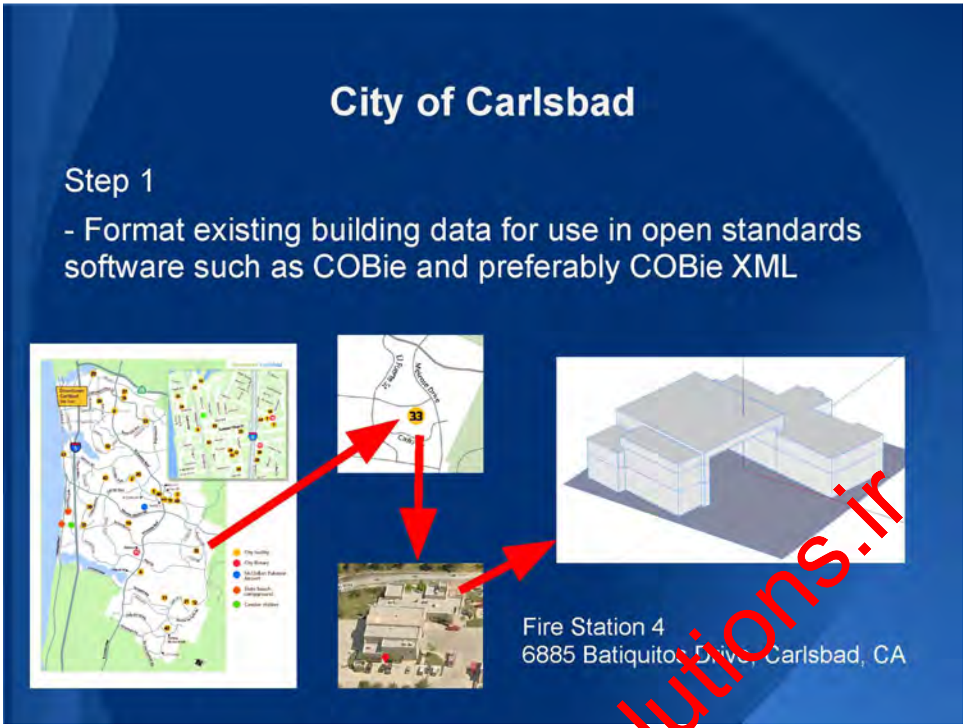
## City of Carlsbad

Current Conditions

- Same as every other municipality in the country . . . we need to decrease costs and improve value to citizens

- Work Order Management is a challenge

- Facilities insurance value is hard to establish . . . so a Cost of Replacement report is desired





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# City of Carlsbad

Step 3

- Run reports in desired programs

| Site Information | |
|---|---|
| Name | City of Carlsbad Fire Station |
| Scheme ID | (S23_2136) |
| Gallery Link | BIM Gallery |
| Live Link | Site in Onuma System |
| Site Area | 2.02 Acres |
| Total Estimated Site Cost | $3,260,693 |

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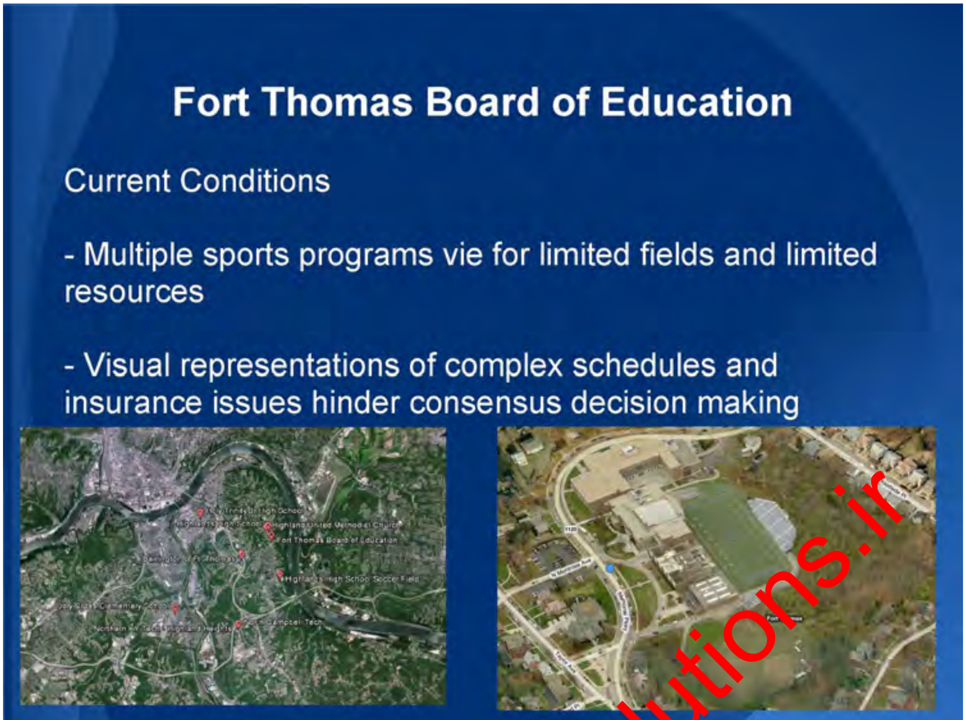
# City of Carlsbad

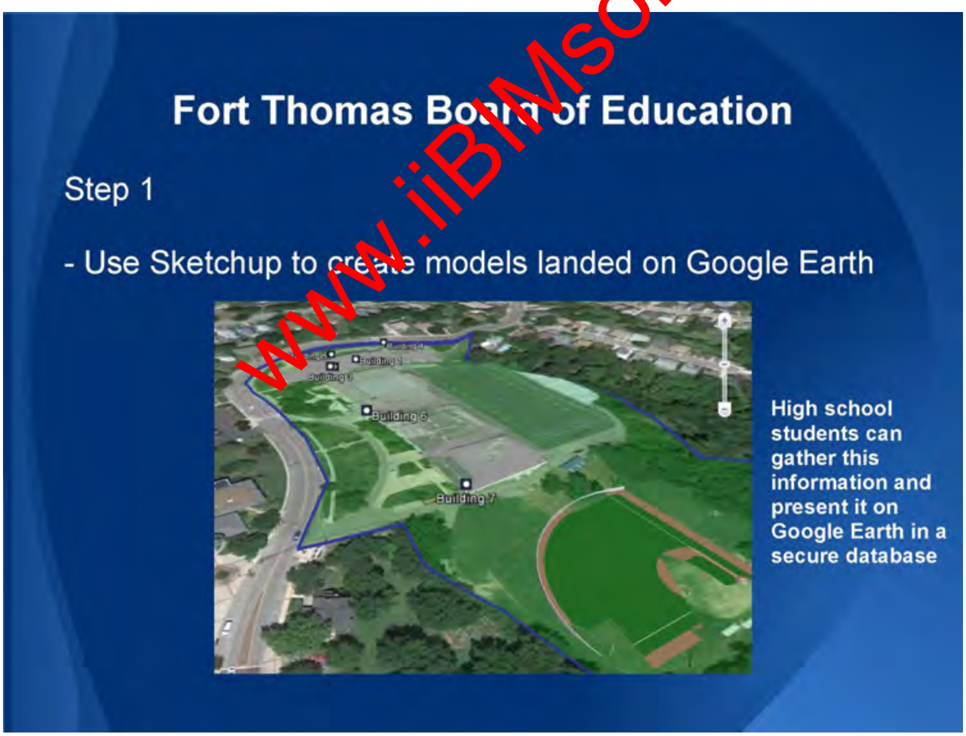
Benefits

- Work Order Reports

- Total Cost of Replacement Reports

+/- 640,000 square feet of building space at 52 Locations

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## Fort Thomas Board of Education

Step 2

- Use open standard compliant software to plan options that visually represent complex issues of many kinds


Much web-based software allows data to be shared in a "mash up" to plan potential scenarios, including field design and scheduling

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## Fort Thomas Board of Education

Step 3

- Generate visual reports with input from all stakeholders


All types of information can be included and related in custom reports attributed to specific people

## Fort Thomas Board of Education

Benefits

- Allow girls and boys equal access to the mind-body benefits of being a student-athlete - abstract value

- Avoid Title 9 Litigation - priceless


Data can be reviewed and approved in transparent processes that allow people to say "I see what you are talking about."

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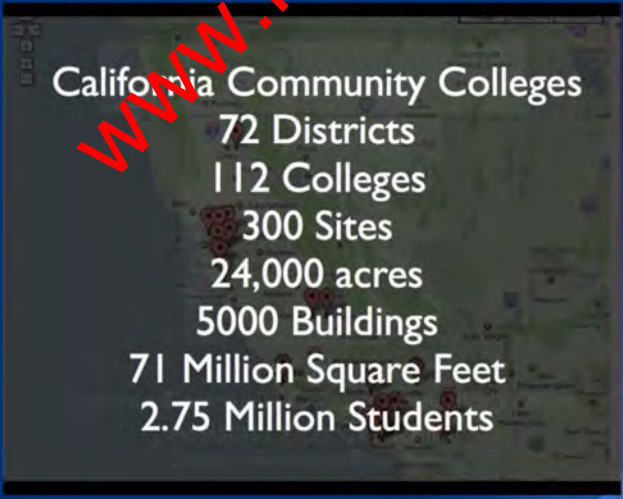
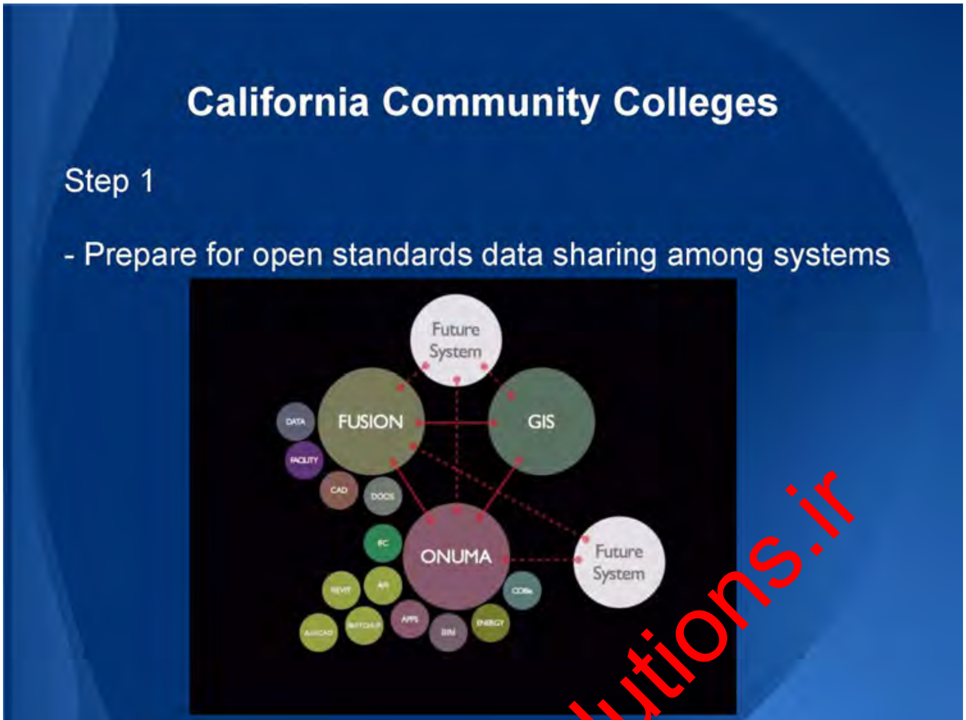
## California Community Colleges Foundation

Current Conditions: Support the following . . .







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## California Community Colleges

Step 3

- Roll out with a campus-by-campus approach


Fred Harris
CCC Finance VP
indicates that
Real Time
Building Census
data improves
planning and
operations

## California Community Colleges

Benefits

- Improved annual reporting to the Chancellor
- Eliminate need for facilities data collection every year
- Class scheduling coordination
- Improved project management
- Departmental space allocation confirmation

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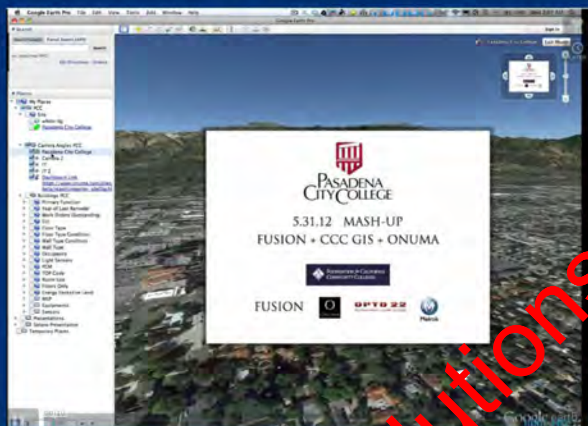
## Pasadena City College

Current Conditions

- Advanced understanding of data sharing allows "mash-up"

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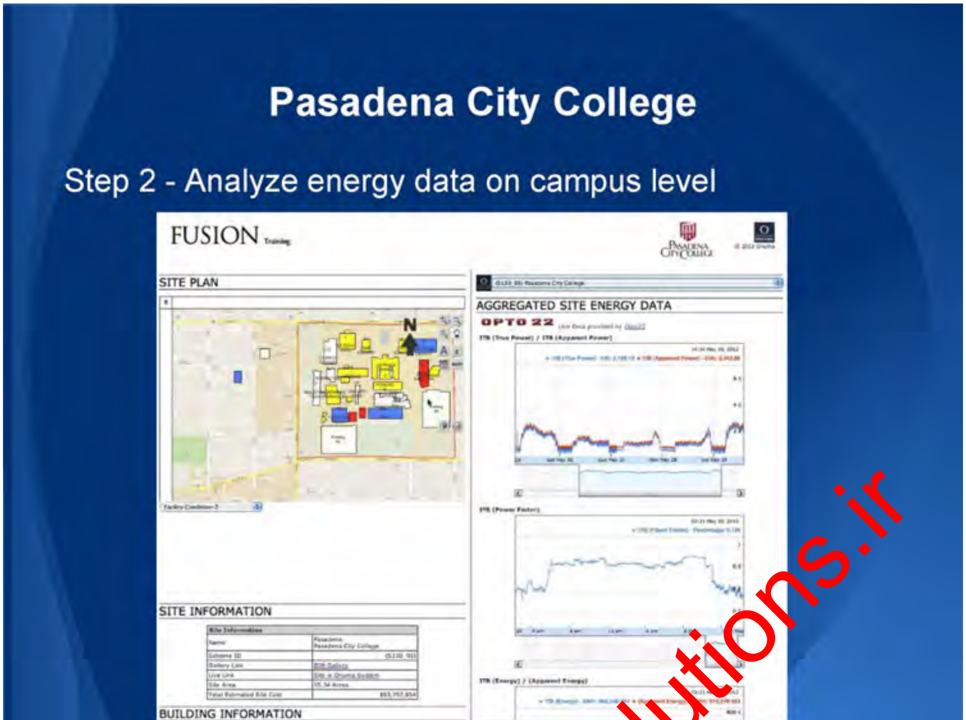
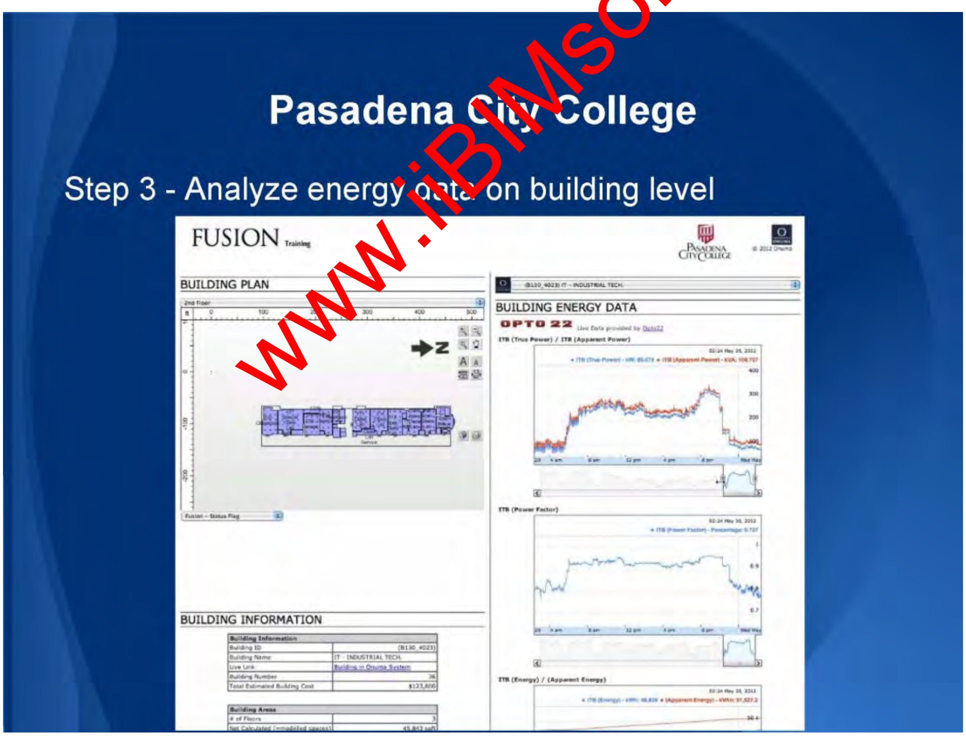
## Pasadena City College

Step 1 - Mash up data together using proven processes

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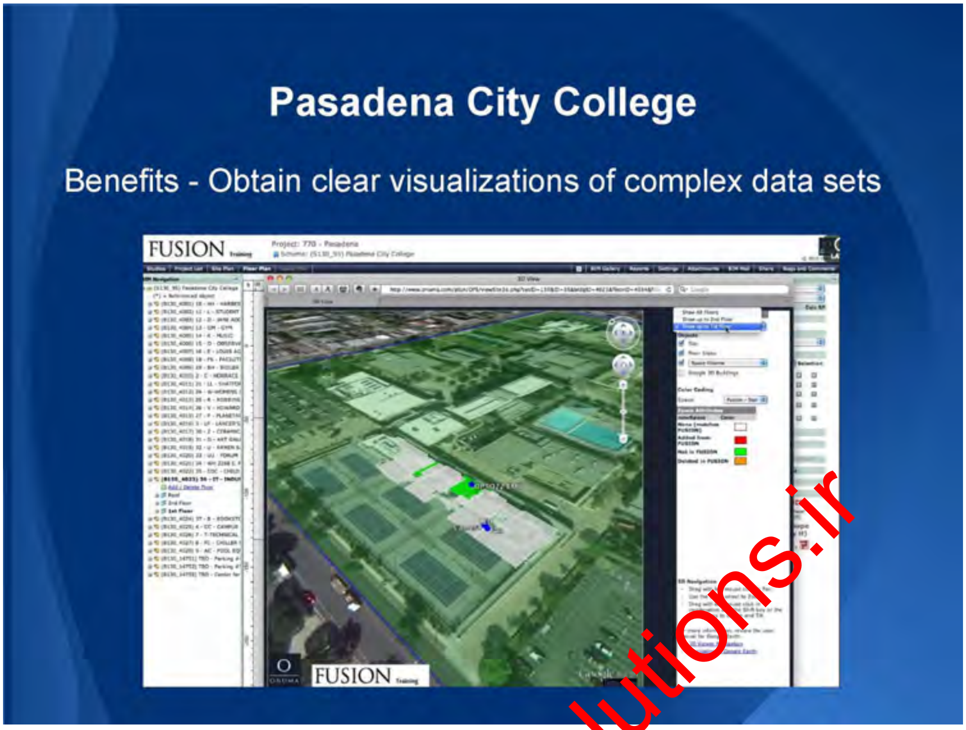


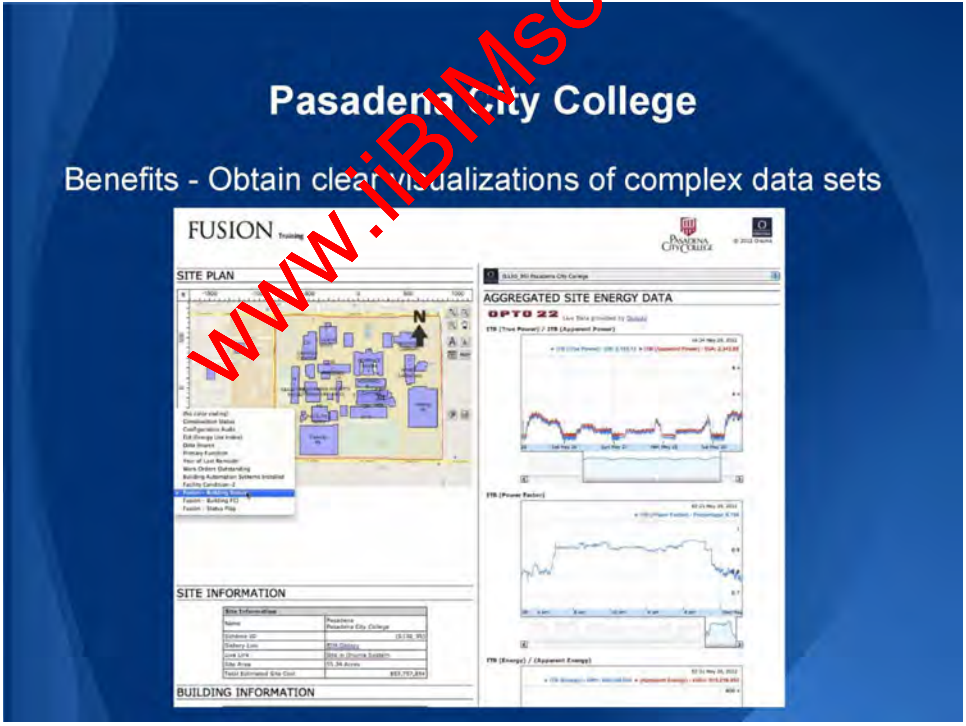


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## Conclusion

- More is possible today than most realize

- Web-based, open standard compliant software allows extensive data sharing for a *Real Time* Building Census

- Energy Management and Smart Grid participation is a key result from establishing a *Real Time* Building Census

For a *Real Time* Building Census Action Plan PDF, contact Ryan Ghere: rghere at MABECGroup dot com

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## *Real Time* Building Census:

### Immediate BIM Benefits for Large Portfolio Owners

A Presentation in Three Short Acts

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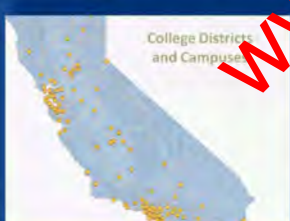
Kimon Onuma, FAIA; Ryan Ghere; Michael Bordenaro; James Salmon, Esq; Toby Considine; Bob Smith, PhD, and other BIM Education Co-op supporters





# *Real Time* Building Census:

## Immediate BIM Benefits for Large Portfolio Owners

### Questions & Answers

Robert "Bob" Smith, PhD, Professor Emeritus, California State University pre-submitted a question to get discussions started. He assists Green Energy efforts that involve an Enterprise Energy Management Information System prototype for five cities.

Bob asked if the Pasadena Community College Energy Management systems can be demonstrated live.

He would like to see energy use analysis reports a municipality, such as Huntington Beach, can use.

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# SMALL GREEN BIM:
## Using Climate to Compute Form

*François Lévy, AIA, AIAA; Principal, François Lévy, Architect and Partner, synthesis-intl.*

### ABSTRACT

Building information modeling (BIM) is often discussed in the context of large architectural projects, whose energy performance tends to be dominated by internal loads and more weakly affected by climate. Small building energy performance, however, is strongly climate–– dependent. This paper discusses the largely untapped potential to leverage the geometrical and attributed data of BIM to aid practitioners in making improved design decisions for climate–– indexed projects. Use of such a sustainably–oriented workflow may also support quantitatively–validated architectural formalism.

### INTRODUCTION

Rapid developments in building design and analysis software over the last decade, coupled with advances in desktop and laptop computational power, have led to the emergence of digital modeling processes for the design and documentation of buildings: BIM. Its proponents promise a more collaborative design process among stakeholders (AIA 2007), greater production efficiencies, increased conflict detection (Post 2009), and fewer documentation and construction errors. Much of the professional and academic BIM conversation has focused on large projects and by extension large architecture firms. In part this has been due to the early adoption of BIM by a few such firms and the technology's early inroads among large construction firms and facility owners, who saw the construction efficiency and post––occupancy value of BIM, respectively. Small firms and projects have until very recently largely been ignored. This may be for a variety of reasons including possible technological lag among small firms, and the perception that such projects do not warrant the time and computational investments implied by BIM. This is unfortunate and represents a missed opportunity, not only because the efficiencies that larger practices enjoy from the exploitation of BIM models are also available to small–– and medium––sized design studios, but because BIM may lend itself particularly well to design processes for climate–– indexed, skin––load dominated, sustainable buildings.

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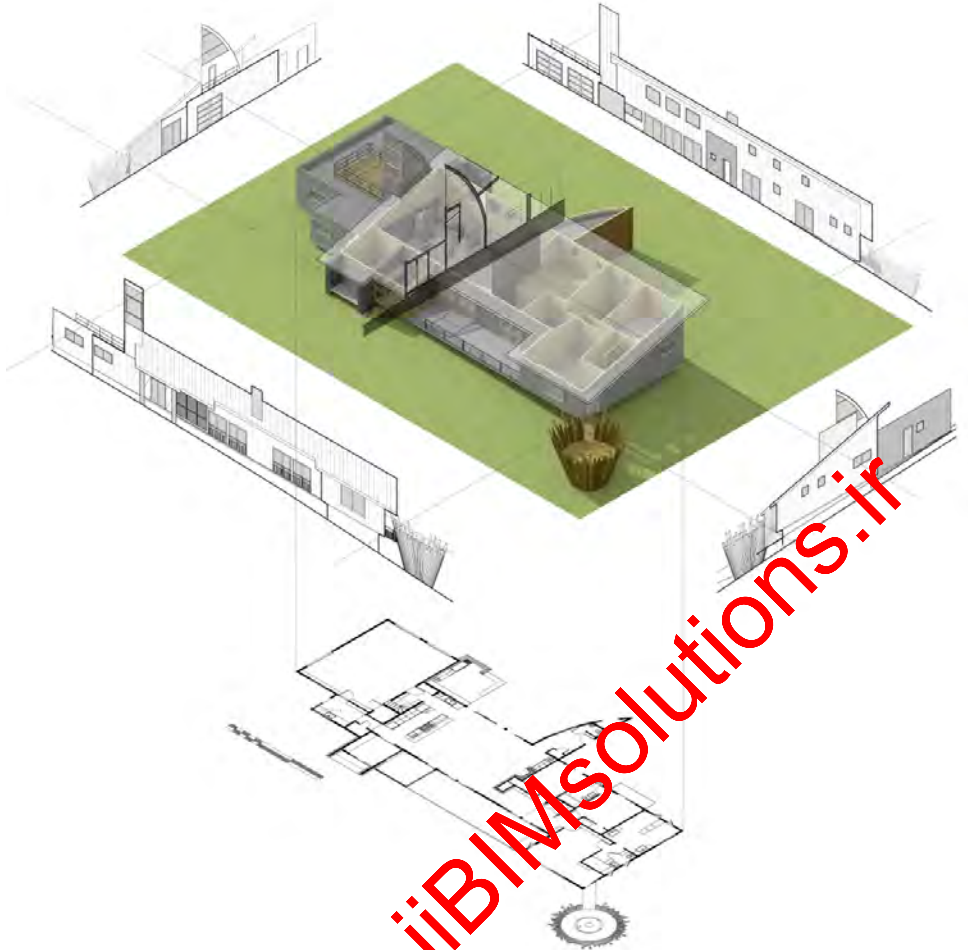

Figure 1. 2D views and reports are derived from a comprehensive BIM

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## BIM FOR DESIGN

BIM--authoring software applications combine three- or four- dimensional models with imbedded intelligent building objects related in a contextual database. As a result of BIM's data- rich 3D modeling, various design disciplines can extract and manipulate relevant tabular and graphical building views (reports and drawings, respectively) (Eastman, et al. 2008). BIM is less commonly thought of as a design tool, yet the ability to rapidly derive alternate, information--rich views of building models can yield an efficient and effective design process (Laiserin 2010). It might be borne in mind that even "construction documents" are not fabrication documents, but intended to convey design intent only (Simpson and Grant 2005A and 2005B).

BIM is well suited for this task. Moreover, the energy performance of smaller buildings is far more influenced by site and climate than their larger counterparts. Climate and how we design for it has a much larger impact on a small building's energy consumption and performance. Good quantitative data is essential for architects to make more intelligent choices about how they design all projects (Austin Energy 2000)—but especially small ones given their skin--load dominated energy performance. Hence BIM may be key to making quantitatively informed decisions in the early phases of design for high performance, skin–load dominated buildings. This represents an inversion of the habitual view of BIM as a tool for large projects late in the design process (construction documents). Furthermore, residential buildings alone represent nearly 20% of US energy consumption (US EIA 2009).

In addition to drawings, architectural project documentation in any design phase likely also consists of tabular views, including but hardly limited to:

- Door, window, fixture and finish schedules;
- Floor area takeoffs, either for the quantification of project or program scope, or to confirm compliance with land development codes;
- Material takeoffs, such as net exterior wall area, roofing area, concrete volume, counter area, and so on;
- Envelope energy code compliance calculations, confirming compliance with total thermal conductance codes;
- Lighting power density calculations, such as commonly required by energy code;
- Various building performance design guideline reports, such as rainwater harvesting calculations, passive heating or cooling calculations, and so forth (Levy 2012)

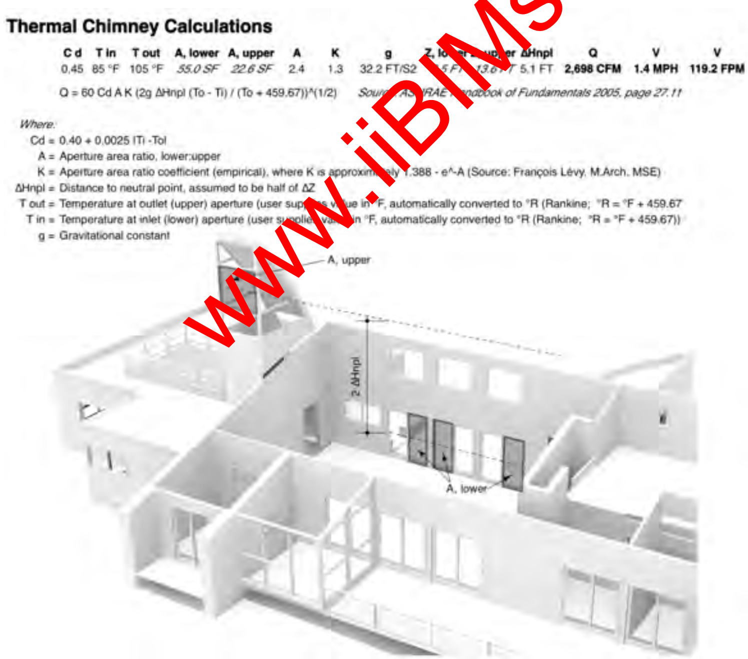


*Figure 2. Worksheets or reports applying rigorously derived design guidelines may be integrated into BIM, allowing the designer to optimize sustainable aspects of the project.*

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In a traditional drafted or CAD workflow, such tabular views are manually created and updated, if they exist at all as part of the drawing documentation; often they are separate and independent text or spreadsheet files. Creating and maintaining these schedules and reports can be a tedious and error--prone process. In BIM, the geometrical (length, area, volume, location) and characteristic (material type, cost, U--factor, etc.) data are either intrinsic to objects or can be readily assigned to them. Thus the creation (and just as importantly the updating) of these schedules and reports may be automated. Once established, such reports may be incorporated in standard project templates and leveraged for reuse in other projects.

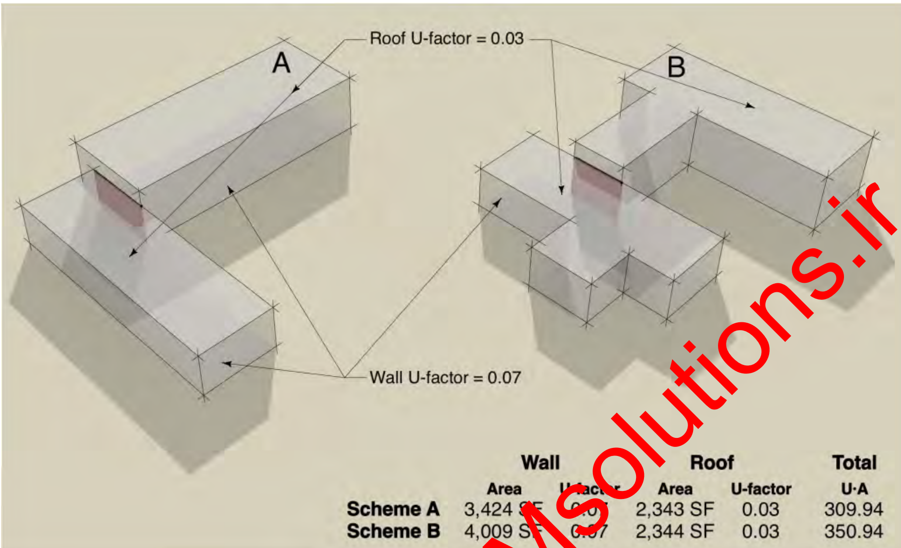


*Figure 3. BIM may be used to support quantitative validation of qualitative design process, even at LOD 100 (conceptual design). Here, two competing massing schemes are analyzed for respective thermal conductance using baseline envelope characteristics.*

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A commonly heard refrain is that BIM is "just a tool", independent of design. However, it is abundantly clear that technology influences the nature of design (Lyle 1994). BIM is far from merely a more efficient drafting environment or process. BIM is as much a potential design environment as it is for production, as BIM processes lend themselves to quantitatively informed design in a variety of design tasks, far beyond construction documents. Analyses that may be performed to help ensure improved sustainable building performance include:

- **Site analysis**: site modeling (DVA 2010), slope analysis, viewsheds, cut and fill calculations, and drainage analysis;
- **Massing analysis**: solar access (Bun and Perlin, 1980), volumetric studies, architectural contextual studies, and form--based code compliance;
- **Design for solar geometry**: shading device design, roof optimization, solar collection potential (Vliet 1982), and daylighting (IEA 2000, Reinhart and LoVerso, 2010);
- **Passive thermal controls**: south--facing aspect op.mization (Balcomb 1980), thermal mass analysis, total envelope thermal conductance (Grondzik, et al.2010), wind--driven and stack--effect natural ven.lation (ASHRAE 2005; Bahadoori 1978);
- **Building hydrology**: rainwater harvesting (Brown et al, 2005), roof and gutter design (SMACNA 1993), wastewater reduction (Nelson et al. 2008);
- **Material waste reduction**: envelope material use efficiency, cost analysis, sustainable

design guideline compliance, such as advanced framing (Lsitburek 2006).

Such analyses might be performed outside a BIM workflow, but may be more effective with BIM. This is hardly an exhaustive list of the design uses that an imaginative user may put into play in such a workflow, but it is nevertheless indicative of the potential for sustainable and climate-–indexed design that BIM represents. To ignore this potential is a missed design process opportunity. As a technological environment with inherent social ramifications, BIM has an impact on sustainable designers, and integrating BIM in practice is a green building challenge. At the same .me, there is evidence that excluding principals from the technical nature of design poses risks to the long-–term health of architecture practices (Jamieson 2011).


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*Figure 4. Optimal shading and solar collection analysis may be carried out within a sustainable design BIM workflow.*

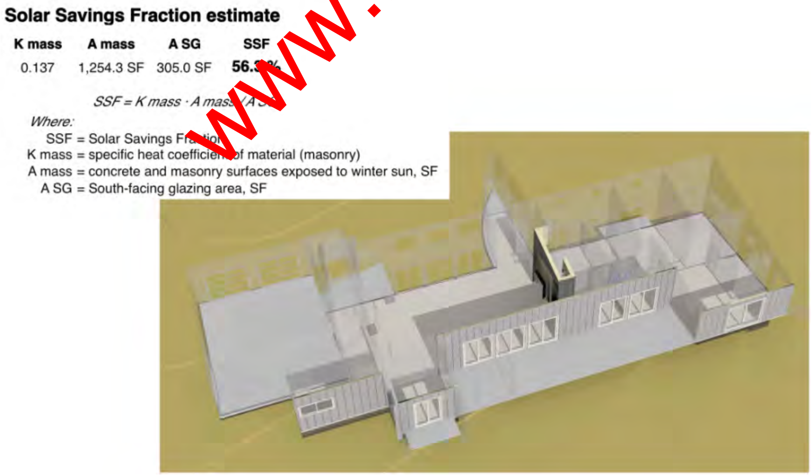


Figure 5. The user is free to filter building model components to selectively report appropriate data. In this case, south-facing glass is compared to exposed internal thermal mass to calculate the estimated Solar Savings Fraction (the theoretical improvement in performance of a passively heated building compared to a conventional one of the same size at the same location).

## CONCLUSION

BIM authoring tools do not, contrary to a common perception, necessarily force specific design selections prematurely. Such applications routinely include "generic" modeling elements (Anderson 2010) such as undifferentiated walls, slabs, roofs, and openings. These model elements are quite suitable to conceptual and schematic design phases of architectural design (AIA 2008). They also have the benefit, unlike pure "sketch model" digital artifacts, of being data-rich. Such inherent geometrical and potentially assigned data may be mined and manipulated in sustainably-oriented, design guideline worksheets, reports and tools whose expert use may lead to improved performance of climate-indexed buildings, particularly smaller, skin-load dominated architectural projects (Levy 2012).

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# How Do You Set Up A BIM Enabled Collaborative Framework?

*Viktor Bullain, Regional VDC Manager, Turner Construction*
*Chris Everist, LEED AP Senior VDC Engineer, Turner Construction*

## ABSTRACT

In response to market demand to improve the way construction projects are delivered, owners are requesting projects "utilize BIM technology". BIM technology as a tool has proven to deliver efficiencies, however, the success of BIM implementation is challenged without an organized collaborative framework set up to support it, or the people invested to work within it.

In this paper we describe the implementation of an integrated planning process where all project key stakeholders agree on project goals early. The team identifies together, how as a group they will invest in their people, steadfast commitment to improving processes, and the tools required reaching these goals. Definition of project standards starts with clearly understanding what the desired results are. Only then can the team begin to set up an organized project framework.

Some benefits of a collaborative approach to "utilizing BIM technology" within an organized framework include maximizing communication, reducing waste, and spawning innovation. Implications of a collaborative approach to problem solving include higher confidence in preconstruction and construction, a safer job site, and enjoying the relationships with the people we work with.

## THE NEW OPERATING SYSTEM OF THE AEC INDUSTRY

Owners and Agencies are looking to improve the predictability of capital investment costs. More and more owners recognize the value of early collaboration, starting as soon as the concept phase. Specifically increasing predictability and reducing the risk of budget over-runs. Figure 1 below shows that despite of the difficult market conditions in the past few years, integrated delivery methods continued to gain popularity (Design-Build Project Delivery Used for More Than 40 Percent

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of Non-Residential Construction Projects).

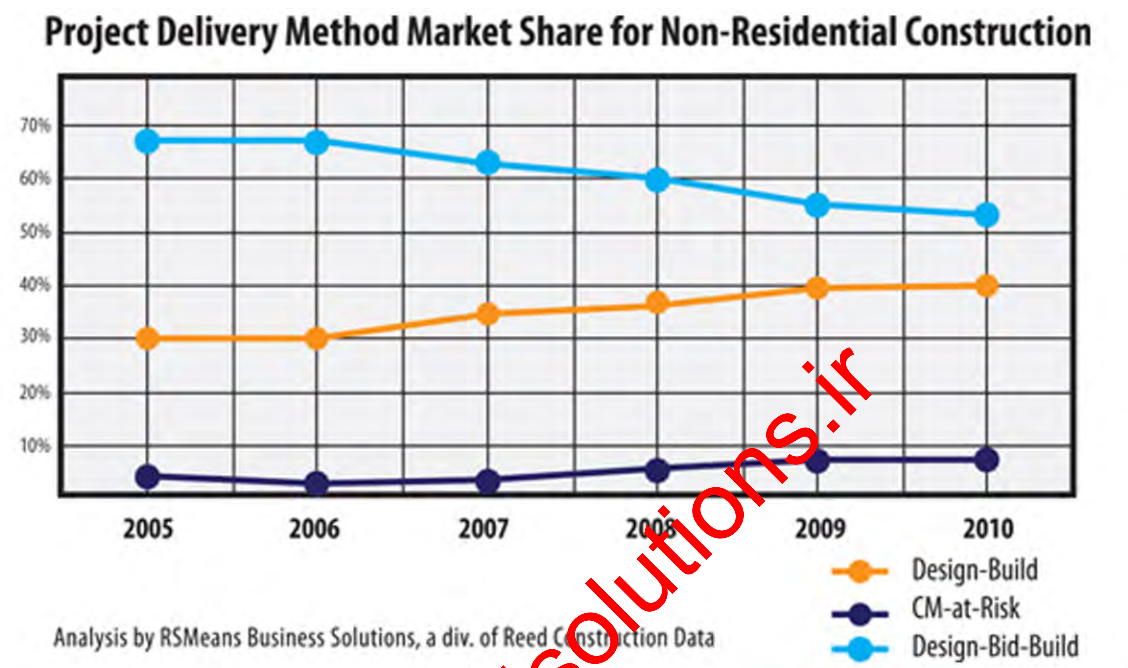


Figure 1

Design Build and Integrated Project Delivery requirements combined with the use of new technologies and lean production methodologies are dramatically shifting the way AEC teams collaborate. Lean processes are the new operating system of the AEC industry and BIM is one of the technologies driving this change.

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## HOW DOES CONTRACT TYPE AND DELIVERY METHOD IMPACT COLLABORATION?

Highest potential for collaboration is indicated in red in Figure 2:

| Project Delivery | Contract Type | Procurement Type |
|---|---|---|
| Design Bid Build | Lump Sum | Sole Source |
| Multiple Prime | Cost Plus Fee | Negotiation |
| Construction Management @ Risk | GMP | Qualification Based |
| Design Build | Target Price | Best Value Competition |
| | Unit Price | Low Bid |

Figure 2

Communication

Is maximizing communication between designers and builders a priority that owners consider when selecting a delivery method? Integrated delivery methods such as Design Build are set up to allow cross functional roles to communicate. Take for instance the Toyota's G21 project (known now as the Prius). The project engineer Takeshi Uchiyamada knew that he did not "know everything" so he "surrounded himself with a cross-functional team of experts and relied on the team" (Liker, 2004). The Prius project resulted in the creation of the "Obeya" system which means "Big Room". The "Big Room" is where experts were gathered to "review progress and discuss key decisions". The benefit of the "Obeya" system included not only the introduction of an innovative environmentally sustainable mode of transportation, but a significant reduction in product development time. "Toyota's product development process is now routinely down to 12 months or less for derivative vehicles in Japan, an impressive feat, considering that most competitors require twice as long." (Liker, 2004). How do we measure communication in the construction industry? The graph in Figure 3 compares the amount of communication over the project lifecycle between different delivery methods.

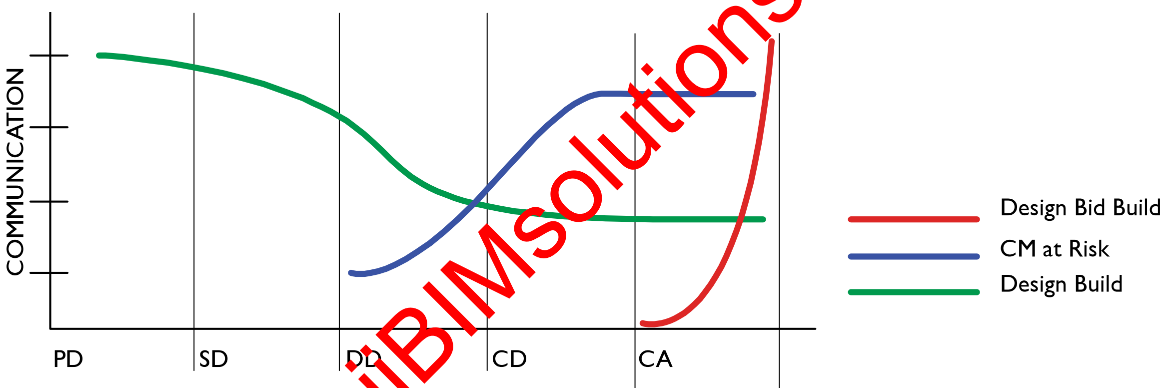


Figure 3: Communication Graph

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Waste

What are some examples of waste in design? The time and resources required to re-design can be considered waste. Our team leverages BIM technology to maximize cost and constructability feedback to design teams early to reduce the need to re-design. Maximized cost and constructability feedback has the benefit of reducing the amount of RFI's. How would you spend your time if you had less RFIs to manage?

## STANDARDS

Adoption rate of new technologies increases rapidly when standards are introduced (Abbate, 2000). The same is true for project teams in the AEC industry. When standards are agreed on upfront the ability of the team to communicate dramatically increases. The BIM Execution Plan captures the standards for the project and defines the goals, methodologies and procedures for collaboration.

### Implementation methodology

Wikipedia defines a methodology as a guideline for solving problems. Thankfully our industry has a set of predefined methodologies that structure the way complex problems are addressed. Typical complex problems in construction include estimating the cost of construction, specifying construction systems and scheduling and managing a sequence of construction activities. An integrated construction process starts by setting up naming conventions for not only file names but model content. Model content in Revit is referred to as "Families". Our team uses the Uniformat 2 Classification of Building Systems to define Family naming conventions because it represents building assemblies that are easier to translate into BIM objects than CSI material codes. These Family naming standards help cross discipline teams define a common language to structure the valuable non-visual information in a model. After agreeing on how model content is to be organized, we define how the information will be reported and delivered to the team. For instance, our integrated teams use a tool called the Content Plan to guide the modeling process. The Content Plan helps us outline the design content before executing the work. Once the design has been executed, the Content Plans becomes a framework for reporting quantitative information and system scope transparently to all stake holders.

Turner has developed in-house tools for checking and maintaining agreed upon standards across the project lifecycle. We use a Revit plugin that reports content organized according to the Uniformat methodology. Furthermore, the same plugin enables us to quickly rename sets of Revit model content from Excel.

## CASE STUDY

Many manufacturing teams have already realized the benefits of the Plan – Do – Check – Act (P,D,C,A) cycle (Deming, 1986). How often do we start implementing a technology without planning the process first? Most AEC project teams have been following the Ready – Fire – Aim cycle instead. Some planning at the beginning of the project can help reduce rework and increase the flow of information. A major private correctional facility owner and operator expressed interest in maximizing the value of BIM on new construction projects. In this short case study we will like illustrate the steps we took to implement BIM as a platform for collaboration.

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### Standards enable Social BIM

The team started by defining the goals for the VDC/BIM process using the BIM Execution Planning process. The BIM Execution Plan captured what the model would be used for and the input required to support the use.

Turner introduced The Content Plan process in the planning phase. Estimators used the Content Plan as a tool to request model scope and naming conventions based on an agreed upon naming schema from the design team (Figure 1). The Content Plan developed as a QC tool to measure what analysis was possible (Figure 2).

**Floors - Slab on Grade**
**Slab Edge**
**Foundation Walls**

| Assembly Code | Assembly Description | Designer Description |
|---|---|---|
| A1010 Standard foundations | | Footings / Grade Beams |
| A1010 Standard foundations | | Spread Footings |
| A1010 Standard foundations | | Strip Footings |
| A1010 Standard foundations | | Grade Beams |
| A1020 Special foundations | | Elevator Pit Slab |
| A1020 Special foundations | | Elevator Pit Walls |
| A1030 Slab on grade | | Slab on Grade |
| A1030 Slab on grade | | Slab on Grade Turn Down Edge |
| | | |
| | | |

Figure 4

**Turner Construction**
Quick Report

| Category | Family | Type | Assembly Code |
|---|---|---|---|
| Floors | Floor | B1010_3" Metal Roof Deck_STRUCTURAL_STEEL_3" | B1010400 |
| Floors | Floor | B1010_3" LW Concrete on 2" Composite Metal Deck_STRUCTURAL_CONCRETE_5" | B1010 |
| Structural Beam Systems | | Structural Framing System | |
| Structural Columns | W-Wide Flange-Column | B1010_W12X40_STRUCTURAL_STEEL_40 | B10 |
| Structural Columns | HSS-Hollow Structural Section-Column | HSS6X6X3/8 | B10 |
| Structural Foundations | Wall Foundation | A1010-CSF-4.0_STRUCTURAL_CIP-CONCTERE_24" | A1010110 |
| Structural Foundations | Wall Foundation | A1010_CSF-5.0_STRUCTURAL_CIP-CONCTERE_24" | A1010110 |
| Structural Foundations | Wall Foundation | A1010_CSF-3.0_STRUCTURAL_CIP-CONCTERE_24" | A1010110 |
| Structural Foundations | Foundation Slab | A1010_SL[illegible]_STRUCTURAL_CIP-CONCTERE_5" | |
| Structural Foundations | Footing-Rectangular | A1010_RS[illegible]X6.0_STRUCTURAL_CIP-CONCRETE_24" | A1010100 |
| Structural Foundations | Wall Foundation | A1010_CSF-[illegible]5_STRUCTURAL_CIP-CONCTERE_24" | A1010110 |
| Structural Foundations | Footing-Rectangular | A1010_SSF-[illegible]_STRUCTURAL_CIP-CONCTERE_24" | A1010100 |
| Structural Foundations | Footing-Rectangular | A1010_SSF-5.5_STRUCTURAL_CIP-CONCTERE_24" | A1010100 |
| Structural Foundations | Footing-Rectangular | A1010_SSF-5.0_STRUCTURAL_CIP-CONCTERE_24" | A1010100 |
| Structural Foundations | Footing-Rectangular | A1010_SSF-7.0_STRUCTURAL_CIP-CONCTERE_24" | A1010100 |
| Structural Foundations | Footing-Rectangular | A1010_SSF-8.0_STRUCTURAL_CIP-CONCTERE_24" | A1010100 |
| Structural Foundations | Footing-Rectangular | A1010_SSF-9.0_STRUCTURAL_CIP-CONCTERE_24" | A1010100 |
| Structural Framing | K-Series Bar Joist-Angle Web | B1010_18K7_STRUCTURAL_STEEL_18" | B1010350 |

Figure 5

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The organized B.I.M. Content, e.g. Revit families named based on the agreed upon methodology, increased the integrity of the models by increasing the flexibility and detail of the analysis. The design team set up a Family Template file that included most Family Types to be used for the project named based on the agreed upon naming schema. The use of the template significantly reduced variance in Family Types placed between individual designers. The designers added new Family Types by copying existing Families and renaming them based on the standards to represent other systems.

Design Coordination

When BIM content is organized; Navisworks search sets are more reliable and can be paired with one another at a higher level of detail. This has the potential to increase the quality and speed of the constructability review process. For instance, if structural foundations are named to include a specific code associated with structural foundations, they can be paired with underground plumbing named to include specific codes associated with plumbing. The benefit is being able to analyze smaller batches of work (Figure 3).

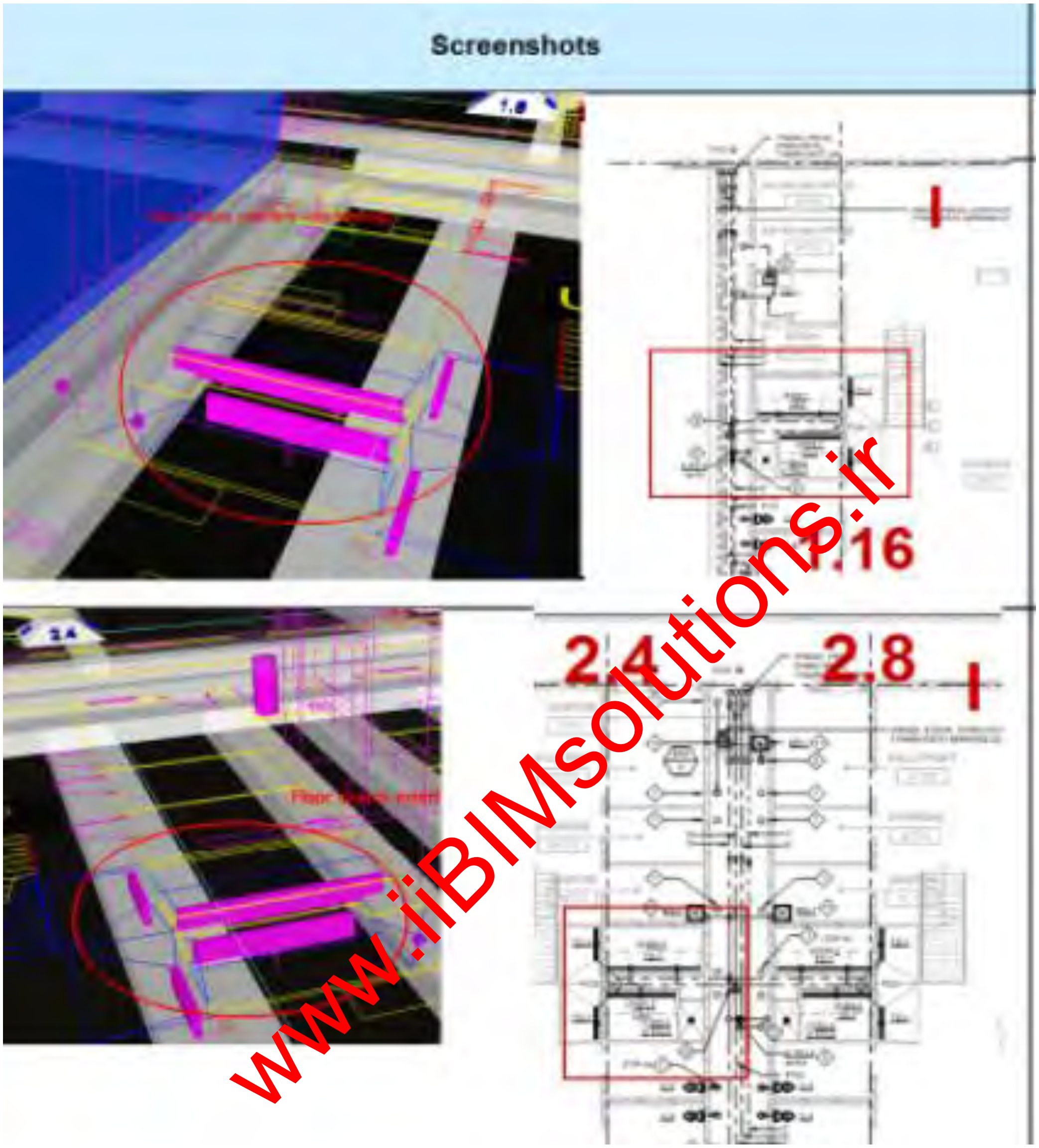

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Figure 6

## 5D ANALYSES, WHAT'S IN IT FOR ME?

The preconstruction team was able to extract quantities from the organized model (Figure 7) on a regular basis for estimate updates. The quantities reported based on a standard methodology were compared against subsequent quantities and trends were analyzed and compared to cost estimate trends. This analysis would not have been possible with a model that was not organized (Figure 8). The preconstruction team also linked the model to an identically organized database that included additional information such as productivity (Figure 9). This has the potential to automate and reduce the timeframe for construction cost estimate feedback and increase the reliability of schedules.

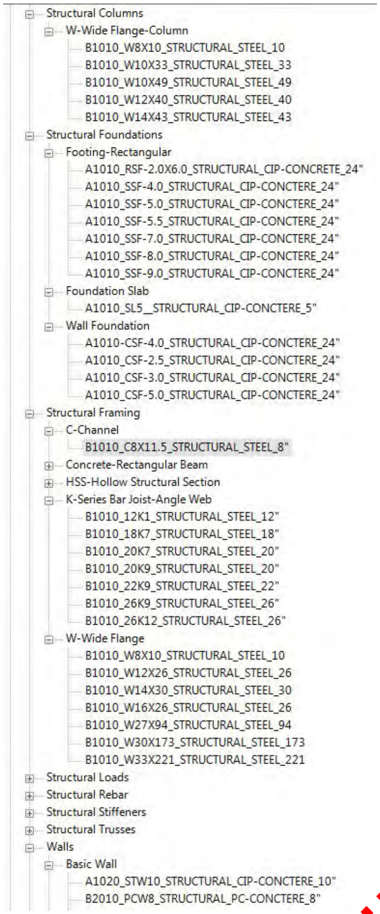



Figure 7

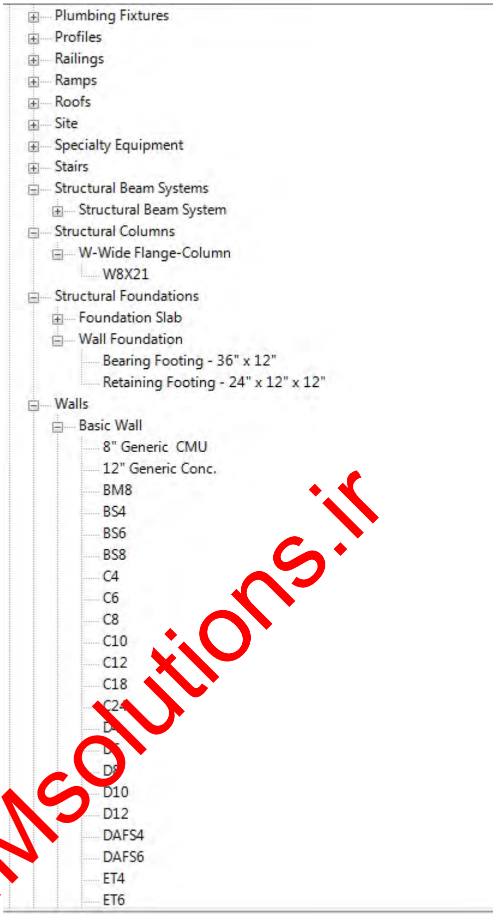
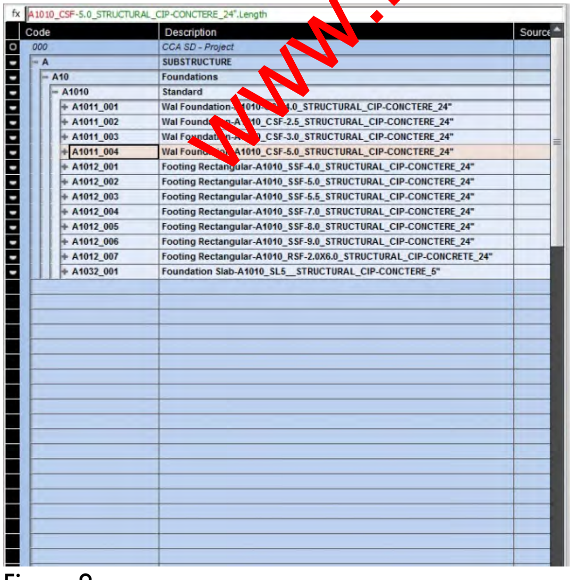



Figure 8



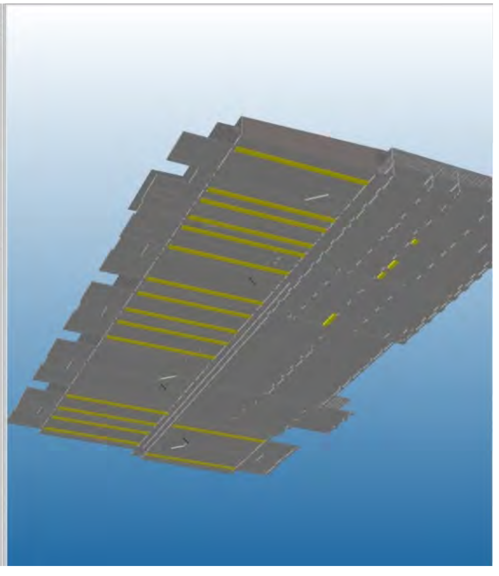



Figure 9

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## WHAT ARE THE BENEFITS OF ORGANIZED MODELS?

Why would a design team want to implement standards that benefit downstream use of the BIM?

- Cost feedback is 50% faster
- Design Changes are easier to manage due to Continuous Cost Control
- Less RFIs and less Change Orders reduce CA time
- What is the value of having fun on a daily basis and enjoying the relationships with the people you are working with?

Designers often continue designing after a package is released for estimate review. Typical review times can be as long as 3 – 4 weeks depending on the scope of the package. The cost feedback can impact the design in a significant way. If the review time is reduced and the cost feedback is available in 1-2 weeks, the risk of rework of the design is significantly reduced. Market conditions have been squeezing fees and project budgets since 2009. The need for more efficient project delivery is increasing. Project teams that understand how to collaborate with one another will be able to deliver projects faster and at a higher quality projects while not increasing costs. Planning for efficient project delivery however is not always achievable because of constraints of fragmented contractual relationships. Owners and developers need to be educated about the benefits of planning upfront so they can realize project savings and achieve higher operational efficiencies.

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# SNOWFLAKE THEORY:
# Project Based Approach to BIM Management & Level of Detail

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*Monica Lubag, BIM Specialist, Balfour Beatty Construction*

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## ABSTRACT

It has been said that construction projects are similar to snowflakes in that every single one is unique in its own way. It is our belief that due to this uniqueness the approach to a project should be unique as well in order to provide the most appropriate and efficient management strategy. This presentation will show 3 separate projects of different size and scope and how the BIM delivery differed in surprising ways for each in order to utilize BIM and Technology in the most practical way possible.

## Case Studies:

### San Francisco State Library Renovation and Addition:

This 7 story 300k+ SF renovation project is a strong example of pragmatic use of technology. This project was a renovation and addition to the J. Paul Leonard Library at San Francisco State University that consisted of the structural connection of 3 originally seismically separate structures. BIM coordination for the project was performed during the demolition and abatement phase of the project. This project exhibited very tight ceiling conditions so all major trades (Mechanical, Electrical, Plumbing and Fire Sprinkler) were involved in the modeling and coordination process to coordinate the spaces. While substantially complete through the BIM Coordination on the ground floor abatement and demolition was completed revealing some large discrepancies between design and site conditions. The biggest issue was the slab to slab elevation on the ground floor of the building. Deviations of up to 4" were found in areas which had as little as 24" of planned ceiling space.

To allow for corrective action for these problems an accurate field survey of the slab was needed. The first attempt involved utilizing Laser scanning then updating the model for the ground floor of the building the cost was over $7,000 a floor due to equipment rental/services. We then elected to manually measure floor to floor heights then update the models which on a comparable floor which amounted to a cost of only about $1,000 per floor. Ultimately it was determined that the 3D laser scanning provided much more detail than what was needed for our coordination efforts.

This practical approach to our as-built surveys was instrumental in our cost savings on the project and also extremely valuable for our implementation of BIM on the project. This project demonstrates how a practical value based decision steered us towards manual field measurements over 3D point clouds.

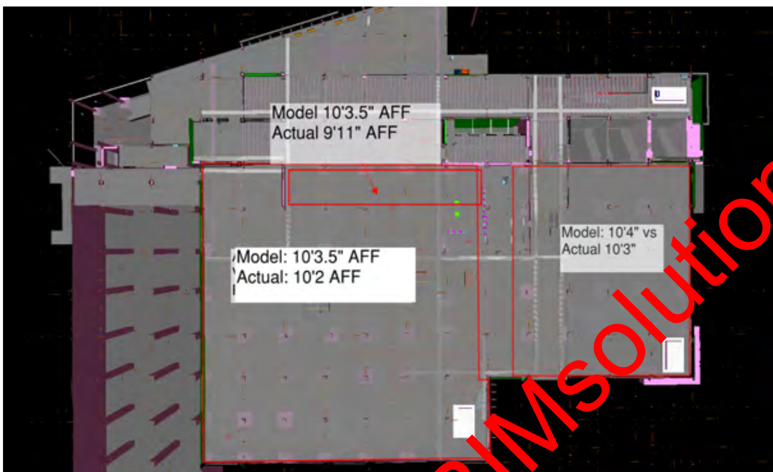


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Figure 1 - Image showing up to 4" discrepancies on slab height

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Figure 2 - image showing the example of manual field measurements

**Palomar College Theater Renovation and Addition:**

This approximate $17 million theater renovation and addition project for a Community College in San Marcos California exhibited a highly congested site with existing utilities surrounding it. At the start of preconstruction there were 3D models available for Architectural, Structural, Mechanical and Plumbing but none for Existing Conditions. This project exhibited a tight schedule for the underground installation and its congested existing condition was a concern that was limiting our ability to properly plan the layout for the underground systems. To address this concern a combination of Ground Penetrating Radar, as built surveys, and a considerable amount of field verification/potholing was used to produce an 'Existing Conditions' BIM. This existing conditions BIM was utilized to enhance our design review and value engineering efforts during the preconstruction phase. It also enabled underground coordination the moment the subcontractors were brought on board to the project. With these conditions being documented well before construction some potentially severe and no doubt costly design issues were avoided and allowed this projects to stay on track with little added cost. Because of the availability of the 3D Existing Conditions model a notable change order saving approximately $50,000 was as a result of our underground Electrical/Telecom duct banks being rerouted along a shorter path.

This case study will demonstrates the value decisions early on in the project planning that lead the construction manager to go above and beyond typical BIM delivery for a project modeling more than typical and how it can benefit the project as a whole.

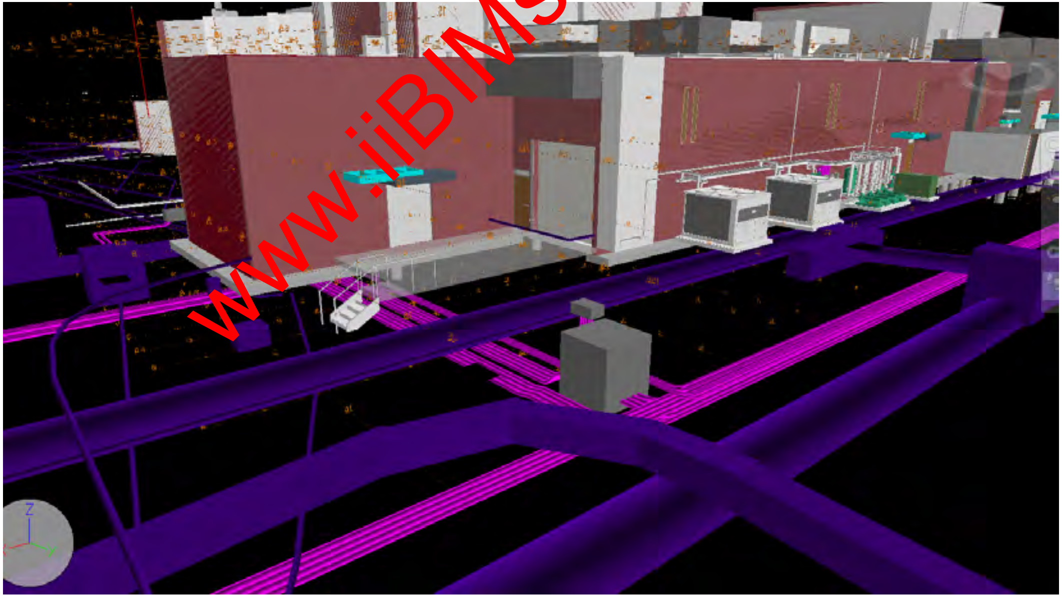

Figure 3 – Underground models for coordination Exiting Condition-Purple

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**Tustin Multi-Purpose Building**

This project involves four Activity Centers at Columbus Tustin, Hewes, AG Currie, and CT Utt Middle Schools in Tustin, California. The first site is laid out with the classrooms and performance area on the east end of the building while the next three sites feature the classrooms and performance area on the west side.

Figure 4 – Rendering of Front of facility

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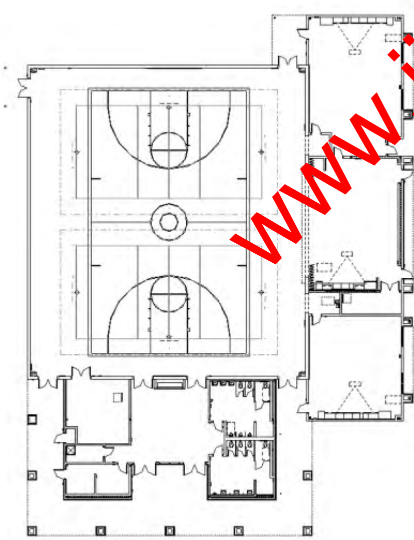

Figure 5: The Columbus Tustin Middle School Activity Centers floor plan

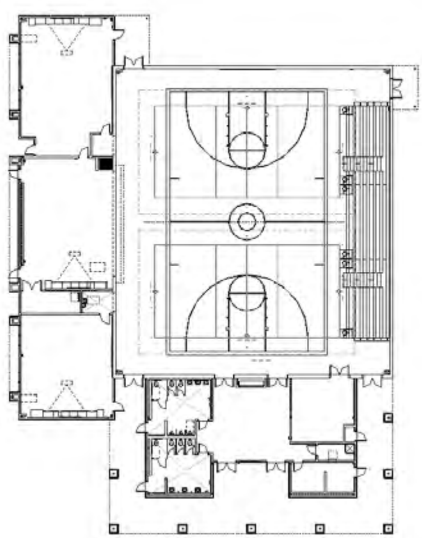

Figure 6: The Hewes, AG Currie, and CT Utt Middle School Activity Centers floor plan

The prototype design for the new Activity Centers is approximately 13,000 square feet including a lobby, gymnasium/ multipurpose area, sports flooring, retractable bleachers, storage space, restrooms, performance area, and two classrooms. Each building was planned to begin construction one month apart and the project cost for the four buildings is approximately $6.5 million dollars which is being funded through the Measure L campus modernization program. This case study illustrates how a small project can still reap great the benefits from this higher than average model detail and BIM coordination effort.

While typical BIM specifications at the construction phase require LOD 400 models for only Structural Steel, Mechanical, Electrical, Plumbing, and Fire Protection the Tustin Activity Centers project required several additional BIM models and participation in coordination meetings. A high level of detail in our 3D models is not usually viewed as practical or fiscally sound for a building of this size. But, given the repeat nature of this project it was determined that we should digitally prototype in high detail this facility despite current industry standards.

Required Models:

- Two structural steel models
- Four concrete foundation models
- Two masonry models showing anchor bolts
- Two framing models which included drywall, king studs and headers
- Two ceiling models with 2 x 4 ACT ceiling grids
- Two mechanical models with equipment, insulation, and air terminals
- Two overhead electrical models which included all panels, lights, and conduit ¾" and larger
- Two overhead plumbing models showing all fixtures
- Four underground electrical models
- Four underground plumbing models with required slope
- Two fire protection models
- Two specialties models which required recessed hose cabinets, basketball backstops and swing clearances, accordion walls and swing clearances, bleacher systems and operation clearances as well as bathroom partitions and roof hatches.

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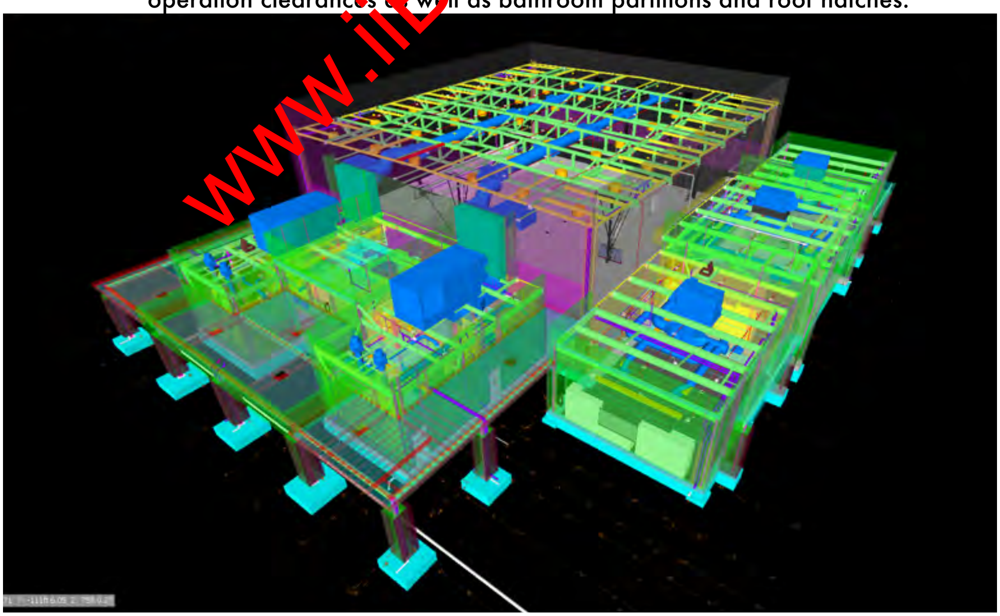

Figure 7: The BIM coordination process for each building included ten different subcontractor models

Building coordination was scheduled to coincide with the actual project schedule and took place in the order of Columbus Tustin underground, Columbus Tustin overhead, Hewes underground, AG Currie underground, CT Utt underground and finally, a "check" of the mirrored version of the previously coordinated Columbus Tustin overhead models. The first underground coordination effort took approx. 4 weeks with bi-weekly meetings and subsequent underground coordination ran for about 2 weeks per site with bi- weekly meetings. The first overhead coordination process began on December 13, 2011 until January 31, 2012 with bi-weekly meetings and the overhead coordination for the three remaining buildings went from February 16, 2012 through March 29, 2012 with meetings only once a week. Overhead coordination time was shortened by 50% after the initial building coordination.

Notable clashes found in the first overhead building coordination process included a discrepancy between the structural steel and vaulted ceiling elevation in the lobby, and that the size of the mechanical shaft was based on the size of the mechanical duct without the required insulation. As a result of these findings, the lobby ceiling was dropped to accommodate the structural steel while keeping clear of the front window and the size of the mechanical shaft was increased. The second round of overhead building coordination was necessary to the coordination process due to the fact that the mechanical units themselves could not be "mirrored". This caused deviations from the initially coordinated mechanical duct layout. Virtual construction of the Activity Centers revealed that the planned condensate pipe design was inefficient and showed an improved location for a roof vent. And finally, the Tustin Unified School District was able to better visualize the building and each of the rooms to better plan for space use.

### Conclusion:

This presentation exhibits 3 projects of vastly different size and type. This diverse set of examples illustrates how project based planning is essential to practical value based BIM implementation. From these examples one should see contrary to popular belief stepping away from technology can be the right course of action for a large project and how it can be the opposite for a small project, ultimately the path towards best value is paved by practicality.

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# 5D BIM CONSTRUCTION WORKFLOW:
## Implementing BIM in Cost Estimating, Scheduling, and Construction Management

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## ABSTRACT

A building information model is an integrated, structured database, informed by the AEC industry, consisting of 3d parametric objects. It represents an evolution from traditional 2D design to a dynamic 3D model built around a database of a project's physical and functional characteristics. In the construction industry, the advantage of using Building Information Modeling has been for visualization and clash detections. With further development within the industry and through implementing tools, the 4D (scheduling) and 5D (cost) capabilities are more frequently adopted by the Contractors, Construction Managers and Owners.

5D BIM is a new way of working with project stakeholders and owners, bringing an integrated information and experience to the project in a visually communicative way. In this paper, the general workflows of the 4D and 5D construction, and the BIM model-based quantity takeoffs, cost estimating and scheduling will be detailed discussed. Some examples and comparisons will also be discussed to show the advantages and some drawbacks of 5D workflow.

## BACKGROUND

According to Myzvimwe (2011), 5D BIM is 3D parametric design models plus time and cost, which is an integration of design models with estimating, costing and scheduling. Figure 1 shows the general workflow of 5D BIM during the construction process. After receiving models from architects and engineers, estimators can perform takeoffs of the models to generate detailed quantities of project. Estimators can also add unit price and costs to the takeoff items to get the total cost of materials for the project. In the meantime, schedulers can also work on the schedule which links all the timelines to model components as BIM managers work on the clash detection and constructability reviews.

The benefit of the 5D workflow is that it can dramatically reduce potential mistakes caused by human error. Additionally, it integrates different teams in a construction firm to work on a same platform as a team, which can dramatically enhance the work efficiency and the communication between key players. By linking the individual 3D components or assemblies with the project delivery timeline, cost and quantities, it is possible to work on a "live model", constructors or designers can quickly see how a change in design impacts both the project budget and schedules. By seeing these changes, constructors can better coordinate design and construction with architects and their clients, and better manage the construction process.

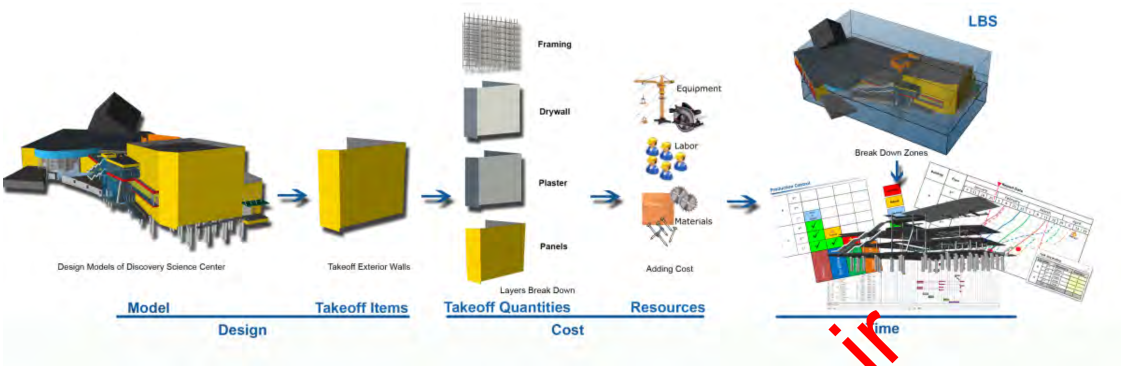


Figure 1: General 5D BIM work flows

### 3D MODEL TAKEOFFS AND COST ESTIMATING

Quantity takeoff is highly important to not only the BIM construction process, but to general traditional construction management, because quantity takeoffs often establish the quantity and unit of measure for the costs of labor and contractor's equipment.

Since a BIM model is an integrated, structured database, and consisting of 3D parametric objects, when importing a BIM model into quantity takeoff software, the software can automatically track the parameters of the design objects and calculate the useful quantities. As Figure 2 shows, when selecting an exterior parapet exterior stucco wall, the quantity takeoff software can detect the parameters of this item from the BIM model, as well as the design conditions, and then it can automatically calculate different quantities, such as Length, Surface Area, Opening Area, Volume, etc. Estimators can select the takeoff results they need and assigned them to associate quantities or assemblies.

Besides directly assigning the takeoff results to project quantities, estimators also need to consider the level of details of the BIM model. Because sometimes a 3D BIM model couldn't catch enough 2D details and some detail items will not be modeled in 3D. Figure 3 shows one of the project's detail sections of the lower roof area, between the parapet wall and lower roof area, there is cricket support which is count as exterior metal stud, is not modeled as 3D. And also the yellow highlighted area which is showed as exterior cement plaster, it should be counted not only the exterior surface area of the wall, but also some of the edge surface area of the openings and parts of soffits.  So when calculate the quantity the cement plaster, estimator should not only takeoff the exterior wall surface area and top surface area of openings, but also need to add formulas to the takeoff items to make them match the 2D drawings.

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Figure 2: Visualized Quantity Takeoff

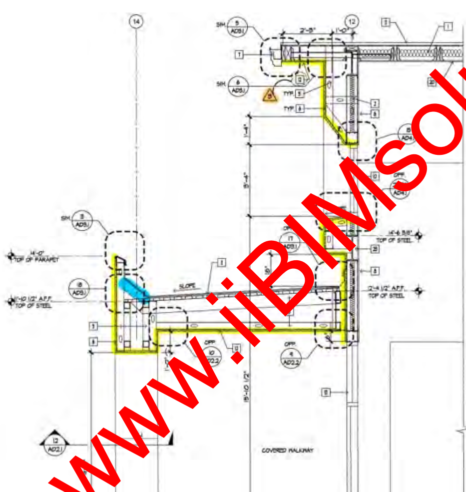

Figure 3: 2D details that 3D model don't have

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By implementing 3D takeoffs, the results can be more accurate than traditional manual takeoff ways. Figure 4 shows parts of the takeoff results comparison of a Balfour Beatty Construction's project between traditional on-screen takeoff and model-based BIM takeoffs. The result of the left side (blue highlighted) is from the subcontractor, who used the traditional on screen takeoff which is based on the 2D PDF drawing. The result of the right side (red highlighted) is from Balfour Beatty Construction, who is using 3D visual takeoff based on the models. By comparing the 2 results from different methods, we helped the subcontractor to find some missed quantities which were caused by human errors. And the total variances of the takeoffs can cause 3 million dollars different of final project budget calculation! After considered all the missed quantities and design details, the revised result from subcontractor which is in the middle are very close to the BIM takeoff results.

| Bldg | 05400 - COLD FORMED METAL FRAMING<br>Element | Square Footage | | Balfour |
|---|---|---|---|---|
| 100 | Exterior Metal Studs | | | |
| 100 | Metal stud framing, 6" 18 ga at 16" O.C. | 5,509 | 13,725 | 10,535 |
| 200 | Exterior Metal Studs | | | |
| 200 | Metal stud framing, 6" 18 ga at 16" O.C. | 22,562 | 30,967 | 29,348 |
| 300 | Exterior Metal Studs | | | |
| 300 | Metal stud framing, 6" 18 ga at 16" O.C. | 22,387 | 38,424 | 32,830 |
| 400 | Exterior Metal Studs | | | |
| 400 | Metal stud framing, 6" 18 ga at 16" O.C. | 21,846 | 38,424 | 33,324 |
| | TOTALS | 72,304 | 121,540 | 106,037 |

Figure 4: Takeoff results from BIM and On-Screen

After finishing the quantity takeoff, the estimators can then add unit price to the takeoff items. This step is quite simple compare to the takeoff process. The biggest advantage of the visualized cost planning is it links the cost with the actual model (See Figure 5). So every time when the design changes, BIM takeoff tools can automatically detect those changes in models, and then it will update the model parameters and recalculate project quantities and cost. In that case, estimators can easily see the updates of quantities and cost, instead of going back to check the 2D drawings, which can initially save project team a lot time and avoid human errors. In addition, estimators can also very easily compare results from different design options, which can result a better coordination between design and construction with architects and their clients.

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Figure 5: Linking Cost with Takeoff Items

## SCHEDULING BASED ON 3D MODELS

Similar with the process of cost estimating and quantity takeoff, the schedule in a 5D BIM workflows allows contractors to link objects that are in a 3D model to the corresponding tasks and activities. By linking a schedule with model and quantities, the actual duration of each task will be based on the actual quantities, which will make the schedule more accurate. Besides that, by linking schedule with model, every time when design changes, the schedule can automatically catch the changes of quantities, and update the duration of each task.

In addition, as the timelines are connected with actual models, a 4D construction simulation can be automatically created at the end of the process. With this visualized timeline it will enable constructors to resolve construction sequence conflictions before the project begins and find missing tasks. \\ In many cases, 4D scheduling and 5D estimating have saved construction companies a considerable amount of time and money because contractors can prevent potential schedule conflicts by the visualized management.

Figure 6 shows a traditional constructions schedule from a Balfour Beatty Construction's project, which is some simple time charts, connected with different tasks. The schedule is broken down by building levels, which makes it long and hard to compare and manage. In a 5D BIM work process, the scheduler are doing the similar process with traditional way, for example, creating tasks, adding logics to tasks, etc. but all the processed will be linked with actual model elements and estimating, and a model can also be divided by different locations. The location-based and model-linked schedule management allows constructor to generate a more accurate and significantly compressed schedule. Figure 7 shows the same schedule with the one in Figure 6, but linked with model and locations. As shown in the new schedule, a constructor can easily manage task buffers, visually identify conflicts, and communicate complete schedules of complex projects - all on a single page. And as the timelines are connected with actual models, a 4D construction simulation can be automatically created at the end of the process. By seeing this 4D, constructor can easily find missing tasks and logic conflictions between different tasks.

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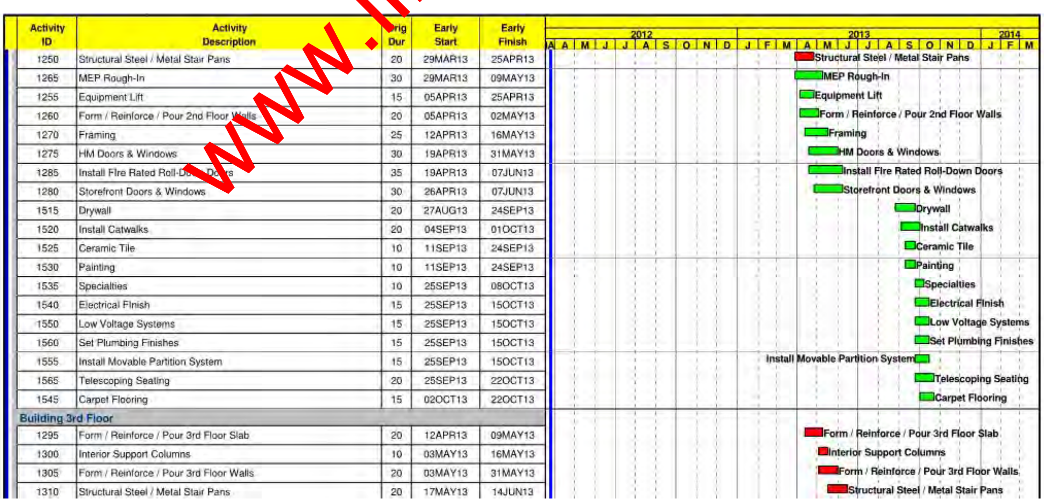

| Activity ID | Activity Description | Orig Dur | Early Start | Early Finish |
|---|---|---|---|---|
| 1250 | Structural Steel / Metal Stair Pans | 20 | 29MAR13 | 25APR13 |
| 1265 | MEP Rough-In | 30 | 29MAR13 | 09MAY13 |
| 1255 | Equipment Lift | 15 | 05APR13 | 25APR13 |
| 1260 | Form / Reinforce / Pour 2nd Floor Walls | 20 | 05APR13 | 02MAY13 |
| 1270 | Framing | 25 | 12APR13 | 16MAY13 |
| 1275 | HM Doors & Windows | 30 | 19APR13 | 31MAY13 |
| 1285 | Install Fire Rated Roll-Down Doors | 35 | 19APR13 | 07JUN13 |
| 1280 | Storefront Doors & Windows | 30 | 26APR13 | 07JUN13 |
| 1515 | Drywall | 20 | 27AUG13 | 24SEP13 |
| 1520 | Install Catwalks | 20 | 04SEP13 | 01OCT13 |
| 1525 | Ceramic Tile | 10 | 11SEP13 | 24SEP13 |
| 1530 | Painting | 10 | 11SEP13 | 24SEP13 |
| 1535 | Specialties | 10 | 25SEP13 | 08OCT13 |
| 1540 | Electrical Finish | 15 | 25SEP13 | 15OCT13 |
| 1550 | Low Voltage Systems | 15 | 25SEP13 | 15OCT13 |
| 1560 | Set Plumbing Finishes | 15 | 25SEP13 | 15OCT13 |
| 1555 | Install Movable Partition System | 15 | 25SEP13 | 15OCT13 |
| 1565 | Telescoping Seating | 20 | 25SEP13 | 22OCT13 |
| 1545 | Carpet Flooring | 15 | 02OCT13 | 22OCT13 |
| Building 3rd Floor | | | | |
| 1295 | Form / Reinforce / Pour 3rd Floor Slab | 20 | 12APR13 | 09MAY13 |
| 1300 | Interior Support Columns | 10 | 03MAY13 | 16MAY13 |
| 1305 | Form / Reinforce / Pour 3rd Floor Walls | 20 | 03MAY13 | 31MAY13 |
| 1310 | Structural Steel / Metal Stair Pans | 20 | 17MAY13 | 14JUN13 |

Figure 6: A Traditional Schedule of A Project

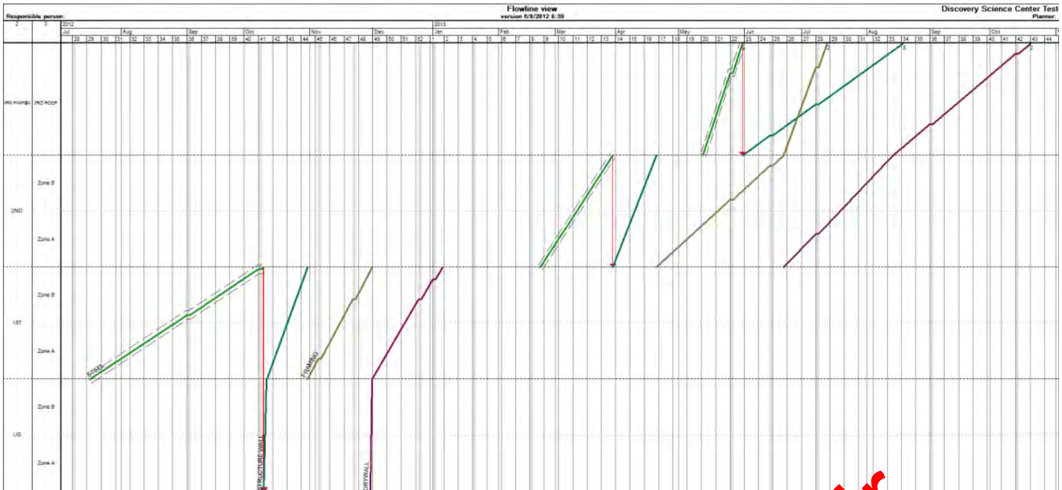

Figure 7: A Flow Line Schedule Which Links Model and Locations

With the incorporation of locations, quantities from BIM model, constructor can add productivity rates and actual task start date to adjust schedules and predict finish date. For example, if a task's starting date is behind the scheduled day, the constructor can change the productivity rates according to the actual activity and associated quantities which is linked with model, then automatically forecast the finished date. This is one of significant benefits in construction management.

Figure 8: Schedule Simulate by Actual Start Date and productivity rates

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## BEST PRACTICE

As discussed before, in the 5D BIM process, quantity takeoff is the most important part, because the accuracy of quantity takeoff directly influences the accuracy of cost estimating and scheduling. However, most times, the models the constructors receive from architects do not have as enough level of details as 2D drawings. In order to make the takeoff as accurate as possible, a BIM specialist needs to sit down with an experienced estimator to go through each detail, fill the gap between BIM models and 2D drawings, and find the best way of takeoff based on 3D models.

Besides that, a 5D BIM workflow requires a highly integrated coordination between constructors and architects. Most times, architects only share their models with constructors at milestone submissions, while the other times architects only share constructors with 2D drawings to update the design changes. In that case, constructors have to manually track the quantities changes, or update the models by themselves, which will slow down the process. In order to take best advantages of 5D

BIM workflow, a better communication between designers and owners will be required, and sometimes, the model sharing rule can be written into contracts.

As the first BIM or Revit project in architecture firms several years ago, the first 5D BIM project in a construction firm will always be painful and cost more time. But keep 3D in mind and take the best advantage of BIM is always the best solution. When comes with problems, instead of complain BIM is not better than 2D, try to find the best solution to fill the gap between BIM and 2D. Once you find the solution, the best practice can be forever.

## CONCLUSIONS

This paper outlines only a general workflow of 5D BIM usage in construction management. As the difference of complexity of each project, and the implications of different software, the workflows could be different.

As discussed above, the 5D BIM construction creates an integration workflow across and throughout the project from design to completion. This fully integrated estimating, scheduling, project controls and also constructability reviews. Besides the internal usage with construction and design teams, 5D BIM can also provide a better communication with owners, show owners what happens to the budget and schedule when a change is made on the project.

Although it still has many limits of 5D BIM construction workflow, such as the detailing in BIM model, non-model related tasks and interoperability between software, solutions can be explored and best practice can be found. And with the development of this industry and working tools, more and more designers, constructors and owners will benefit from the 5D BIM workflow.

## ACKNOWLEDGMENTS

Thanks to Clive Jordan from Vico Office, who provides us a lot of technician support. And thanks to Brad Hardin, Vice President of Balfour Beatty Construction, who greatly support the 5D workflow inside company. Credit also needs to be given to other team members of the BIM department of Balfour Beatty Construction Southwestern region, Daniel Shirkey, Michael Vachon, Monica Lubag, Rudy Armendariz, Elizabeth Angel and Molly Engelbert who also discussed or developed 5D BIM methods in construction.

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# PRACTICAL BIM:
# An Efficient Tool for General Contractors

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## ABSTRACT

This paper presents how Building Information Modeling (BIM) is being used as an effective tool by a general contractor. The paper discusses Suffolk Construction's approach to efficient trade coordination, benefits of using BIM for prefabrication and preparation of shop drawings and visualization for trade sequence and field installation. The paper presents an analogous approach to construction issues and day to day traffic issues. This has helped Suffolk Construction not only in educating its subcontractors but also developing an effective coordination to installation process using BIM.

## INTRODUCTION

Building information modeling has revolutionized the way architects, engineers and contractors work. With the growing complexity of construction projects and shortage of resources, BIM is helping general contractors in saving time and money without compromising the quality of the deliverables. BIM not only facilitates better coordination and communication amongst the project team members but also communicates the same idea of the project to all the stakeholders involved in the life cycle of the project.

One of the most common uses of BIM for a general contractor is trade coordination. In traditional method, the clashes and conflicts were identified by overlaying individual system drawings on a light table. This method was time consuming, manual and error prone and required all the drawings to be current. With the help of BIM, the clash detection now is an intelligent system. It combines geometry clash detection with semantic and rule based clash detection. It allows contractors to check clash detection between specified systems. Suffolk Construction uses a color code system to easily identify the location and type of clash which is discussed in the following section.

Suffolk Construction and its subcontractors are also realizing the benefits of using BIM and coordinated models for pre fabrication. Fabrication and preparation of shop drawings involves constant modification and updating of drawings and documents. These constant changes result in inaccuracy and inconsistency which cause loss of money, time and quality. These inaccuracies in drawings are determined only during the erection starts at the construction site. BIM is now helping the subcontractors to create efficient and accurate designs by providing a parametric solution to the fabricators. Any change made anywhere in the BIM model is updated in all the views on its own and eliminates inconsistency in data. Lastly, the paper discusses how BIM is helping Suffolk Construction in procurement, trade sequence and visualization of the projects to communicate the same idea to all the stake holders involved.

### Analogy between construction issues and traffic Issues

Computer aided modeling techniques have been used by automobile industries for years for accuracy and better quantity. Although, the construction industry has been lagging behind in the adoption of computer aided modeling techniques but there is a strong trend seen in adoption of BIM from small sized to large sized projects. Another analogy between construction and automobile industry is the issues with traffic flow and construction trade flow and how technology is helping to resolve these issues.

There are a variety of automobiles on the road. Some are sophisticated, up to date with technology, fast moving and some are still traditional automobiles with the primary function of transportation from one point to the other. Similarly, there are a variety of subcontractors a company works with. Some subcontractors are sophisticated, up to date with technology and some are slow in adopting the new technology. Managing variety of subcontractors and construction trades results in many of the same issues encountered in the traffic. Suffolk Construction uses Practical BIM in the similar ways that technology is used to maximize the flow of traffic.

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**Traffic Issue #1**: Multiple automobiles attempting to occupy the same space at the same time:

Figure 1: Use of color codes for controlling traffic flow

**Solution**: Three simple colors that easily communicate what each driver should do.

**Construction Issue #1**: Multiple construction trades trying to occupy the same space in a building:

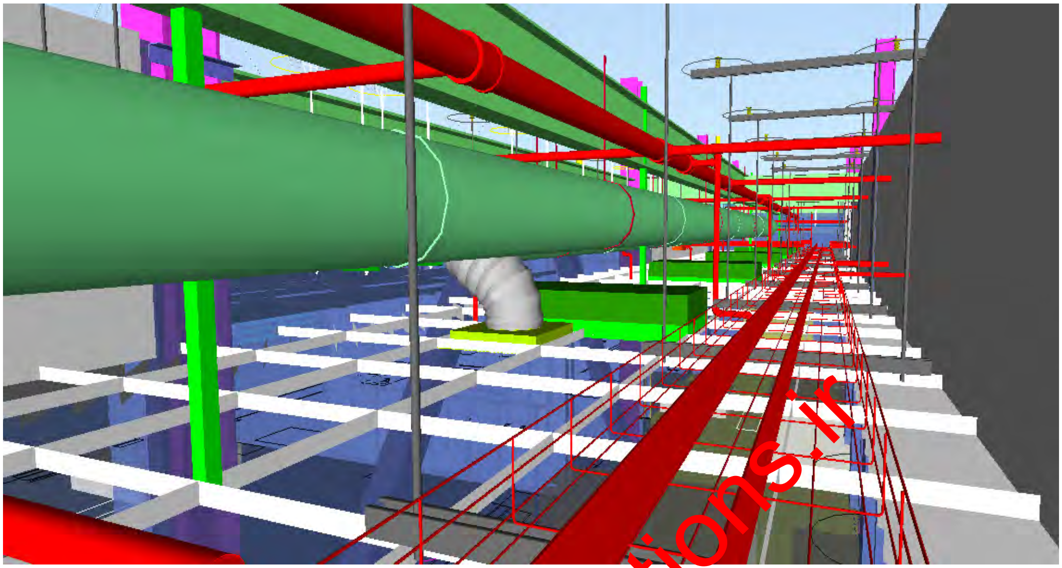

Figure 2: Multiple trades occupying the same space

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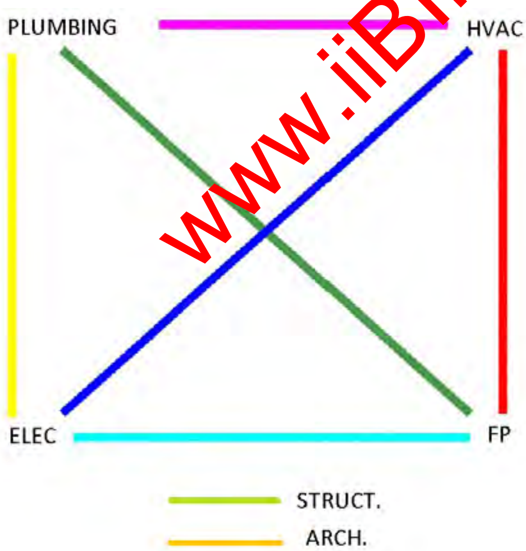
**Solution**: During coordination, Suffolk Construction uses "smart colors" to easily identify the clash locations and clash responsibilities:



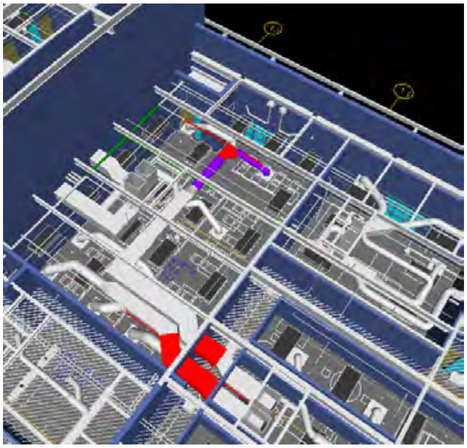



Figure 3: Color Code Chart
Figure 4.1: Color coded trade clashes to easily identify type and location

In addition, rather than requiring that subcontractors refer back to 2D clash reports, when needed for additional direction, notes are added in the 3D environment for reference:

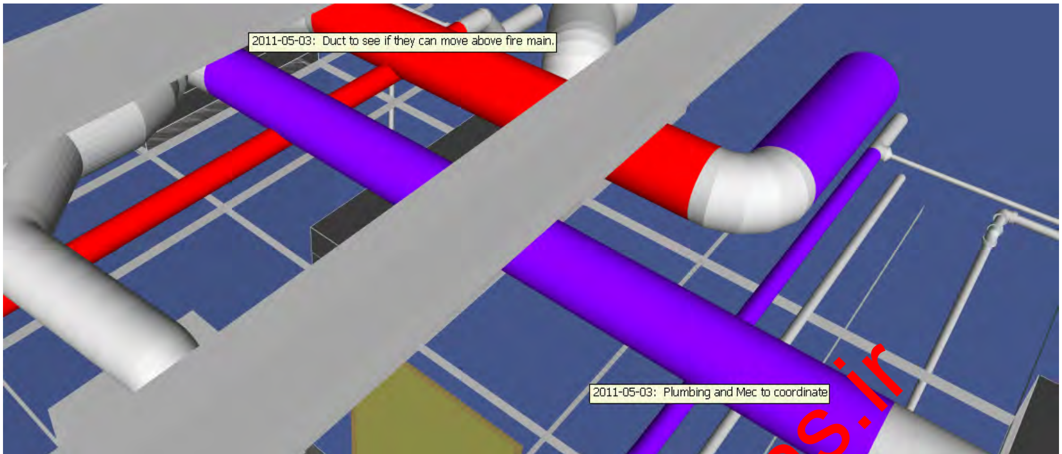



Figure 4.2: Color coded trade clashes with notes for trade responsible for resolution

This practical use of BIM during clash detection/prevention and coordination helps to expedite the coordination process over traditional methods and allows BIM technology to preplan the locations of the building systems.

**Traffic Issue #2**: Unnecessary driving. When trying to find a new destination, a wrong turn means additional driving, stopping and starting that not only slow down the original driver, but those trying to drive around them.

**Solution**: The invention of the GPS. Pre-calculated trip planning with accurate turn by turn instructions:

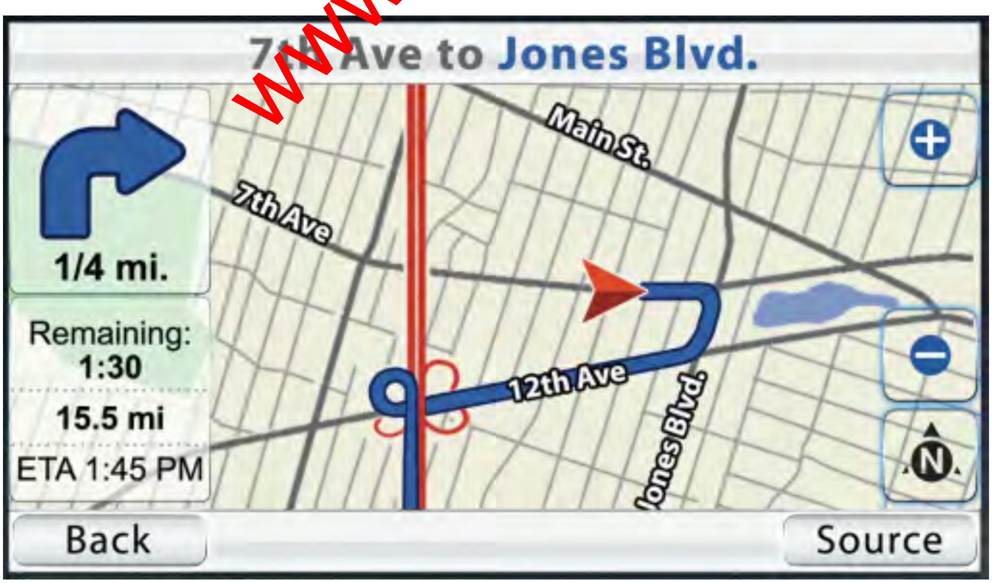



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Figure 5: GPS

**Construction Issue #2:** Unnecessary installation, removal, and/or rework of building materials when the assumed route does not work. Rework not only impacts the schedule of the applicable subcontractor, but also the schedules of those trades working in the same area.

**Solution:** With well-coordinated BIM, subcontractors can now prefabricate, layout, and install their systems with confidence that the pre-coordinated path is accurate. Shop drawings and integrated work plans can also be extracted from the 3D models for additional, precise "turn by turn" detailed information.

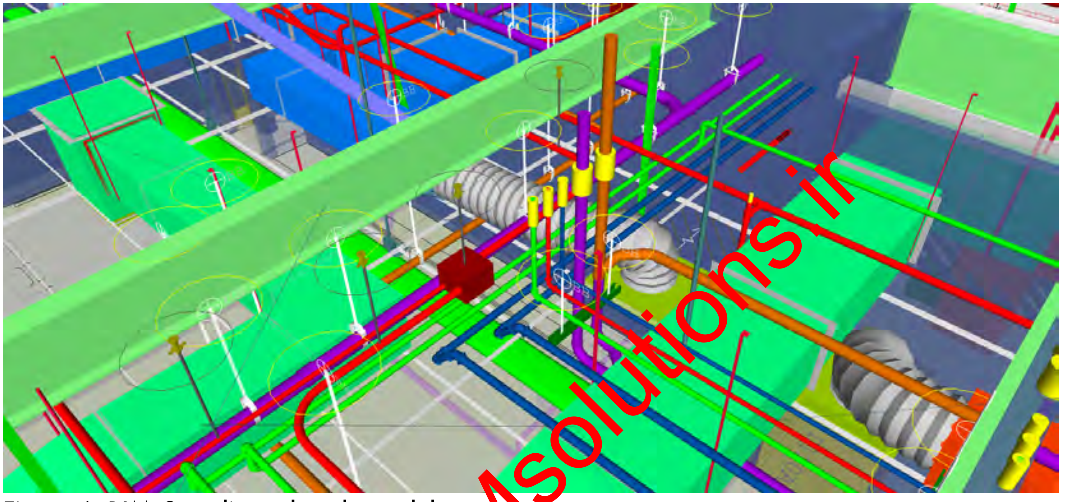

Figure 6: BIM Coordinated trade models

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**Traffic Issue #3:** Traffic jams. All vehicles are moving in the same direction; however, different driving habits cause unpredicted starting and stopping that ultimately disrupts the even flow of traffic.

Figure 7: Traffic jams

**Solution:** Unfortunately, without the ability to know what the driver ahead of you is going to do, the solution to this continues to be a challenge.

**Construction Issue #3**: Without knowing who is in the building, when they are in the building, and where they are working, subcontractors are unable to install their scopes as a consistent rate. When one subcontractor speeds up another one might cut into the free space causing a delay to the trade that was originally behind the first. If one trade has to abruptly stop construction, it causes residual delays to those trades behind them as well.

**Solution**: A practical application of BIM is using the coordinated model as a tool to predict who is in the workspace, when they are going to be there, and what they are working on. One way to accomplish this is by simulating the construction by integrating the schedule together with the BIM. Another way is by simply providing BIM in the field to give the different trades a visual of what the future installation will look like. This can be done with a variety of BIM software applications and eventually by bringing the virtual world into the real world through field tablets using augmented reality.

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Figure 8: Plan view of the room for field installation

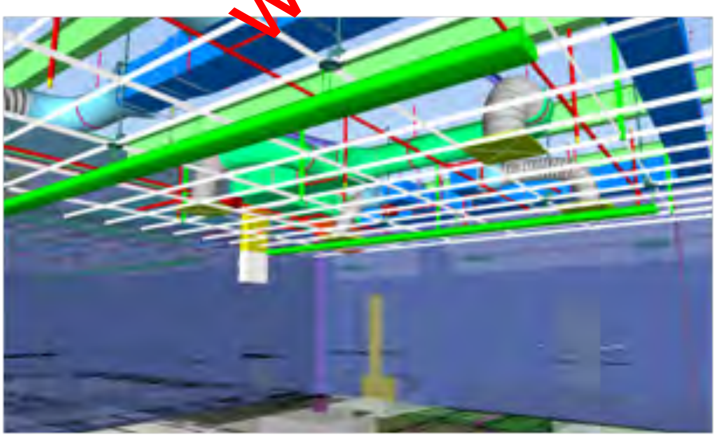

Figure 9: Room view of the room for field installation

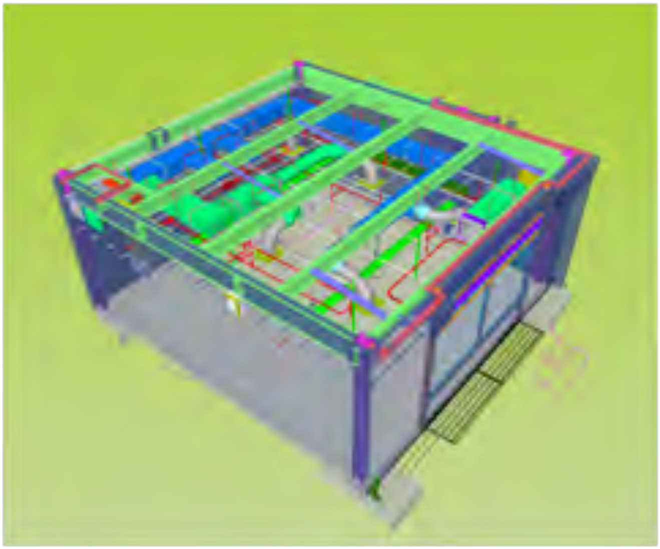

Figure 10: Cube view of the room for field installation


Figure 11: Using iPad for visualization using augmented reality tools

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### Summary and Conclusion

With benefits like better coordination, fewer errors, higher productivity, savings in costs and time and better quality, BIM has become an indispensable tool for Suffolk Construction. It is also providing new revenue and business opportunities. The company is using BIM on most of its projects nationwide and also provides the owner with tools that help in efficient building's operations and facility maintenance.

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# MULTI-DISCIPLINARY COORDINATION: Experiences and Guidelines

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***Gautam R Shenoy, PA; HNTB Architecture***

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## INTRODUCTION

A groundswell of architecture firms have adopted BIM to some degree over the past several years. We've been working diligently to adapt our culture in order to realize the efficiencies of this new process.  Now it's time to improve our collaborative process working with other disciplines within the BIM environment.

## PROJECT PLANNING

- Project Type and Size
    - This topic relates to the planning, setup and daily operation of the models.
    - The type of project and its scale (*aviation, sport, school, healthcare, mixed-use, et al*) will drive the planning of the project setup, families, groups, linked instances and such.
    - It will also be a precursor to picking the right team members such that the varying expertise is fully utilized.
    - Modeling instances (*a separate model for site, phasing, energy analysis)*.
    - Geo-spatial Location is a very important. Project North (*versus True North*), Relocated Project with shared coordinates versus Project (*Internal*) coordinates need to be determined so that on-site coordination is not adversely affected.

- Contracts / Delivery Systems
    - It is important to understand the kind of contracts being established. The deliverables are determined by whether the verbiage requires the project to be a traditional Design Bid build, a Design Assist or a Design Build endeavor.
    - This also predicates how the consultants are evaluated based on their ability to work in BIM.
    - It is necessary to understand the client's expectation, needs and requirements.
    - It is necessary to ascertain if the model(s) will become deliverables at the end of construction to support Project Life Cycle / Facility Management.
    - The delivery of 2D Documents versus 3D Models for each of the disciplines also need to be

decided at this time.
  - Which of your consultants will be working in BIM and to what extent? How long will they be on the team, might they drop off after DD? These contracts need to be developed with each discipline.
  - Most importantly, an exhaustive BIM Execution plan must be authored with inputs from all major participants. This is the road map for the teams and will become part of the contract.

## TEAM FORMATION

- Who will be working in BIM and who will not?
  - It is important to understand how information will be exchanged. The process of collaboration is different when dealing with BIM and non-BIM team members.
  - What is their level of experience with BIM projects?
  - Does everyone subscribe to the BIM process or are there those that use BIM like CAD?
  - A common set of formats need to be set for modeling endeavors.
  - A common set of formats need to be set for documentation creation.

## WORKFLOW

- General Items
  - Interoperability, File formats, drawing exchange. How often will there need to be coordination meetings and what is the model exchange frequency? Typically, structural models are about a week behind architectural and MEP is one to two weeks behind that.
- Consultants working in BIM
  - Interdisciplinary coordination platforms (*local or cloud based*) need to be set.
  - The issue of Project North vs. True North becomes critical at this stage.
  - Establish Linked Views for each of the consultants and have them create Linked Views for you.
- Consultants not working in BIM
  - It is important to allocate more time for coordination procedures with consultants who are not working in BIM.
  - Additional formats maybe be needed to convey design changes and coordination intent.

## COMMUNICATION

- How will you communicate with multiple teams?
  - Meetings.
  - Video Conferencing.
  - Conference Calling.
  - Phone.
  - Email.
  - Instant Messaging.

## SUMMARY

A key factor in the success of a multi-disciplinary BIM project is that everyone involved subscribes to the process. BIM is not a tool; it is a way of working together in a collaborative environment. Disruption to the teams' workflow caused by an Individual vs. Team approach is difficult to overcome. Establishing clear goals, a detailed BIM execution plan and open communication throughout the project will help the team deliver a well-coordinated project.



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# NEED TO KNOW BASIS:
# Managing Varying Levels of BIM Proficiency On a Project Team

***Kirstyn Bonneau, LEED AP, BIM Manager, PBWS Architects***

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## ABSTRACT

This paper proposes a methodology for assigning responsibility on projects utilizing BIM where a firm has a deficiency in staff training. Through evaluation of individuals' BIM knowledge, training, project experience, professional experience, and position within a firm, this method will allow firm leadership to fully utilize staff and effectively manage projects in BIM. The learning curve associated with BIM platforms is reduced as a result of incremental exposure of the software to staff.

## INTRODUCTION

Many firms are hesitant to employ BIM on their projects due to limited training and practice among their project staff. They may have one or two people who are skilled in the use of BIM, but not a full project team. As a result, they are not leveraging BIM to its full potential. Firms can efficiently produce strong documents despite varying degrees of capabilities through a clear understanding of the different roles and responsibilities required to execute a BIM project. By identifying the personnel best suited for each role, a firm can develop comfort and skill within a BIM platform without compromising project delivery. Allowing for incremental experience on BIM projects by teaming experienced staff with inexperienced staff can minimize the learning curve and any resulting drain on project hours while still producing a document set that meets company standards. Fear of powerful but complex BIM platforms prevents many firms from taking the leap into utilizing the latest technology, but adoption of BIM is critical to the ongoing success of architectural firms and can be achieved through effective management of project staff.

Four primary roles; project administration, modeling, annotating, and detailing; encompass the major responsibilities within a BIM project. An evaluation of each team member's professional experience, training in BIM platforms, and number of projects completed in BIM (figure 1) can clearly identify which role allows for the most effective use of their abilities. The following descriptions of each role provide a guideline for understanding how to match responsibilities with personnel on a BIM project.

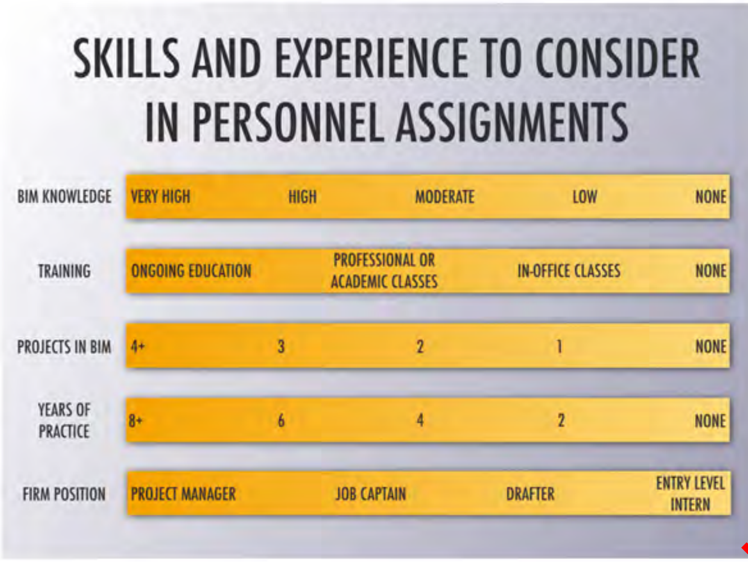


Figure 1

A project administrator is a person with a very high level of BIM knowledge and practice. They have received professional or academic training and completed multiple projects in BIM. Ongoing continuing educations, such as participation in local user groups or online forums, helps project administrators develop an understanding of other users' practices and strategies for efficiency.

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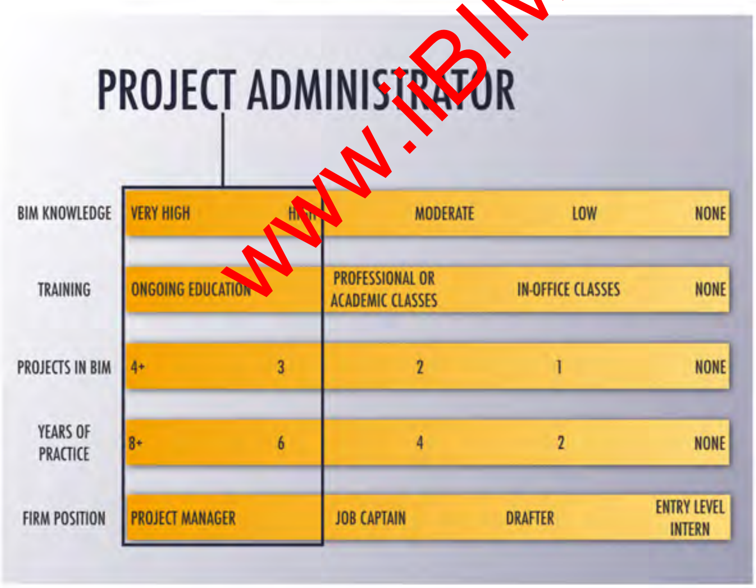


Figure 2

A project administrator is responsible for making it easy and efficient for other team members to work on the project. They develop templates and set up project files so that team members can begin working immediately in a properly configured environment. Project preferences and settings like layer combinations, pen sets, model view options, default tool settings, dimension settings, and markers and labels should all be established by the project administrator to ensure that team members' work meets office standards. Team access and permissions are controlled by the project administrator to ensure that the skill level of those working in the project matches their ability to modify the file. The project administrator oversees interoperability and data exchange by establishing settings and protocols for exporting to IFC or 3D CAD for use in other BIM platforms and for export to 2D CAD. Staff training is conducted by the project administrator to continue development of the team's abilities.

Due to the high level of involvement with developing firm standards and practices, a project administrator requires a high level of dedication to the company. A project administrator should be a project architect, project manager or BIM manager with multiple years at the firm and in architectural practice in general. This level of experience enables the project administrator to interface with principals about firm standards and participate in decision-making about which projects should utilize BIM.

Firms in the early stages of adopting BIM may not have a person with this level of skills and qualifications already on their team. There are strategies for beginning the implementation of BIM even when lacking this person at the firm. The first and most basic option is to use the out-of-the-box settings of the BIM platform. The default settings can allow a firm to get started without a lot of customization and still be productive, although the firm may have to make some compromises along the way. The second option is to hire an outside consultant to develop a project template and settings. This allows a firm to customize their output, but adds to the firm's overhead costs. The third option is to hire a person with the necessary level of experience to the firm. This is obviously a much larger financial commitment, but it also enables a firm to continue training and development without paying additional costs to outside consultants. These three strategies can allow a firm to move forward with a BIM platform even without an expert currently on their team.


Figure 3

Modelers are those persons in the firm with moderate to high level of BIM knowledge and practice.

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They have completed professional or academic training classes or in-office training by the firm's project administrator. They have experience on two to three BIM projects at the drafting or annotating level.

Modelers are responsible for what most people today think of as "BIM." They execute the 3D modeling of building components. They establish views for placement on sheets including site plans, floor plans, enlarged plans, ceiling plans, roof plans, interior and exterior elevations, and sections. Modelers import and export 2D and 3D files as necessary for coordination with consultants, for internal use, or for clash-detection.

A modeler can be a project manager or job captain with multiple years of practice. This level of experience enables them to make informed choices about construction assemblies, section locations, etc. during the modeling process.

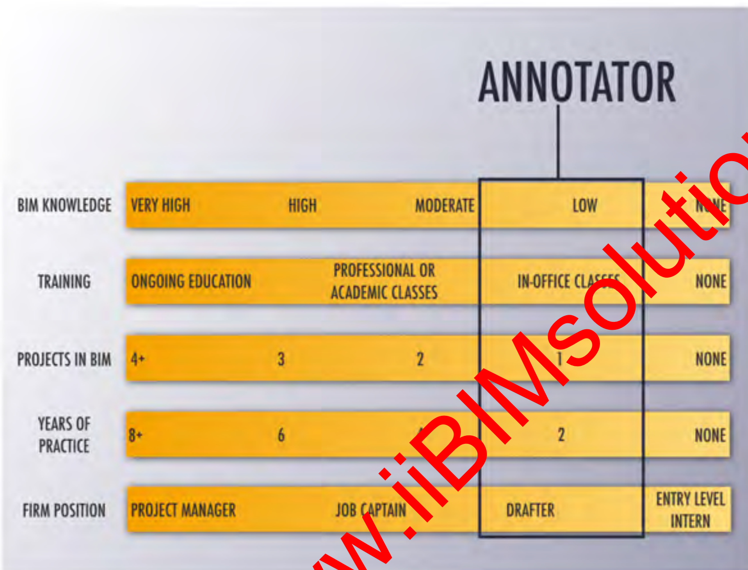

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Figure 4

Annotators are those in the firm with low to moderate BIM knowledge and practice. They have completed in-office training on basic navigation and drafting techniques. They have experience on zero to one BIM project at the drafting level.

Annotators are responsible for 2D annotation which may require some understanding of 3D tools and 3D component information such as wall, door, or window type identifiers. They dimension, keynote, and label drawings. They may complete some 2D clean up of 3D drawings such as adding hatches or line-work. Annotators may also assist the modelers in placing established drawings on sheets.

An annotator can be a job captain or a drafter with two to three years of practice. They must have a strong understanding of construction documentation including proper dimensioning techniques, keynoting protocols, etc.


Figure 5

Detailers are those persons with no to low level of BIM knowledge and practice. They have completed in-office training on basic navigation and drafting techniques. No prior BIM experience is required at this level, but a detailer should have basic CAD skills.

Detailers are responsible for 2D documentation such as wall sections and details. These may be completed in the BIM platform, but they could also be executed using traditional CAD with base drawings output from BIM by the modelers.

A detailer can be a drafter or an intern. Entry level technical staff can occupy this position on the project team. If the project has been modeled well, the junior staffs working on the details have strong guidance from the base drawings created by the modelers. This results in better, more coordinated drawings even in 2D.

## CONCLUSIONS

Allowing team members to work in BIM even if they are not fully proficient in the platform can still yield strong documents. A well-managed team can meet the firm's standards for deliverables and develop staff skills in the process resulting in a reduced learning curve. Firms can start using BIM right away by focusing on increasing their skills incrementally. They can keep up with the industry's leading technology without sacrificing their current product or productivity.

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# COMMON SENSE BIM:
# The Non-Technology Side of BIM

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## Abstract

This paper summarizes various non-technology aspects of Building Information Modeling (BIM) and Virtual Design and Construction (VDC), and why these aspects are important to the entire BIM/VDC process being used throughout design and construction projects. This paper is presented from an "industry experience" viewpoint rather than a rigorous academic study. As such, principles are stated and explored from the authors point of view and made without references to others work. The acronyms "BIM" and "VDC" are used throughout this paper. Common definitions of these terms are: BIM typically refers a 3D model or "product"; whereas VDC refers to the "process" we are using, the "organization" of who is working on the project, and the "product" or 3D model. However, for the purposes of this paper, we will use the terms in a somewhat interchangeable format.

## Introduction

The term "BIM" has come to mean many different things to many different people. Just try doing an internet search for the term and you will come up with a wide variety of definitions. To many, BIM is all about technology. However, BIM is much more than technology. One common understanding of Virtual Design and Construction is that VDC is 80% social, 20% technology. So, if we are focusing on technology, then we are missing most of what BIM is. Do you buy that? Probably not, if you spend your waking hours thinking BIM is all technology.

While the technology is important, what are the things that go into making BIM an important aspect of a project? Is it that we can see our project in 3 dimensions, making the project easier to understand? Or, is it important to link our schedule to the objects within the model to show a virtual construction simulation of the project? How about extracting quantities from our model for estimating purposes? Is it important whether these processes are integrated with each other? That's the technology side of BIM. But, let's look at some common sense principles that discuss the non-technology side of BIM. What is meant when we say that VDC (or BIM) is 80% social?

## Attitude/Mindset

To implement BIM within a company or on a project, the proper mindset is a must. There is an old saying "if you think you can, you're absolutely right; if you think you can't, you're absolutely right". Too often we have people within our organizations, especially those at the executive level, that don't believe in BIM and don't want to do it. Or, there is a mandate from their boss to implement BIM on their project. With the attitude going into the endeavor of "this won't work", they will either intentionally or unintentionally sabotage the project to prove that this BIM stuff was a waste of time and money. You need to have faith and help BIM to succeed on your project or you just may be wasting time and money.

One of the things to keep in mind when implementing BIM on a project is that it is not a 100% full-proof method to avoid mistakes. Many mistakes will be avoided, many communication issues will be solved, many changes will be made in the computer rather than in the field. But just because there is a mistake or an issue doesn't mean BIM was not a success. On a recent remodel project, the structural engineer modeled the existing and new steel and concrete structure using Revit. The existing information was obtained using old as-built drawings. Once we had demolished the interior of the existing structure, we then laser-scanned most portions of the building and brought the scans into our Revit model. The project schedule was tight and the steel detailing was already done. Steel fabrication was underway. After we analyzed the model with the laser-scan, we found that there were errors in portions of the existing model. We tried to stop the project so that we could update the steel detailing but the owner wouldn't allow any changes to the schedule. As the steel started to arrive, we had to make many "field" adjustments to make the beams fit. Some people saw this as a failure of BIM. While the model helped in many ways, the steel fabrication fell short. However, one lesson that we can learn from this is if you have important information that can or will cause a challenge to the project (i.e. additional cost), the project team must act on the information for it to be of value. We knew that problems existed, the model and laser scan proved that. We didn't, or were unable to act.

## Contract Types

As a contractor, one of the most common contract types these days is a Lump Sum contract. This means, we bid our price for a scope of work and the price doesn't change, assuming that the scope doesn't change. Given that scenario, many people don't want "BIM" on their projects. Or, more specifically, they don't want to pay for BIM. They see BIM as a cost and not as a savings. As an example, many of the subcontractors we work with bid on lump sum projects, regardless of the requirements, and then when they win the project, they do everything they can to get out of some of the requirements, and especially the BIM requirements. One subcontractor recently told us that they thought they were bidding on "2D BIM", not 3D BIM. However, these same subcontractors, regardless of contract type, will then detail everything in 3D on these same Lump Sum projects because they will save time and money using the 3D detailing and coordination tools. In addition, the 3D detailed models drive their manufacturing processes.

We've all heard the buzz about IPD or Integrated Project Delivery. IPD is a contractual relationship between the architect, the owner, the contractor (and possibly key subcontractors) to formalize their collaboration and information sharing during the project. Risk is shared and, many times, any bonus or profit is shared. There's that "risk" word. And, yes, with an IPD agreement, the risk is shared. We are all trying to shed our risk and let others assume all of the risk in a project. The

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goal of shared risk is that we will all do the right thing for the project and work together to find the best solutions for a project.

So, the question is, do you need to have an IPD contract to do IPD? In my humble opinion, you do not. We can all agree to work together, share information, and make the project successful as a team; with or without a formal agreement. We are not trying to put each other out of business. We are not trying to take advantage of the owner. However, we do need to use good business sense (and common sense) when working together by making sure we are protecting the interests of our companies.

If we don't have a formal IPD agreement, one of the ways we protect ourselves is with a "electronic document release" signed by the recipients of the information. In this way we can share our electronic information, allow others the ability to use and re-use the information, but with the understanding that, while the electronic information is a bonus, at the end of the day the paper documents rule.

## Collaboration

With or without a formal IPD agreement we can collaborate and communicate on our projects. Although many times overlooked, collaboration/communication is the key ingredient in BIM. The biggest benefits that BIM can offer are when we share our information, electronic or otherwise, and break down the typical information silos we have on our projects. What does this entail, you might ask? Trust. We need to trust each other and understand that we aren't trying to find fault with each other's work. Rather, we are trying to help each other to do a better job, to make the project a success. On a recent project, the structural engineer was concerned about sharing his model with us and didn't want any feedback. When we tried to give feedback, he let us know that he was the engineer and knew his job. After a couple of pretty rough meetings, where we pointed out some "challenges" to his design, and didn't try to point a finger at him but offered suggestions for resolution, he started to understand that we had his best interest in mind too. It didn't take long before the environment was very collaborative and he eagerly worked with our field staff and asked for their suggestions. Probably the best outcome from this scenario is that he is now a better engineer for having an open mind and taking the time to understand some of the construction challenges that we presented to him.

What does collaboration look like? Every project we work on, each separate entity, whether designer or subcontractor, says that they are collaborative. But, do we just agree to meet on a weekly or monthly basis and that's the extent of our collaboration? To be effective, we need to a little more formal planning on what collaboration means and how we go about collaborating. Some suggestions are:

- **Goals:** setting common goals amongst all team members. If we all know where we're going, we can all help to get us there.
- **Communication:** How are we going to communicate? Is it just through email? Is there a list of team members that I can reach out to for questions? Is this a flat organizational structure or do I need to work through channels? If so, what are those channels?
- **Our Environment (Physical and Virtual):** where will we work (co-location?), how do we share information? Is a Facebook-type solution the answer? How often should we meet in-person.
- **Water-Cooler Moments:** Provide an environment where team members can interact socially as well as during the work day. Co-location is a great method of collaboration but lunches or fun events after-hours can develop a sense of community

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- **Transparency, Openness, Trust and Sharing:** we openly share project information with each other. When we don't share, the trust breaks down.
- **Differences of Opinion:** team members can express opinions and ideas without the threat of ridicule or scorn. Leave ego's at the door. Respect others and, in turn, be respected.
- **Personalities:** recognize differences in people and how they act or react to others within their environment. We are all different, and that's a really good thing. If we all think the same way and we always agree on everything then the probable outcome is that nobody is thinking.
- **Shut Up and Listen:** practice your listening skills and get as much, or more, than you give.
- **Brainstorming:** create an opportunity where the ideas can flow, team members can discuss options, and let great things just happen.

## Change

BIM is a change in our business process. BIM is not a piece of software you load on your computer and all of a sudden you have "BIM". Change is scary and many people don't like to change. But, what does the change look like? To make BIM successful, we need to collaborate better, we need to break down information silos, we need to trust each other, we need to speak up and share our ideas sooner rather than later, we need to realize that planning upfront can save time and effort later on, we need to recognize that BIM is a savings and not a cost, we need to recognize that we don't know it all and that there are better ways of doing things, we need to look for and accept lean principles to make our projects more efficient, we need to accept that change is inevitable.

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Sounds good, but really, how do we go about changing? There are two methods of change: blunt force trauma or finding common ground. Blunt force trauma involves mandating that people are going to act a certain way and do certain things, follow guidelines to the letter, regardless...because YOU said so. The outcome of blunt force trauma is lack of buy-in from the project team, lack of initiative if anything is not "to the letter of the law", and your project team constantly trying to prove to you how stupid the mandate is.

Another method, finding common ground, is looking at your current processes and finding those areas to tweak to make it more efficient. Most importantly, you are including the project team throughout the entire process. If I can show you how using Revit to create 2D plans and sections takes a fraction of the time that it takes using AutoCAD, and you get the same output, would you consider using the Revit method rather than your traditional AutoCAD method? Finding common ground will result in the project team buying in to the approach (because they are part of the decision making process), will be less of a disruptive change to the organization, and will encourage project team members to take initiative and/or speak up if things aren't working according to plan. They want this new method to succeed because they own it.

Again, BIM and VDC is a change in our business processes. When we look at our typical hierarchical structure (figure 1), we see how information is typically distributed in silos. A more open, collaborative environment allows information to be shared with everyone on the project and not silo'd by the hierarchical structure. We can use all of the technology in the world but it's when we change how we develop and use information that we are truly making breakthroughs in our business process.

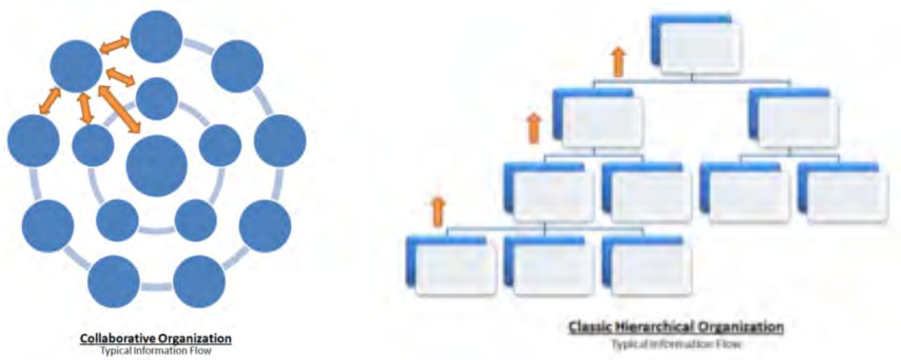


Figure 1: Organization Structures and Information Flow

## Ego's

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Common sense BIM is leaving your ego at the door. Everyone has good ideas, everyone is trying to do the best for the project, you are not more important than the person sitting next to you. Frequently, I hear people throughout our industry talk about how things need to change. We have this great opportunity with BIM to really change how our projects are structured; what kind of information we use and re-use; to become more efficient, make a better product, and increase our bottom line. But, then those same people say "I'm doing things my way, others have to change." Wrong, wrong, wrong. In a recent lecture by an industry-leading figure, the topic came up about change. This person mentioned that the change would come from the younger generation. They would need to figure it out because the old dogs won't change. In fact, although this person was advocating the changes and talking all about what great stuff that BIM is, he was adamant that he would do nothing to effect the change necessary.

At my company, we were looking at making changes to a certain business process on one of our projects. So, we hired a college intern to analyze our current process, modify the existing process to be more efficient, implement the change, and then write a report on how to improve our efficiency. While it was a noble effort, it was destined to fail from the start. We place a high value on our college interns and recruit and hire from within the ranks of college interns every year. But, we asked, and expected, someone with no little to no construction experience, and only a modicum of incentive, to analyze and then create a more efficient business process. As you can imagine, the results did not equal the expectations.

We all need to do whatever it takes to make our projects successful. We all need to be flexible and change. We all need to look in the mirror and remind that person in the mirror he or she needs to change too...needs to change first. So, how can YOU change to make your projects more successful? What can YOU do to make sure others on the project are a success?

## True BIM?

"Ah, but are you doing TRUE BIM", he asks. If you spend 10 seconds at a computer, googling the definition of BIM, you will overwhelm your system. There are a tremendous number of definitions for BIM. Not surprisingly, some have even tried to define "TRUE BIM." To some, unless you are doing 3D, 4D, 5D, 6D, xD and having everything completely integrated, you are not doing TRUE BIM.

But what is BIM? Building INFORMATION Modeling. Just about any introductory BIM presentation will talk about the i in BIM, the information, being the most important aspect. We work on projects, big and small. We use a variety of tools and processes to create, to consume and to deliver information on our projects. We may just detail a small conflicted area of a project. We are using 3D tools. We are visualizing the work area and sharing with all team members. We are coordinating various trades or scopes of work in 3D, possibly 4D (schedule or logistics), maybe even 5D (cost). Are we not doing "BIM"? We need to use the project information, in the most efficient manner, for the most benefit to the project (for current needs and future need).

## Metrics

"You tell me that BIM is a savings and not a cost. Prove it". Have you ever had anyone say this to you? All too often, we have those saboteurs, those deniers, those that want nothing to do with BIM ask us to show them the numbers to prove BIM is really what we say it is. Right now, in our industry, a lot of people and a lot of institutions are actively trying to define and develop metrics to prove that BIM is actually good for our projects. If I can show you that on this one project, on this one task, we spent 6 hours doing "BIM" but saved 160 hours in the field (Figure 2), is that a good metric? Will that help change your mind? If I show you that this quantity take-off using our traditional methods takes 40 hours and I can do the same thing with "BIM" in an hour or two, and the results are the same, is that a good metric for you. Will you try BIM now? Or, do I need to develop metrics for an entire project, a project you control, a project you don't want to use BIM on, and try to prove it under those circumstances? What will it take for you to accept that BIM is a savings rather than a cost?

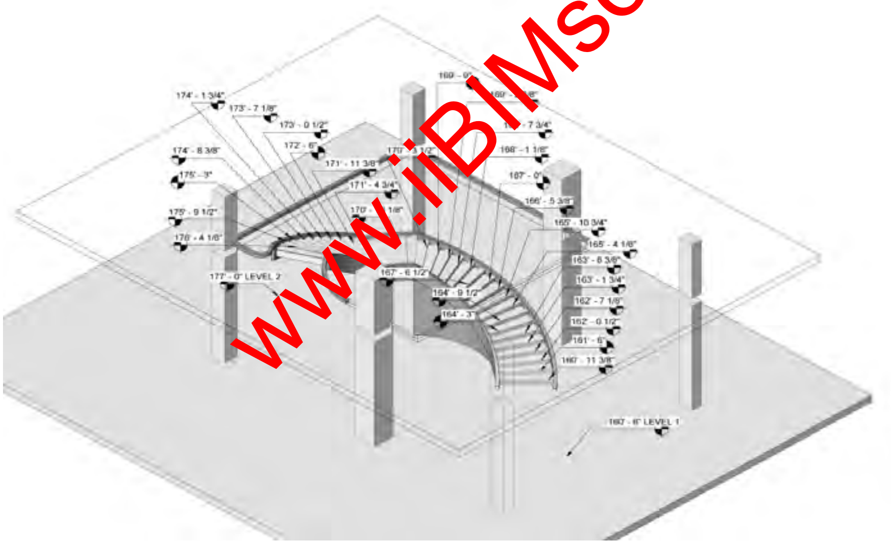

Figure 2: Concrete Circular Stair Detailing

In figure 3, we produced a steel quantity take-off using traditional methods in about 40 hours. Using a Revit model quantity take-off method, we produced the take-off, along with collating and comparing the data, in about 2 hours. The difference as shown in the table is less than 1% difference. Would this make you think that a BIM quantity take-off is comparable to a traditional quantity take-off?

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| Type | Length | Number | Total Length | Weight per LF | Total Weight (SK-Weights per LF) | SK-Total Weight | Difference | PCS - Total by Type | Difference to SK Beam Count | SK-Takeoff Total by Type |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 777 | | | 604902.49 | 593169.37 | -5284.09 | 777.00 | 11.00 | 766.00 |
| | | | | | | | 0.87% | | | |
| HSS6x6x1/2 | 12.75 | 3 | 38.25 | 35.24 | 1347.93 | 6001.37 | -203.23 | 13 | 0 | 13 |
| HSS6x6x1/2 | 13.08 | 3 | 39.25 | 35.24 | 1383.13 | | -113.53 | | | |
| HSS6x6x1/2 | 13.83 | 7 | 96.81 | 35.24 | 3411.58 | | -440.78 | | | |
| W10x12 | 2.92 | 9 | 26.28 | 12 | 315.36 | 324.00 | -58.86 | 9 | 0 | 9 |
| W12x14 | 10.08 | 6 | 60.50 | 14 | 846.97 | 46683.00 | -8.77 | 243 | -4 | 247 |
| W12x14 | 10.92 | 6 | 65.52 | 14 | 917.28 | | -16.08 | | | |
| W12x14 | 11.17 | 3 | 33.50 | 14 | 469.01 | | -5.21 | | | |
| W12x14 | 11.08 | 3 | 33.25 | | | | | | | |
| W12x14 | 12.00 | 1 | 12.00 | | | | | | | |
| W12x14 | 12.50 | 10 | 125.00 | | | | | | | |
| W12x14 | 13.17 | 1 | 13.17 | | | | | | | |
| W12x14 | 13.08 | 16 | 209.33 | | | | | | | |
| W12x14 | 14.00 | 140 | 1960.00 | | | | | | | |
| W12x14 | 14.08 | 2 | 28.17 | | | | | | | |
| W12x14 | 15.33 | 23 | 352.59 | | | | | | | |
| W12x14 | 15.50 | 1 | 15.50 | | | | | | | |
| W12x14 | 17.00 | 4 | 68.00 | | | | | | | |

Figure 3: Quantity Take-off

## Leap of faith (Conclusion)

My last common sense BIM suggestion is to take a leap of faith. Right now at this time in our lives, without a lot of metrics, regardless of contract type, with very few projects that would meet some definitions of "true BIM", we need to accept that what we know today and what we've learned in the past, is changing rapidly and may be obsolete. We need to accept that change occurs every day on every one of our projects. We need to realize that everyone in our organization, and every team member from other organizations working on this project, is important and has valuable input into this project, regardless of title. We need to realize that there is no "easy button" and there is no magic. We need to create, consume, use and re-use project information and to share the information without worrying about "turf", while at the same time protecting ourselves. We need to trust all of those people and organizations working on this project. BIM is not going away.

Whether you buy into or not, the industry is moving full steam ahead to implement BIM in a variety of ways on a variety of projects. We don't need to be stupid about BIM implementation. You don't need to go buy every piece of software available and hire 10 new BIM modelers. And, you don't need to model every last nut and bolt to take advantage of the information within the BIM models. But do accept that fact that BIM is a good thing, BIM can save time and money, and sometimes disruptive change to your business process can produce outstanding results.

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# IMPLEMENTING BIM:
# A Consultative Approach

***Leo Salcé, Intl Assoc AIA, LEED AP; Senior Consultant, Microdesk***
***John Barkwell, Microdesk***

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One of the most common questions for firms contemplating making the transition to BIM are, what are the next steps and how do I get there?

There are numerous theories on how to best go about implementing BIM in a firm, but there is no single cookie-cutter implementation approach. No two firms are alike. Therefore, your BIM implementation plan must address the firm's own unique business and processes.

The first thing your firm needs is executive sponsorship to ensure there is real commitment to the move, plus a clear vision of what the organization's goals are and an awareness of the impacts a major transition will have on the organization, from processes to staffing to technology needs. When moving to BIM, it is important to remember that it is more than a lateral move; it is a change in process, too. Firms doing this on their own tend to suffer from painful lessons learned, so having your process assessed by a professional consultant is recommended.

With this framework in place, you can then set yourself to the task of defining a well thought-out implementation plan. Outlined below are the common steps:

1. **Define the organizational framework**

- Create a modeling plan that outlines the roles and responsibilities for everyone involved, from
what will be modeled to who has ownership of what, by doing the following:
- Develop a company template with all of your standards
- Outline a staffing plan that clearly defines the roles of engineers and drafters, as well as organization structure relative to the types of projects you'll be doing
- Define an internal and external communication system
- Create a training and support plan

## 2. Select the right software

Determine what BIM software(s) will best address your organization's needs, from one to all of the following tasks:

- Model Creation
- Model Integration
- Clash Detection/Model Mediation
- Model Sequencing
- Model Quantity Takeoff
- Collaborative Project Management

At this stage you must also ensure IT and hardware are able to meet the software requirements in orderto allow for a smooth transition and avoid frustrations. Also consider a server strategy for accessing theBIM model from multiple locations.

The success of the implementation will be based on doing an early assessment of the company's current workflow and state of technology to better provide a clear and complete roadmap.

## 3. Create a Project Deployment Plan

When rolling out your new tools and processes, it is often best to by identifying an initial pilot project and defining:

- Specific project goals and objectives
- Clear internal and external collaboration plans
- A document management workflow
- A BIM management workflow
- Construction Management, Cost Management, Project Closeout workflows, If required.

## The Consultant
## When do you get your BIM Technology Consultant onboard?

As early as possible in the implementation. Start the conversation and have your firm be assessed on current workflows, setup and processes. BIM is a process not software, so you want to strategically map your current processes to a BIM process.

Understanding the necessary steps involved when making the transition and making the appropriate investments in consulting and technology are crucial for a successful transition.

Below is a list of common services provided by experienced BIM technology consultants throughout a BIM implementation:

· Assess the current state of the firm in terms of processes, workflow and setup from actual production work, PD, SD, DD, CDs to internal and external collaboration efforts. Based on the assessment a report should be provided with a list of recommendations and a roadmap for timeframe.

In the Assess phase, the consultant will gather all the necessary information about the firm, their processes, and their goals for the implementation.

In the Plan phase, they will use the information gathered during the assessment to develop a

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comprehensive plan to guide the implementation. A proper plan defines the scope of the project, what is to be done, who will do the work, and when it will be done.

· Identify a pilot project provide recommendations based on project deadlines, budget, timeframe and level of complexity.

· Define staffing needs
Staff Augmentation – provides qualified candidates that have proven business, cultural and software skills to help with a specific task or an entire project. This project mentoring or onsite support is sometimes extended as a contractual BIM/CAD management service.

· Provide custom and tailored training based on the project needs
Fitting the curriculum to your specific goals is the best way to ensure that the class covers exactly what you need to know in the shortest amount of time. Training ranges from the basics on how to get started to complex modeling technique or advance topics.

· Provide project mentoring and support
Project mentoring is an extension to training that provides onsite "over the shoulder" support as the team begins their pilot project and sub-sequentially follow up projects

· Develop / Update BIM Standards for the firm
Help your firm organize data so that it can be easily accessed and used throughout the designbuild-operate lifecycle

· Develop a Company (BIM software) template.
Migrate company's standards to maintain fidelity or enhance the level of production in place. Having a good project template is the single most important thing in improving efficiency, quality, clarity, and consistency in your projects.

· Pre-Build (BIM Software) project specific content or company-wide standard content (walls, doors, windows, schedules, etc)
Establish an extension to your existing support team to develop content, styles and families to ensure a successful transition

· Provide On-Site Installation / Deployment
A successful deployment is essential to maintaining a stable technology environment, that is also scalable as the firm grows

· Provide Process Automation / Custom solutions
Analyze the firm's existing processes, design systems and practices to reduce redundancy and increase proficiency from developing workflow techniques to programming widgets or add-ons or scripts to facilitate the use of the data in the model

· Provide Project Optimization and Evaluation
A post implementation assessment aimed at checking how efficiently you are using your BIM software and making recommendations for improvement

· Provide Project Visualization, Coordination and Analysis (if available)
Facilitate the deliverable of still and animation renderings for Actual project bidding.
Provide an analytical model, analysis and report from sustainable design calculations to

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structural analysis validation

Represent the firm or the sub in coordination meetings to drive the discipline model

### Common obstacles

Being aware of these common pain points is the first step to walking into a BIM implementation with eyes wide open and knowing potential issues to prepare for.

Training:

- Lack of time to learn the software
- Steep learning curve
- No clearly defined modeling requirements and staff responsibilities (drafting and designing tasks are no longer separated)

Coordination:

- Defining who owns all the BIM model elements
- Difficulties in format conversions between platforms
- BIM requires architects and engineers to know a lot about the model very early, often before they even have the information
- Liability if the BIM model is sent to a fabricator

Documentation:

- Drafting tools in BIM not yet as well developed as in CAD
- Conversion of CAD to BIM standards is time consuming
- BIM cannot produce drawings as quickly as CAD
- Annotation more difficult in BIM than in CAD
- Last minute changes in 2D CAD are easier than in 3D BIM
- Manual editing required for unwanted graphics

Design:

- Over-modeling, not knowing when to draw the line
- Lack of confidence in the accuracy of the model
- Underestimating the level of effort involved in design/modeling. BIM models appear further developed than the actual design may be.

These issues and common perceptions emphasize the need for professional consulting and a well thought-out implementation plan to address or avoid obstacles before they get in the way. When moving to BIM, again, it is important to remember that it is more than a lateral move; it is a change in process too. Understanding the necessary steps involved when making the transition and making the appropriate investments in consulting and technology are crucial for a successful transition.

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# NORTH CAMPUS BRIDGE:
# Natural History Museum of Los Angeles County

***Fabian Kremkus, AIA, BDA; Associate Principal, CO Architects***

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**Project Description:**

The Bridge project for the Natural History Museum of Los Angeles County is significant in terms of the use of BIM because the computer model was used by all involved parties and served as a tool for the following:

- To visualize CO Architects' ideas and to illustrate the concept to our client, the Natural History Museum and Don Webb from Cordell Corporation.

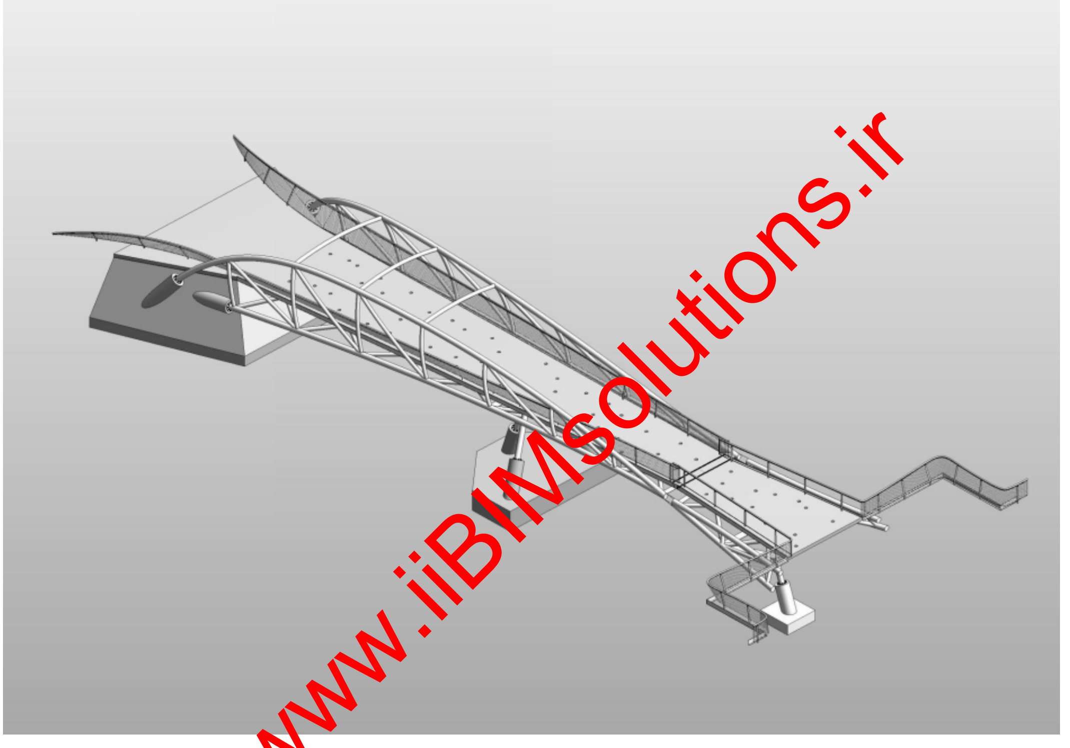
- To create a rapid prototype model.

- To create and control the form during our communication with the structural engineer, Jackie Vinkler, SE of John A. Martin & Associates. The spline model from the Revit conceptual mass was used to create the structural model. Many adjustments were made to the supports and lateral system to achieve the final system that satisfied the structural and aesthetic aspirations. Coordination sessions involved many discussions about how to communicate the complex truss geometry to the fabricator, and we agreed that it would be best if the computer model itself became a part of the contract documentation. The structural and architectural model was kept up to date in order to accomplish a coordinated model that could be handed to the fabricator.

- To develop the mock up and flush out constructability issue with our contractor, Valley Iron, and the general contractor, MATT Construction. We held coordination meetings early on to receive their input, and many comments were incorporated into the final documents. A mock-up was built based on our Revit model simulating almost all steps that would be needed to build the final project. This instilled confidence in all parties and eliminated risk. The budget, the fabrication and schedule were met without a single problem.

- To compare our model to the model of the fabricator during the shop drawing review period in order to review necessary size and curve adjustments. Weld sizes were also determined this way. All parties quickly gained a full understanding of all components, and the final product was error free. Even the shipping of the bridge section was simulated in the computer to determine how the project could be broken into pieces and to develop a load that could still pass beneath bridges along the planned route. This minimized field welding and made the delivery and erection process goes very smoothly. The installation of the structural steel components was completed within two weeks.

Today, the bridge serves as a new beacon and urban entrance symbol for the Natural History Museum, welcoming the visitor in a new and exciting way. The bridge is one of the crucial components helping to bring the museum experience to the outdoors.



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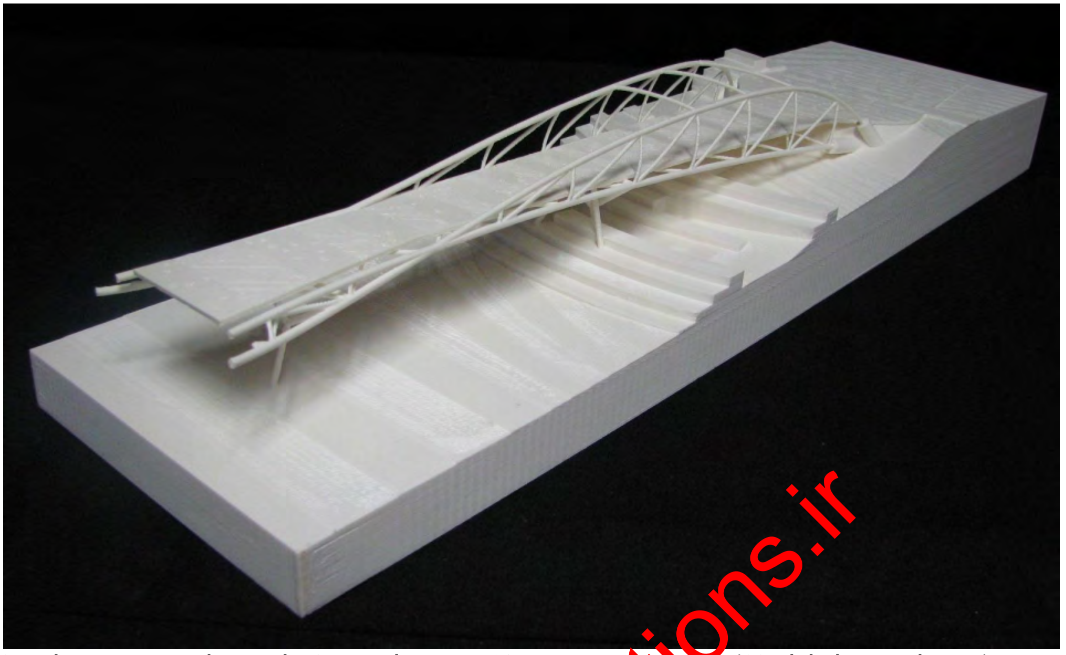
North Campus Bridge at the Natural History Museum, Los Angeles (Revit Model screen shot in house)



North Campus Bridge at the Natural History Museum, Los Angeles (Model Photo in house)

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North Campus Bridge at the Natural History Museum, Los Angeles (Photography: Tom Bonner)

North Campus Bridge at the Natural History Museum, Los Angeles (Photography: Tom Bonner)

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# A DECISION SUPPORT METHOD:
## For Reducing Embodied Environmental Impacts During Early Stage Building Design

*John Basbagill and Mike Lepech; Stanford University*

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## ABSTRACT

Decisions made in the early design stages critically determine a building's embodied environmental impact. However, designers are faced with many decisions at this phase of the design process and lack intuition on which decisions are most significant to a building's embodied environmental impact. Life cycle assessment (LCA) is a method that can enable better early stage decision-making by providing feedback on the environmental impacts of building design choices. This paper presents a method for applying LCA to early stage BIM decision-making. An impact allocation scheme shows the relative distribution of impacts among building elements, and an impact reduction scheme highlights those building component material and size decisions achieving the greatest embodied impact reductions. An overseas residential compound is used as a case study for introducing the proposed method to industry practice. Results show that the method assists in the early design process of the compound by providing support for decisions that can achieve significant reductions in carbon footprint.


## INTRODUCTION

Buildings consume significant amounts of energy and materials. They account for 41% of the total energy consumption in the U.S. (Fumo, Mago *et al.* 2010) and 38% of the nation's greenhouse gas emissions (DOE 2011). Embodied impacts due to building materials are also significant (Fay, Treloar *et al.* 2000; Bribian, Uson *et al.* 2009) and, in cases where buildings have been designed for low- or net-zero energy, can approach impacts due to operational energy use (Citherlet 2001, Thormark 2002, Winther and Hestnes 1999). A significant portion of a building's life-cycle impacts are determined by decisions made in the early design stages (Cofaigh, Fitzgerald *et al.* 1999; Kotaji, Schuurmans *et al.* 2003). Choosing materials with low embodied impacts at this stage can therefore significantly reduce a building's life cycle impact (Lawson, Partridge *et al.* 1995).

Life-Cycle Assessment (LCA) is a method for predicting how a facility will perform over its lifetime, which includes raw material extraction, manufacturing, construction, operation, maintenance, repair, replacement, and demolition (Langdon 2007). LCA considers environmental as well as social and economic impacts, and commonly applied environmental indicators include global warming potential, carcinogenicity, and resource consumption.

Adoption of LCA methods to architecture, engineering and construction (AEC) projects has been limited due to time and effort for implementation. Yohanis and Norton (2006) note the difficulties in obtaining complete environmental impact data for building components and tracking material flows. BIM software lacks interoperability with LCA software (Bribian, Uson *et al.* 2009), and system boundaries are often unclear (Gluch and Baumann 2004). Designers occasionally use LCA to validate a chosen design solution but not to compare alternatives during the early design phases (Lee 2009).

An additional challenge of performing LCA during early stages is the large number of decisions that an AEC designer may consider. Materials and sizes must be determined for hundreds of components at some point in the design process, and these decisions are typically deferred to engineering and construction teams in the design development stage (Kienzl, Chaszar *et al.* 2003). Postponing decisions leads to significant increases in the building's impact, and changing decisions at a later design stage is costly (Schlueter and Thesseling 2009). In order for LCA to be an effective early stage design decision-making tool, designers must be enabled to understand which decisions most significantly determine a building's environmental impact and which decisions are less important.

This paper introduces a framework for providing designers with intuition on how buildings' embodied impacts are distributed throughout building elements and which material and size decisions most critically determine a building's embodied impact. Since the framework requires a minimal number of inputs and can easily accommodate design changes, it is most appropriate for the early design stages.

Within this paper, related studies are reviewed in Section 2. Next, the proposed decision support framework is presented in Section 3. Finally, in Section 4 a case study application of the method is presented. The study shows how impacts are allocated throughout the building as well as which building component decisions are the most important in terms of environmental impact, and the results are discussed.

## RELATED STUDIES

Articulation of the stages and decisions within the building design process has been a field of research since the 1960s, and the body of literature is vast. The relationship between environmental impact implications of building design decisions and their temporal occurrence in the design process is a more recent research area. Studies have shown that the earlier decisions are made in the design process and the fewer the changes to these decisions at later stages, the smaller is the building's environmental impact. For example, Wang, Zmeureanu *et al.* evaluated the environmental impact implications of various early stage design parameters using LCA methodology (2005). Hauglustaine and Azar (2001) and Coley and Schukat (2002) developed methods for providing operational energy feedback to designers at the early design stage using a limited number of design variables.

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Researchers have also used LCA to develop schemes for classifying early design variables and estimating embodied impacts of buildings. Pushkar, Becker *et al.* used LCA methodology to group design decision variables into small clusters then show the degree to which each variable determined environmental impacts at each phase in a building's life cycle (2004). Scheuer, Keoleian et al. conducted a post-occupancy study of the relative importance of embodied impacts versus impacts associated with operational energy use (2003). Bribian, Capilla et al. conducted LCA on commonly used building materials, in order to provide guidelines on early design stage material selection based on minimized embodied impact (2011).

An early stage decision support method that shows which building material and size choices can achieve the greatest embodied impact reductions is neglected in all of the above studies. Sensitivity analysis can be applied to show the effects of changes to building materials and sizes on embodied impact. Maintenance, Repair and Replacement (MRR) impacts have also not been included in prior research in this area. These limitations are addressed by the proposed method.

## METHODOLOGY

*Scope*

The goal of the proposed methodology is to enable designers to understand the environmental impact implications of building components' material and size choices. The UniFormat 2010 classification system is used to predict embodied impacts for building components essential to the building structure. UniFormat Level 1 elements within the project scope are: Substructure (A), Shell (B), Interiors (C), and Services (D). The remaining Level 1 elements (equipment and furnishings, special construction and demolition, and building sitework) are not considered, since these decisions relate to interior aesthetics, require specialized knowledge of site conditions, or otherwise involve decisions that would be impractical to make by designers before the design development stage. Further detail on the classification scheme is presented in section 3.2.

The shaded area in Figure 1 shows the phases of the building life-cycle that were considered in the analysis. Only MRR impacts of the operational phase have been included in the scope. HVAC, lighting, and plug loads have not been considered, since the research focus is on the significance of embodied impact decisions. Demolition and on-site construction have also been excluded, since impacts associated with these phases have been shown to be difficult to calculate (Pushkar, Becker *et al.* 2005; Schoch, Prakasvudhisarn *et al.* 2011) and small when compared with other phases (Scheuer, Keoleian *et al.* 2003).

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Researchers have identified several impact categories that are useful in measuring the environmental impact of buildings, including global warming potential, non-renewable energy consumption, human toxicity, acidification, and eutrophication, among others (Jolliet, Margni *et al.* 2003). Although the authors recognize the importance of all of these categories in comprehensively assessing environmental impact, this methodology considers only global warming potential. The metric used for this purpose is carbon dioxide equivalents ($CO_2e$) using the relevant 100-year global warming potential (Wright, Kemp *et al.* 2001), which measures the total amount of greenhouse gas emissions of the building, considering all relevant sources.

| Uniformat element | Assembly | Sub-components | [2]Number of material choices | [1]*Thickness* Min (m) | Max (m) |
|---|---|---|---|---|---|
| [3]*A: Substructure* | piles | **piles**, ***vapor barrier***, caps, slab-on-grade, grade beam, rebar, *formwork* | 2 | 0.1 | 0.4 |
| | footings | footings, ***vapor barrier***, slab-on-grade, grade beam, rebar, *formwork* | 2 | 0.1 | 0.4 |
| | mat foundation | *foundation*, ***vapor barrier*** | 2 | 0.2 | 1.8 |
| *B: Shell* | columns and beams | | 10 | n/a | n/a |
| | floor structure | | 12 | n/a | n/a |
| | roof | | 15 | n/a | n/a |
| | stairs | railings | 9 | n/a | n/a |
| | cladding | | 7 | 0.02 | 0.08 |
| | exterior walls | **wall structure**, insulation, membrane, gypsum, paint | 6 | n/a | n/a |
| | glazing | *glass*, *polyvinyl butyral*, **frame**, hardware | 5 | 0.007 | 0.02 |
| | doors | hardware | 3 | n/a | n/a |
| C: *Interiors* | partitions | ***partition structure***, *gypsum*, paint | 2 | 0.4 | 0.6 |
| | doors | hardware | 2 | n/a | n/a |
| | wall finishes | **covering**, *paint* | 2 | 0.009 | 0.02 |
| | flooring | ***surface***, ***insulation*** | [4]22 | 0.1 | 0.2 |
| | ceiling | plaster + gypsum + paint | 1 | 0.006 | 0.02 |
| [5]*D: Services* | mechanical | (17) | [6]1 | n/a | n/a |
| | electrical | (16) | 1 | n/a | n/a |
| | plumbing | (22) | 1 | n/a | n/a |
| | fire | (4) | 1 | n/a | n/a |
| | conveying | elevator | 1 | n/a | n/a |

(1) Size ranges correspond to italicized sub-component. For assemblies with multiple italicized sub-components, size ranges represent combined thicknesses. Size ranges correspond to all material choices.
(2) Material choices correspond to bold sub-component. Remaining sub-components have one material choice.
(3) Substructure consists of one of the three listed assemblies. Remaining three elements consist of all listed assemblies.
(4) Floor surface has 13 material choices, and floor insulation has nine choices.
(5) Large numbers of services sub-components preclude enumeration.
(6) Duct insulation is a mechanical sub-component with 13 material choices. Remaining mechanical sub-components have one material choice.

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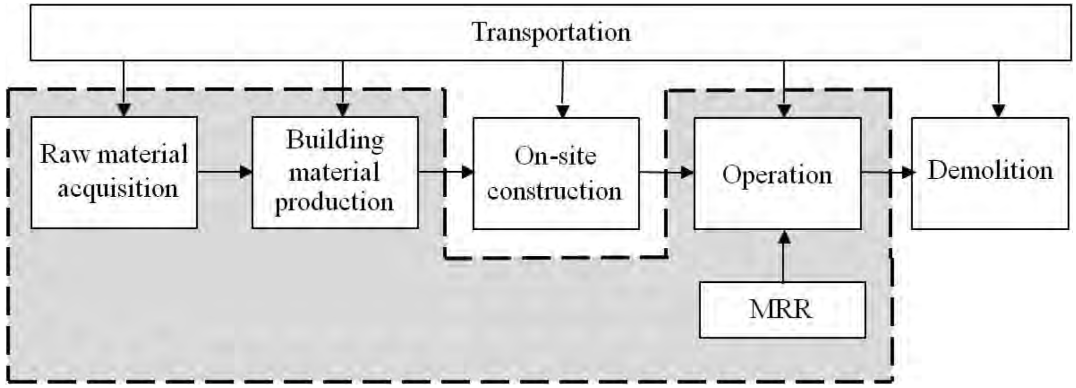


Figure 1. Building life-cycle phases included in proposed method for reducing embodied impacts of early stage designs. Operational phase is limited to MRR embodied impacts.

*Building component classification framework*

The framework used to structure the building component decisions is based on Uniformat 2010. Table 1 outlines assemblies and their enumerated sub-components for each of the four Uniformat elements. Material choices for each component are determined using RSMeans (RSMeans 2007) and Athena EcoCalculator (Athena 2011). These choices are not meant to be exhaustive but rather representative of common materials. Thickness is chosen as the sizing variable, since this is the easiest parameter to determine size ranges for a majority of the components. Specifications from equipment supplier documentation are used to determine the ranges. Size ranges are not articulated for every component, namely components whose sizes are best determined by structural analysis methods applicable to later design stages.

Table 1. Building component classification framework

*Analysis process*

The general steps involved in the proposed building carbon footprint analysis process are shown in Figure 2. The arrows in the figure represent data dependencies between process steps.

The analysis process begins with a BIM representing a given design configuration. The BIM describes the building's geometry as well as any building component materials and sizes known at the early design stage.

The pre-operational carbon footprint is calculated based on the building material quantities extracted from the BIM. Minimum and maximum quantities for each building component material are calculated using the material and size ranges from Table 1. The material quantity formulas were developed by senior estimators at Beck Technology and were also taken from Athena Eco-Calculator. The minimum and maximum pre-operational carbon footprints are determined by multiplying each minimum and maximum material quantity by a unit impact (kg $CO_2e$ per kg of material).

A Maintenance, Repair and Replacement (MRR) schedule is used to determine the operational phase impacts associated with mechanical, electrical, and plumbing (MEP) equipment as well as fire and conveying equipment. The MRR schedule is determined by the gross floor area, building type, location, and structural and mechanical details defined in the BIM model. These parameters are entered into an online facility operations reference database (CostLab 2011), which returns each

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service component's MRR dollar costs for every year of the building's operation. Equipment supplier documentation is then used to look up a typical material, material quantity, and cost for each service component. Minimum and maximum material quantities associated with the MRR costs are then calculated. These quantities are multiplied by a unit impact (kg $CO_2e$) in a similar fashion to the pre-operational impact calculation to determine the minimum and maximum operational carbon footprints. The life-cycle embodied carbon footprint is then determined by summing the pre-operational and operational $CO_2e$ totals. Designers can modify BIM design choices based on the embodied impact feedback.

The results present designers with an impact allocation scheme, which shows the minimum and maximum embodied impacts possible for each of the building components. A building component's minimum impact is determined by selecting that component's material and size with the smallest unit impact; the material and size with the largest unit impact are chosen for all other components. Maximum impacts are determined in a similar fashion. The minimum or maximum impact is expressed as a percentage of the building's total embodied impact.

Designers are also presented with an impact reduction scheme, which shows the degree to which each building component achieves reductions in embodied impact due to changes in both material and size. The maximum impact reduction due to a change in size is calculated by subtracting the smallest possible impact from the largest possible impact. The maximum impact reduction due to a change in material is calculated in a similar fashion. The reductions are expressed as a percentage of the maximum possible total embodied impact of the building.

Designers also receive an impact ranking scheme showing the top five components achieving the greatest impact reductions due to changes in both material and size.

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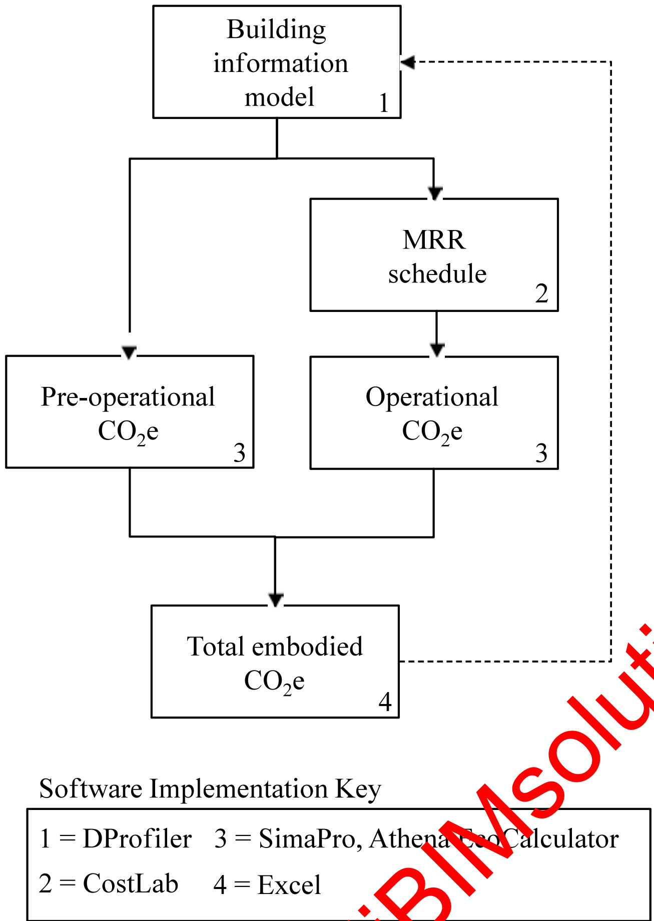


Figure 2. Embodied carbon footprint analysis method includes extracting material quantities from the BIM and determining the MRR schedule to calculate life cycle embodied impact.

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*Implementation*

Four software components were used to implement the method illustrated in Figure 2. DProfiler was used as the BIM software (DProfiler 2012). Carbon impact data was obtained from SimaPro and Athena EcoCalculator (SimaPro 2010, Athena 2011). CostLab provided the MRR schedule and dollar costs for the service equipment, and these costs were combined with carbon data from SimaPro to determine the MRR impacts (CostLab 2011). Excel was used to calculate the carbon footprint metric based on the data provided by the previous software components (Excel 2007).

## CASE STUDY

*Problem Formulation*

A four-building, eight-story residential building complex located abroad is used as a case study in this paper to demonstrate the utility of the proposed method to industry practice. Each building is of identical size, shape, and building materials. At the time this paper was submitted for publication, the complex was in the early design stage. The case study thus provided an opportunity to show which decisions could reduce the embodied environmental impact of the complex the most in terms of building component materials and sizes.

Embodied carbon footprint was calculated in terms of $CO_2e$ as described in Section 3.3. Material quantities were calculated using the following parameters. The total floor area is 50,000 $m^2$, the perimeter is 199 m, and the floor-to-floor height is 3.6 m. The service life of the compound was assumed to be 30 years, and the window-to-wall ratio was assumed to be 0.15. Peak building load was used to size the MEP equipment and was assumed to be 205 tons. Geographic location and orientation were not considered, since it was assumed these parameters would not affect decisions relating to embodied impact.

*Results and Discussion*

The proposed method was applied to the case study project to determine in which building components emboided impacts were concentrated as well as which design decisions could achieve the greatest reductions in embodied impact. Table 2 presents the impact allocation and impact reduction scheme, and Table 3 presents the impact ranking scheme as described in 3.3.
The impact allocation scheme shows that embodied impacts are concentrated in each of the four elements, with each element potentially contributing over 50% of the compound's embodied impact. Many components may contribute significantly to the building's embodied impacts. Fifteen of the 21 components' maximum impacts were greater than 10% of the total embodied impact, and eight were greater than 50%.

The impact reduction scheme shows that significant reductions could be achieved within all four elements by changing materials and sizes. Three of the top five material changes in the impact ranking scheme were located in the shell (B), suggesting a designer should choose to focus on this element when making material design decisions for the compound during the early design stages. On the other hand, two of the top five size changes were located in B, and two were located in the services (D), suggesting a designer should split their efforts in these areas for size decisions. The impact reduction and impact ranking schemes together suggest that significant reductions in the compound's embodied impact cannot be achieved by making size or material changes to the substructure (A) or interior (C).

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Table 2. Impact allocation scheme showing embodied impact concentrations, and impact reduction scheme showing reductions due to material and size changes

| | | *Impact Allocation Scheme* | | *Impact Reduction Scheme* | |
|---|---|---|---|---|---|
| Uniformat element | Assembly | Minimum impact (% total embodied) | Maximum impact (% total embodied) | Maximum impact reduction (material change) (% max embodied) | Maximum impact reduction (size change) (% max embodied) |
| *A: Substructure* | | **0.25** | **59.94** | **10.19** | **1.07** |
| | piles | 2.85 | 59.08 | 10.19 | 0.35 |
| | footings | 13.24 | 59.94 | | 0.35 |
| | mat foundation | 0.25 | 12.48 | | 1.07 |
| *B: Shell* | | **2.91** | **82.02** | **30.35** | **13.65** |
| | columns and beams | 0.36 | 29.58 | 3.40 | |
| | floor | 0.43 | 40.07 | 5.52 | |
| | roof | 0.02 | 3.94 | 0.24 | 0.07 |
| | stairs | 0.00 | 3.98 | 0.15 | |

| | | | | | |
|---|---|---|---|---|---|
| | cladding | 0.02 | 65.52 | 17.54 | 13.20 |
| | exterior walls | 0.64 | 27.63 | 2.56 | |
| | glazing | 0.58 | 18.95 | 0.90 | 0.38 |
| | doors | 0.01 | 0.51 | 0.03 | |
| *C: Interiors* | | **6.67** | **87.50** | **15.59** | **6.08** |
| | partitions | 1.28 | 56.14 | 9.61 | 0.09 |
| | doors | 0.00 | 0.66 | 0.06 | |
| | wall finishes | 1.03 | 30.99 | 1.34 | 1.62 |
| | flooring | 0.25 | 69.65 | 4.58 | 3.06 |
| | ceiling | 2.66 | 50.59 | | 1.21 |
| *D: Services* | | **2.60** | **76.43** | **4.70** | **13.86** |
| | mechanical | 0.54 | 58.27 | 4.70 | 8.24 |
| | electrical | 0.65 | 52.12 | | 5.23 |
| | plumbing | 0.89 | 15.84 | | 0.33 |
| | fire | 0.02 | 0.86 | | 0.05 |
| | conveying | 0.06 | 0.70 | | |

Table 3. Impact ranking scheme showing which building components achieve the greatest reductions in embodied impact due to material and size changes

| *Impact Ranking Scheme* | | | | |
|---|---|---|---|---|
| Rank | Material change | Reduction (% max embodied) | Size change | Reduction (% max embodied) |
| *1* | cladding | 17.54 | cladding | 13.20 |
| 2 | piles | 10.18 | duct insulation | 4.56 |
| 3 | floor structure | 5.52 | lighting fixtures | 2.45 |
| *4* | duct insulation | 4.70 | floor insulation | 1.55 |
| 5 | columns and beams | 3.40 | floor surface | 1.51 |

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## CONCLUSIONS

Understanding the life cycle embodied impact implications of building design decisions is important to creating a more sustainable built environment. The proposed decision support method helps designers to predict which decisions most critically determine a building's embodied impact. The method also points out those building areas in which decisions are less important. The case study results show that by focusing on decisions related to cladding material and thickness, designers can achieve a 17.5% and 13.2%, respectively, reduction in total embodied impact compared to the worst-case decisions. Large reductions can also be achieved for other components in the shell as well as services.

The scope of this method is limited to building components for which size ranges can be easily predicted at the early design stages. The method also assigns the same size range to each material within an assembly; future work will develop material-specific size ranges. Carbon footprint calculations do not consider emissions resulting from operation of HVAC or lighting equipment or plug loads, and climate and geographic location are not considered. Future research will include these operational impacts in order to develop a more comprehensive understanding of the relationship between early stage design decisions and environmental impacts.

The variables in this study are limited to building component materials and sizes. Future work may consider additional design variables which have a significant impact on life-cycle performance and that are commonly decided upon during the early phases of the design process. These include building shape, number of floors, window-to-wall ratio, and orientation. Cost can be introduced as a second objective to show cost versus carbon footprint tradeoffs of design decisions. An optimization method can be employed to show these tradeoffs. Finally, the validation of the method is currently limited to a single case study involving a particular building type and geometry. Additional case study applications will be required to comment more generally on the performance and robustness of the proposed decision support method.

## ACKNOWLEDGMENTS

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# OWNER TAKES THE LEAD:
## Re-purposing Data and Technology for Lifecycle BIM

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*The PREZI presentation for this paper is available online at: http://prezi.com/r2_0ds-w-8fp/3-levels-of-bim-quality-assurance-for-owners/*

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The Los Angeles Community College District (LACCD) is tackling today's economic crisis with an ambitious vision that will transform how it builds its campuses today, and operates and maintains its facilities in the not too distant future. In the midst of a $6 Billion Construction Program in which LACCD will build or renovate close to 100 facilities across 10 campuses, educational and operational budgets are being slashed, classes are being canceled, and with limited operational funds, we face the very real possibility of new buildings being opened without an increase additional staff to operate them. Yet, in spite of these tough economic times, and perhaps due in part to the challenges they present, LACCD is forging a path to use emerging technologies such as Building Information Modeling (BIM) to create energy efficient buildings and campuses that are built with high performance materials, renewable energy systems, and a vision that our campuses will be zero-net energy in their operations by 2020. This paper will discuss how a large community college district's implementation of BIM is affecting a cultural shift in the way our local industry is delivering buildings. Through the use of modeling standards, collaboration within our teams, and an internal quality assurance program, LACCD is shifting our building industry away from traditional 2D deliverables and challenging the industry to look at building information models as a virtual representation of the built environment. It is LACCD's vision that the 'virtual building' be a key source of data and vital component in the operations and maintenance cycle of a facility.

Like other public works programs, Los Angeles Community College District's building program has an eye to the future and is implementing several innovative initiatives that will help improve the design and construction quality of our buildings. More ambitious however, is the goal to move our campuses closer to energy self-sufficiency over the next decade. Our building program officially began in 2001, with the passing of our first bond program (Proposition A, $1.2 billion), and then was bolstered by a second $950 Million bond release just 2 years later (Proposition AA). However it was not until 2008, with the passing of the third bond installment of our program (Measure J, $ 3.5 Billion), where the district decided it was time to require the use of Building Information Modeling for many of its new and larger renovation projects. Although the District had been eyeing the use of BIM in its construction program for several years, the technology was still relatively new. However, with the large windfall of construction funds, and many architects and builders hungry for work, the timing was ripe to begin forging a path to integrating BIM technology into our building program requirements.

Upon passage of the bond in November 2008, LACCD immediately set out to develop its own BIM standard. In parallel, we also began assessing the capabilities of the local AEC industry in their use of building information modeling. Either eager for work, or eager to show their capabilities, many within the industry were clamoring for the use of BIM; and as the announcement of our BIM requirement became public, many architects and builders who had worked with us before but never used BIM on our projects were suddenly "BIM savvy". As the requirement for BIM started to level the playing field, determining the level of sophistication became a greater challenge. While many companies touted their capabilities, we would come to realize many were still only using BIM on small test projects, or to benefit a particular workflow of one of the members of the team. More importantly, those who were using BIM, were not necessarily using it in a collaborative or "social" manner, meaning that the approach of full team participation or "life cycle BIM" where all parties, including the owner would be involved in all stages of the process, was not the format many were accustomed to. In this manner, our BIM requirement now served two-fold in that we would not only use BIM to help improve the quality and efficiency of our buildings, but also push BIM implementation into more a 'mainstream' practice, focusing on more pedestrian buildings such as classrooms, laboratories, administrative offices, and libraries, as opposed to hospitals and museums piloted by early adopters.

By March 2009, our first draft of the LACCD BIM Standards was ready and was issued for use on one of the first projects of the Measure J bond. In addition to this new mandate, came the requirement that new buildings must perform at least 20% better than minimum energy standards, and the requirement for architect and builder to qualify as a team, and deliver in a design-build format. Just like that, and within a few short months, LACCD's building program was transformed and a new model for public work contracting was born.

In developing its own BIM Standards, LACCD first looked at established National Standards as a basis, and then set out to develop criteria specific to the needs of our organization. Four sections to the standards were developed. The first outlines our core goals and objectives for using and requiring BIM. The second identifies technology requirements, applications of BIM to be used, and what software shall be required. The third section promotes team collaboration, and requires teams to map out their BIM delivery process, develop a BIM Execution Plan, and explain the various information exchanges needed to design, analyze, and construct the facility. Finally, and perhaps most importantly, we define a quality assurance program that requires owner, architect and builder to actively participate in the BIM process, and to check the completeness and organization of the models.

One of the earliest hurdles we faced was whether to require our competing teams to use a single brand of software for consistency sake, or to follow the industry by keeping an 'open specification' and allowing our teams to keep their current workflow and software platforms. Meeting with several major software vendors and talking with builders and architects in Southern California, we decided to follow the industry and maintain the open specification that would allow for better flexibility and depend on increased interoperability across various platforms and model types.

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While we feared facing challenges of data or geometry getting 'lost in translation', there are now enough software options in the industry that allow for models of various formats to aggregate in to one "federated" model with all disciplines and display the pertinent data within the model. This critical step of allowing us to see all the systems together has had a profound effect on designer, builder and owner alike, in that we are now able to clearly see the BIM as the source of all deliverables. Moreover, seeing the entire building in multiple dimensions, allows all parties to visualize the buildings much more quickly than a 2D set of drawings alone ever could, and has prompted us to refer to BIM as "the virtual building".

With the idea that teams should be able to use the virtual building to help them design and construct a building before a shovel even hits the ground, we are now able to begin to get our facilities and college project managers to complete virtual walks of the building, and create a punch list of design and constructability concerns during design and pre-construction.

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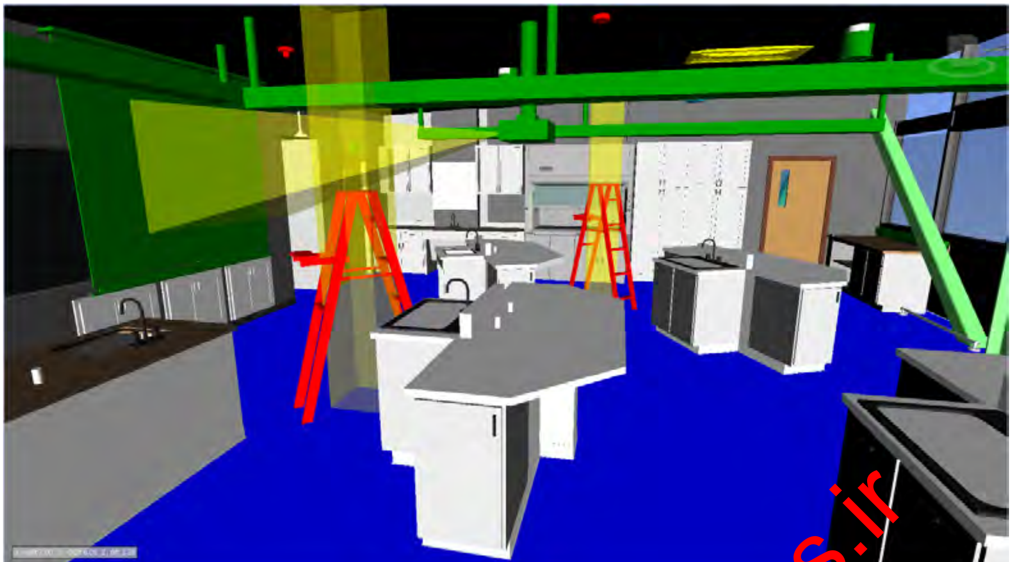
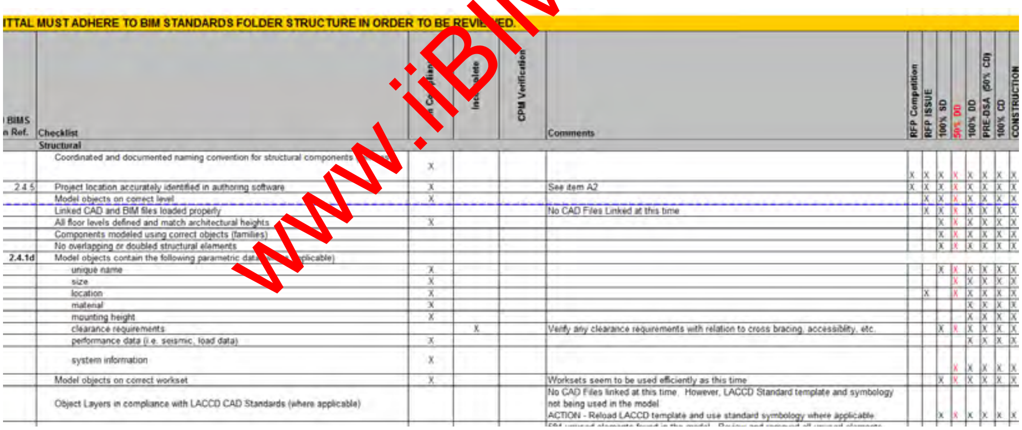
A virtual building walk by the owner reveals a potential design and operational concern
Source: LACCD

The virtual walks led to some practical applications of model reviews as a means to ensure our owner is getting what they paid for. Focusing on aspects of constructability, safety, maintenance and pedestrian accessibility, model reviews have now become the basis for our quality control process, using screen captures and mark up tools within the software to document progress and flag issues that could create delays or cost overruns in the field, or long term maintenance issues long after the builders are gone.



Modeling safety and maintenance access to mechanical units concealed in ceilings above laboratory casework. Source: LACCD

For those who were still intimidated by the idea of BIM, the quality assurance checklist was developed as a simple spreadsheet with reference to our standards built in to the language of the document. The checklist is completed by the designer and builder, and their progress verified by construction managers representing LACCD, to ensure deliverables are being met, standards are being followed, and progress is in alignment with the team's payment requests.

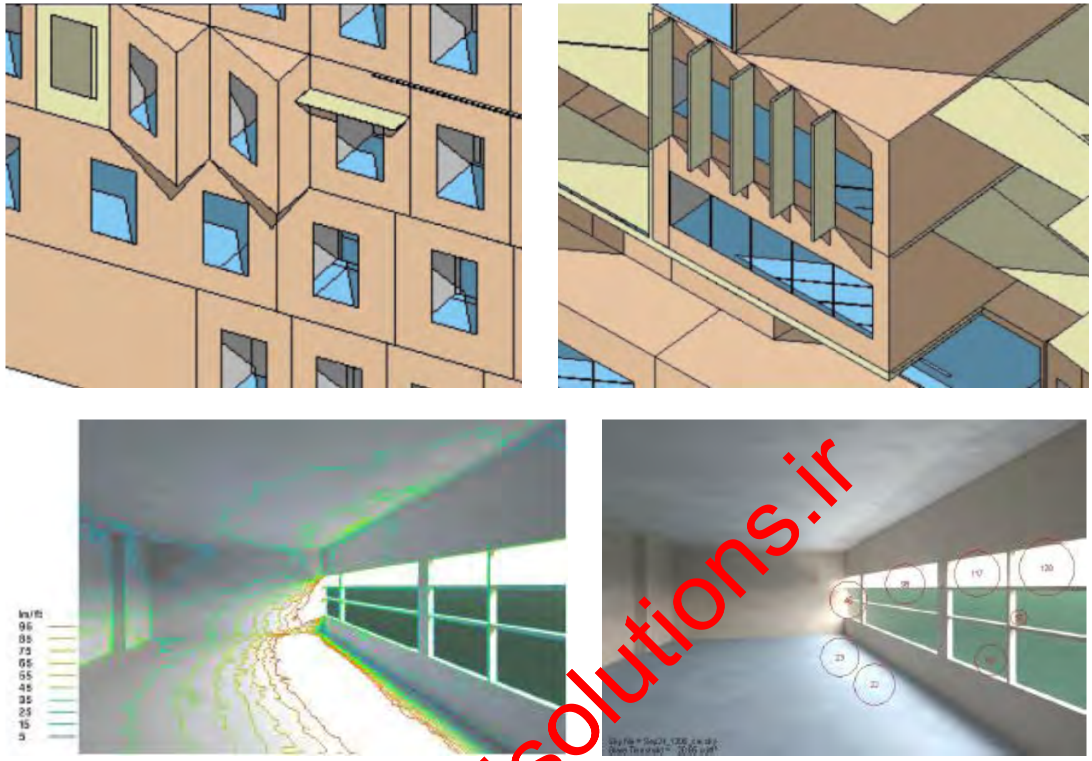


ITTAL MUST ADHERE TO BIM STANDARDS FOLDER STRUCTURE IN ORDER TO BE REVIEWED.

| BIMS Ref. | Checklist | In Compliance | Incomplete | CPM Verification | Comments | RFP Competition | RFP ISSUE | 100% SD | 50% DD | 100% DD | PRE-DSA (50% CD) | 100% CD | CONSTRUCTION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Structural** | | | | | | | | | | | | |
| | Coordinated and documented naming convention for structural components | X | | | | X | X | X | X | X | X | X | X |
| 2.4.5 | Project location accurately identified in authoring software | X | | | See item A2 | X | X | X | X | X | X | X | X |
| | Model objects on correct level | X | | | | | X | X | X | X | X | X | X |
| | Linked CAD and BIM files loaded properly | | | | No CAD Files Linked at this time | | X | X | X | X | X | X | X |
| | All floor levels defined and match architectural heights | X | | | | | | X | X | X | X | X | X |
| | Components modeled using correct objects (families) | | | | | | | X | X | X | X | X | X |
| | No overlapping or doubled structural elements | | | | | | | X | X | X | X | X | X |
| 2.4.1d | Model objects contain the following parametric data (where applicable) | | | | | | | | | | | | |
| | unique name | X | | | | | | X | X | X | X | X | X |
| | size | X | | | | | | | X | X | X | X | X |
| | location | X | | | | | X | | X | X | X | X | X |
| | material | X | | | | | | | | X | X | X | X |
| | mounting height | X | | | | | | | | X | X | X | X |
| | clearance requirements | | X | | Verify any clearance requirements with relation to cross bracing, accessibility, etc. | | | X | X | X | X | X | X |
| | performance data (i.e. seismic, load data) | X | | | | | | | | X | X | X | X |
| | system information | X | | | | | | | X | X | X | X | X |
| | Model objects on correct workset | X | | | Worksets seem to be used efficiently as this time | | | X | X | X | X | X | X |
| | Object Layers in compliance with LACCD CAD Standards (where applicable) | | | | No CAD Files linked at this time. However, LACCD Standard template and symbology not being used in the model<br>ACTION - Reload LACCD template and use standard symbology where applicable | | | X | X | X | X | X | X |

The un-intimidating BIM QA Validation Checklist - a simple spreadsheet. Source: LACCD

Digging deeper in to the models, we began to analyze how model data is used to validate building performance and ensure the District that a built facility will perform 'as designed'. By checking and validating the integrity of the data, LACCD intends that the models be used to help operate and maintain the facility upon completion. The concept here is to use BIM geometry and data for performance models such as daylighting and energy use. To measure the level of performance, part of the scoring criteria for selecting a team includes sustainable design analysis where teams utilize a 3D model to analyze factors of solar orientation, sun and shadow studies, climate analysis, and heat transfer, glare and any other factors pertinent to the design.



Sustainable Analysis models analyzing daylighting and glare factors
Source: LACCD

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Despite this validation, one of the challenges we face today is teams understanding the difference between the need to provide an energy model to meet state energy performance requirements and analyzing the various sustainable design features that might reduce energy use to begin with. As technology continues to advance, we hope these two types of models will converge into a holistic building lifecycle performance model that is geospatially located and can automatically take in to account local environmental factors. Today, however, we are still seeing multiple models that do not always complement or yield consistent results.

As we move toward the next stages of our building program, the focus continues to shift toward the owner, and LACCD continues to look at how all of this BIM data can be re-purposed and used for operating and maintaining our facilities for years to come. Currently there is an effort to model existing buildings in to our district wide GIS system, and recently we have acquired a web based collaboration system that shall serve as a digital file cabinet for all project documents delivered at various stages of each building's lifecycle. Additionally, LACCD looks to begin testing IFC compliant models and COBie formatted data with our Computerized Maintenance Management System. Connecting these with our GIS and the state's space and building inventory system (FUSION), will help ensure the district keeps reliable data for state funding, building and campus operations, and effectively manage energy use to meet our ambitious goals in the coming decade.

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# COLLABORATIVE BIM:
# A Structural Engineering Example of a Generative BIM Process

*Jonatan Schumacher; Director of Advanced Computational Modeling, Thornton Tomasetti*

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## INTRODUCTION

In recent years, the building industry has seen vast technological developments. Three-dimensional modeling is becoming an industry standard, and projects are handled primarily in BIM environments. Moreover, the concept of integrated project delivery (IPD) is spreading, as organizations such as the AIA have endorsed the IPD system. In short, IPD relies on new technologies, and leverages early contributions of knowledge and expertise, to save time and reduce requests for information and change orders during the construction phase. If the project is planned thoroughly early on, and utilizes emergent technologies, the project owner can save time and cost in the construction process.

Looking upstream towards the designers, BIM alone does not help us realize an integrated design approach. Especially at the conceptual design stage, traditional BIM and parametric modeling tools don't allow us to collaboratively explore architectural concepts. Creating a reliable parametric model takes time and effort, especially if building features are geometrically complex.

Given the vast number of software tools utilized in a building project, and the relatively slow development and adoption of interchangeable file formats such as IFC (Industry Foundation Class), knowledge exchange between engineers and architects is still slow and manual, often limiting the number of design options that can be explored at the conceptual stage. To overcome this problem, custom tools and methods are being developed in the structural engineering field, which allow the architect and engineer to collaboratively explore a large range of design options at the early design stage.

By studying a larger range of design options more quickly and accurately, the design process can be streamlined early on. Combined with custom interoperability procedures and automated ways of creating intelligent building information models, cost estimates can be calculated precisely, at any stage of the project.

### AL MINAA STADIUM | 30,000 SEATS | BASRA, IRAQ:

Architect: 360 Architecture, Kansas City | Contractor: Al Jiburi GCC
In November 2010, 360 Architecture and Thornton Tomasetti decided to jointly submit a proposal for the Al Minaa Stadium (see figure 1), a design build project for a 30,000 seat soccer stadium in Basra, Iraq.

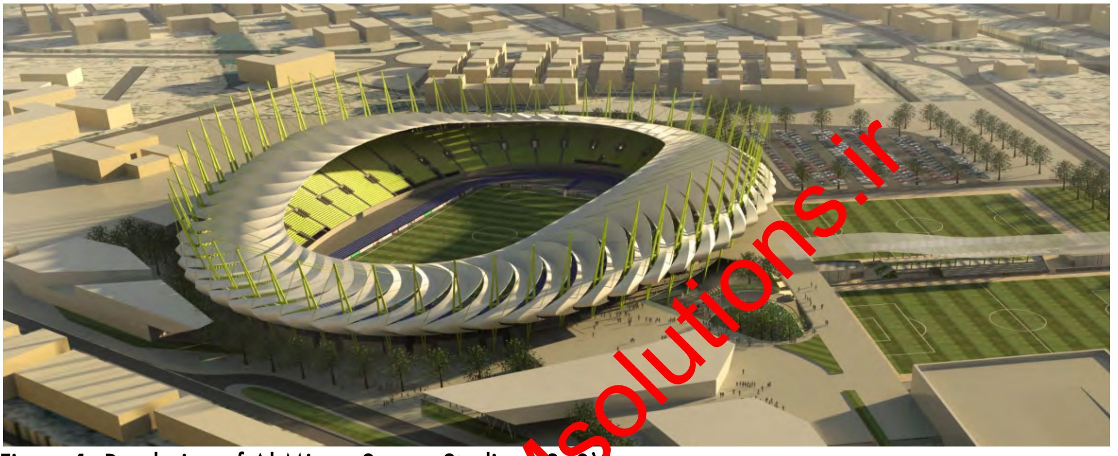

Figure 1: Rendering of Al Minaa Soccer Stadium (360).

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The design of the roof surface is inspired by a water wave pattern. The surfaces are of complex doubly-curved nature. The roof structure is a very unique 3-dimensional combination of cable stayed curved steel pipe trusses and fabric cladding that is formed in a sweeping configuration above the seating area.

For the competition entry, it was important to create a three-dimensional parametric model of the roof, so that its behavior could be tested, understood and optimized. Given a very tight schedule of only five days, 360 and TT decided to jointly create a 3D BIM model of the roof structure, including fabric surfaces, trusses and columns. An engineer and architect sat together on the same computer for three days to create a sophisticated parametric model, which would be informed by architectural and structural parameters simultaneously. Due to the complexity of the roof trusses and the very limited time frame, the visual programming language Grasshopper (McNeel) was chosen as the appropriate modeling tool. Grasshopper is a plugin for the CAD application Rhinoceros3D (McNeel). It was used to build generative algorithms that describe the geometry of the façade surfaces and roof truss structures.

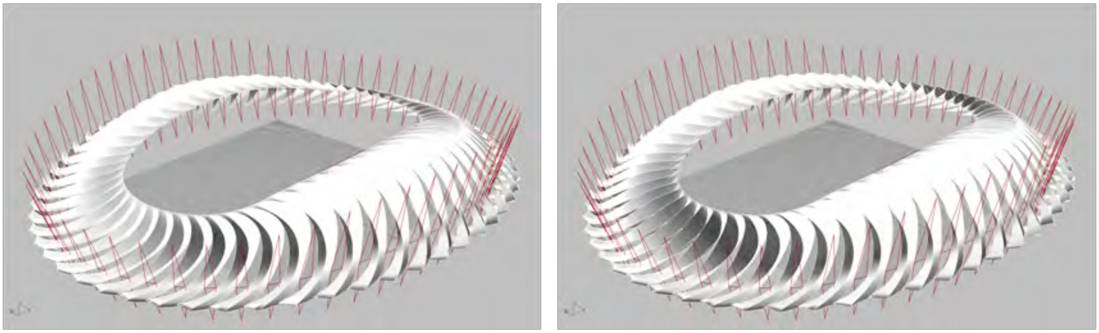

Figure 2: Different Design Options In Generative Roof Model.

The 3D model was derived from both structural and architectural parameters. Architecturally, it was important to define the shape of the fabric roof surfaces (see figure 2), while the engineering model aimed to deliver a clean and versatile wireframe model of the underlying roof trusses, which could be used for finite element analysis (figure 3). The software used for structural analysis of the truss steel members is SAP2000 (CSI). The intent of the engineers was to test and evaluate a number of possible truss configurations within a few hours, which would allow them to find the most efficient roof structure.

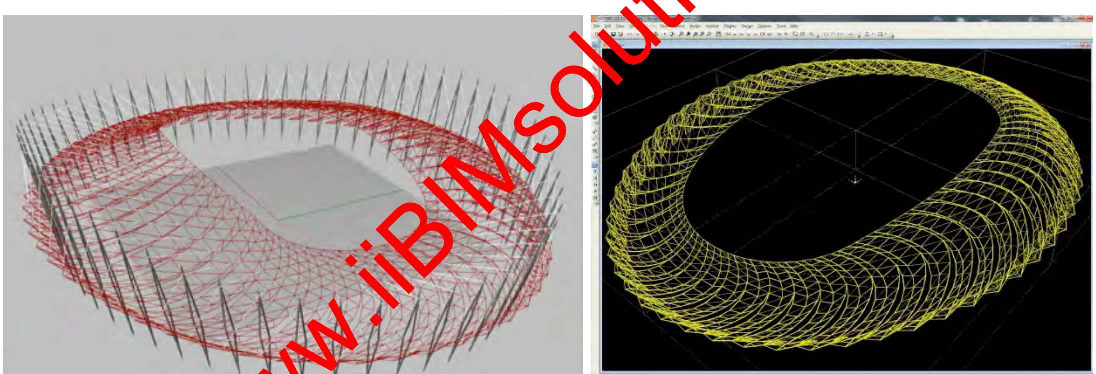

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Figure 3: Parametric Truss In Grasshopper Model - Automatically Linked Into SAP2000 Analysis Model

Grasshopper is an open-source environment that allows contributors outside of McNeel to develop plug-ins for the software. One of the contributors is GeometryGym, a company that develops a suite of Grasshopper plug-ins for structural engineers. Thornton Tomasetti acquired their plug-in "Smart Structural Interpreter" (SSI-tools), which would allow them to define all of the member properties directly within Grasshopper, and then send geometry information of the roof structure to SAP2000. Within an hour of creating the analysis model in Grasshopper, TT engineers had analyzed the behavior of the roof under live-, dead- and wind loads. The programmatic nature of the modeling software allowed the engineers to modify the truss configuration inside of Grasshopper, and re-connect it to SAP for continued analysis in an iterative process, conducted on day four of the collaborative design process. Intuition and experience of the engineers allowed them to quickly find a working solution without having to change their traditional analysis process.
By the end of the day, TT engineers had successfully designed an efficient roof structure of the stadium. Next, a documentation model had to be created, which could be used to create a set of

drawings to communicate the design intend to the client. Revit Structures 2011 (AutoDesk) was used for the creation of the building information model and drawing documentation. A custom geometry translator, developed at Thornton Tomasetti, was used to convert the SAP2000 model into Revit geometry by accessing the API's of both programs. The translator reads necessarily information such as start and end point coordinates and section property, for every element in SAP2000; and creates a Revit model with elements of the same type at the same locations. After geometry translation, TT BIM modelers could create a documentation set from the model and submit a thorough proposal after five days of work.

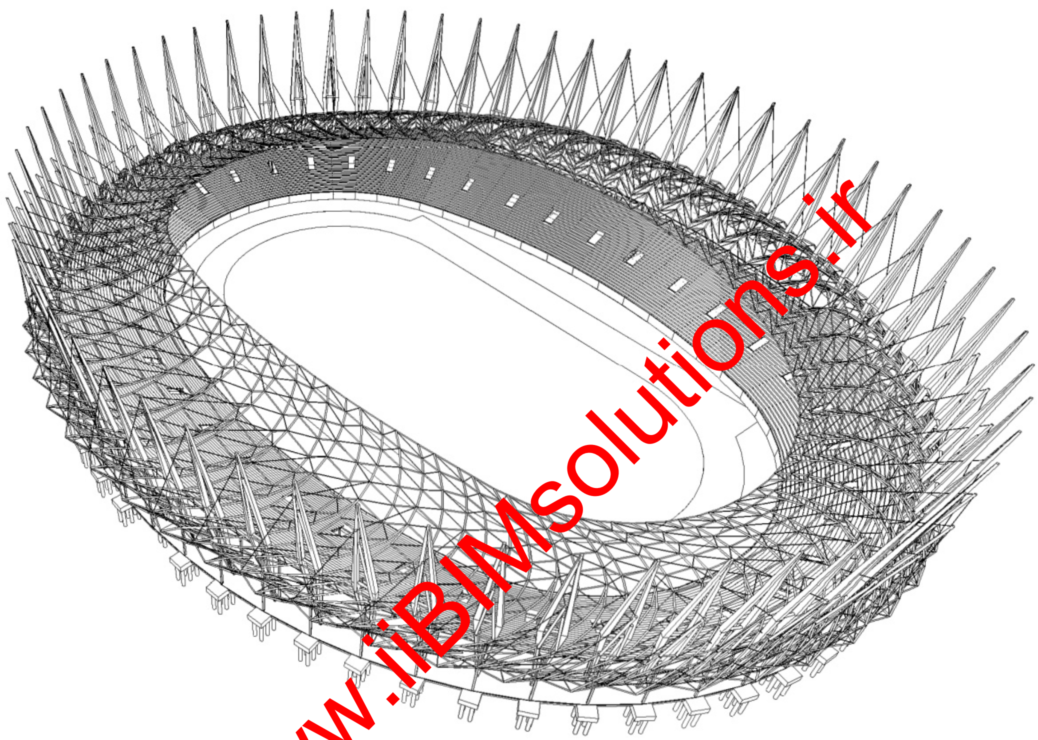

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Figure 4: Automatically Created Revit Model for 2d Documentation

The willingness to try a new increased collaboration effort, and the high level of computational modeling, and the information that could be extracted from the model helped winning the stadium competition in the winter of 2010/2011. This success story led to both 360 and Thornton Tomasetti increasing their staff that is educated in design and analysis with Grasshopper, so that the group collaboration effort can be continued, as the project progressed.

Over the course of the next twelve months, 360 and TT could collaboratively take a revised version of the original competition phase Grasshopper model through the entire Schematic Design and Construction Documentation phases. With a good working model, a trained team and a thorough workflow in place that relied on custom geometry translators, the various analysis models utilized for fabric analysis, structural analysis and 3D documentation could be automatically generated to large parts, saving man-hours which would usually be spent on remodeling the geometry. This allowed the engineers and BIM modelers to spend more time on creating thorough project documentation, and less time on the BIM management aspect, and new levels of drawing documentation quality were achieved (figure 16).

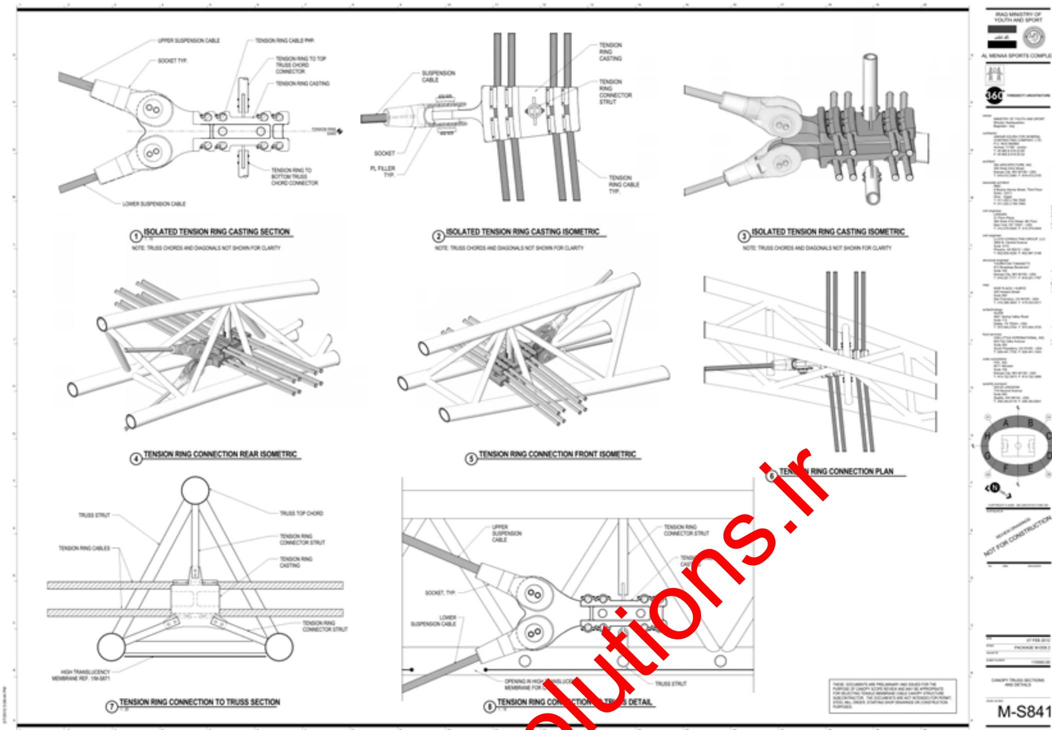


Figure 5: 3D details provided as part of 100% structural CD set by Thornton Tomasetti

It may appear risky to rely on a new working process during a short time frame of five days. But the fact that the architecture/ engineering team from 360 and TT have a longstanding working relationship had formed the trust required to explore this enhanced working methodology. Without the use of custom developed tools and the generative modeling engine Grasshopper, it would have not been possible to create a validated roof structure and a BIM documentation model in only five days.

From this example, it is apparent that successful implementation of integrated automation and optimization techniques in multidisciplinary design environments can only be achieved when a number of key requirements are met. These requirements include willingness to openly collaborate and share information early and frequently during the design process between all key contributors, as well as the ability to use computational technologies beyond the traditional scope found in our in the building industry.

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# PRACTICAL BIM SUPPORT:
## Creative Training Solutions for BIM Managers

*Brian D. Andresen; Director, CAD/BIM Systems, WLC Architects Inc.*

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### ABSTRACT

Education and Training is a topic I've heard a LOT of instructors talk about. I've sat through entire seminars dedicated to explaining the need and importance of the topic. They share how companies fail without it, and with it, how users, managers, and owners all benefit and grow from the experience. Well I'm going to take this opportunity to skip all that fluff, and go further, beyond that to the next level ...you know...to the real world. Where users are WAY too busy, owners are trying to save every penny, and change requires dragging full grown adults kicking and screaming into the next generation. I've discovered many ways of getting this accomplished without breaking the bank, becoming the most hated person in the office, or losing your mind in the process.

### CHANGE DRIVES PROGRESS

Anyone over the last 20 years that has used a computer, or bought electronics know that with technology, things change FAST! Improvements, updates, and upgrades become available every three months or less, and the ONLY way to keep up is to stay educated and informed. This is why I consider "training" for myself and my company to be the highest priority...but how? Well, the typical training scenario is a dark, isolated room, phones off, instructor going on for 8 hours, usually multiple days, and by the end your brain is mush, you've retained half of it, and you'll be all over Google, AUGI, and any other forums just trying to get your project done. So when I was asked to provide "training" for WLC Architects, I immediately jumped into "How can I do this differently? How can I be out of the box, using fresh concepts to keep the users interested, and not blow the budget?" Here's what I came up with-

### BE BEYOND FLEXIBLE

Start with simply providing flexible training options. I took the usual three to five day courses, dropped the filler, and ended with five half day sessions. No one enjoys spending all day getting drilled with new content, while wondering what emails, phone calls, or meetings they are missing. This also allows two outcomes: Busy users spend half the day training, while getting their work done the other half, or if they can afford the time, spend it reviewing and getting accustomed to the software. After a few sessions of that, I broke it down further to one hour sessions for lunch meetings. This worked out great for the users that either couldn't spare half days, maybe missed specific sections, or wanted to cover certain parts over again. Architects and Project Managers are usually VERY busy, especially in these tough times, and by allowing them options, they appreciate it. They see that you're trying to work with them, and will usually respond by helping to make it work out for whatever's best for everyone.

## FOCUSED & FUNCTIONAL

My "Team Focus Group" concept started a few years ago when I began to notice three distinct problems beginning to form. First was a pattern that I would help a user with their project, then move on, only to later find out the user (for some reason) let the project get behind schedule. (Guess who they blamed?) The second was worse, I would commit to a new project, and then find out two other new projects were starting in other office locations, creating schedule issues. Third, were times principals would ask questions about company-wide information, and I wouldn't know, due to a lack of overall company involvement. The solution for all three was my creation of a TFG system (Team Focus Group). This allows me and my staff to dedicate each week towards a specific group of users to work on projects, coordinate workflow, standards, implementation, or anything else CAD/BIM Management related. From there each week we rotate groups until the cycle starts over again. This allows (and forces) me to fully understand what is going on companywide while also making sure no project falls behind.

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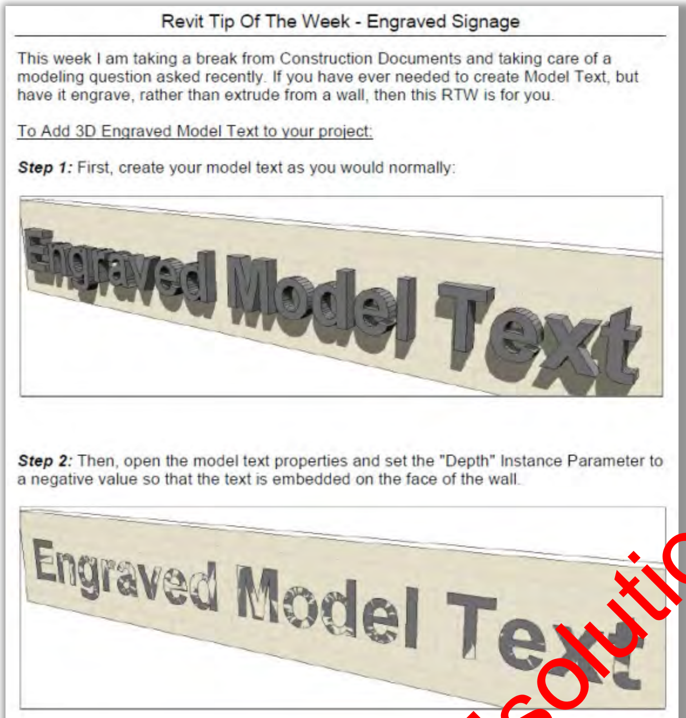
## FAQ DATABASE

Create a Resource Hub ASAP! Offering users a place to turn to, when you're not available, is vital when trying to support multiple users, with multiple offices, with a limited support team. All you do is create a centralized database, and simply start collecting anything you find online, questions you've been asked, tips and tricks you've learned over the years, etc. Users enjoy it because they are able to ask and get the answer immediately, conferences become less problematic, and you find yourself not having to answer the same question twenty times. It's a total win, win, win. For you, the end user, and the company!


Revit Tip Of The Week - Engraved Signage

This week I am taking a break from Construction Documents and taking care of a modeling question asked recently. If you have ever needed to create Model Text, but have it engrave, rather than extrude from a wall, then this RTW is for you.

To Add 3D Engraved Model Text to your project:

***Step 1:*** First, create your model text as you would normally:



***Step 2:*** Then, open the model text properties and set the "Depth" Instance Parameter to a negative value so that the text is embedded on the face of the wall.



## WEEKLY UPDATES

Once you're providing multiple training opportunities, support options, and lunch seminars, it becomes clear to everyone involved that users are getting large chunks of great information. But what about the ones that already know it? This is where CTW's (CAD Tip of the Week) come in. These are simple, straight forward emails/posts sent to the entire firm giving tips and tricks, workarounds, shortcuts, and anything that helps efficiency, progress, and solidifying users understanding with the software or hardware. Also, note these do NOT need to be life changing information, a simple new keyboard shortcut will suffice, just get it out there!

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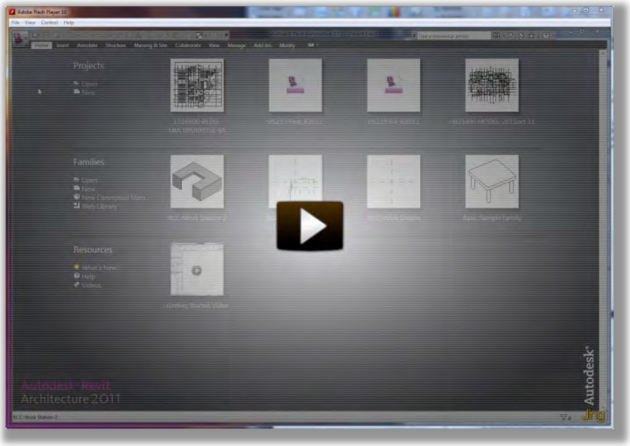
## VIDEO REFERENCES

Two years ago I thought video recordings would be expensive, time consuming, and more work than it would be worth to offer this more advanced form of CAD/BIM support. Well I have to tell you I was surprised to learn it's not at all! I started using Jing, a TechSmith product that is free and easy to use to create quick, five minute or less videos. I did a test run between a PDF CTW and Recorded CTW and found it took twenty minutes for the PDF (create screen captures, type out the text, mark them up, and create the final product), while only thirty seconds was spent, recording the same process live. Users found these much more enjoyable, informative, and explanatory versus the standard PDF version.




## JOIN A LUG

Last but certainly not least, are local user groups. These things are the core of what allow users to come together and learn the latest and greatest their software has to offer. I have three in my area alone and while I am the President of one, I enjoy all three. Everyone always asks me; why share your secrets? The answer is simple; If you have 30 members, and everyone shares one tip or trick they learned over the past month, then yes, technically you just gave away one secret, but in that same meeting you will have gained 29 new tips or tricks! User groups are GREAT for networking and learning more about software. Join one today, or start one yourself, you will be amazed at what gets accomplished at those meetings.

## CONCLUSION

So there they are! With these ways to train your users, you can get more information taught, with less “force” needed. The owners are happy you didn’t cause projects to slow or users to complain, and production can continue to excel and improve. I have always enjoyed out of the box thinking and hopefully you do to. These options offer not only the ability to work with the users schedule’s, needs, and wants, but they see your efforts, and your attempts to make them better at what they do. I encourage anyone who is interested in these concepts that would like to know more, to please contact me and I would be more than happy to take the time to go into more detail and offer examples of each one. Thank you for your time and I appreciate the opportunity to share my ideas with you, as I in turn continue to learn more and more from all of you!

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# BIM STANDARD INDEXING:
## Stakeholder Provisioned Internet Accessible Information

*David E. Ways, AIA, NCARB, LEED AP; BIMPAGE, LLC*

**ABSTRACT**

This paper introduces the concept of developing a standardized system for indexing the tremendous amount of information about Real Property that exists and is increasingly being generated, to facilitate efficiency and stakeholder collaboration while advancing the process of Building Information Modeling and Geospatial Information Systems integration. A new generic Top Level Domain (gTLD) on the Internet dedicated to storing and sharing Real Property information that utilizes a standardized indexing system could greatly increase the productivity of the construction industry.

### INTRODUCTION

Stakeholder Provisioned Internet Accessible Information (SPIAI) is a proposed minimum standard for storing and sharing real property information "bim", to make it globally accessible via the Internet, as the stakeholder determines, subject to Digital Rights Management (DRM). This information could be in any format and is not required to be interchangeable from one software package or operating system to another, only that it is locatable via the Internet and accessible as predetermined by the stakeholder who provisions it.

The intent of this proposed minimum standard is to improve efficiencies in every industry reliant upon bim, for the purchase, development, design, permitting, construction, management, sale, etc., of real property, by streamlining the process to locate and disseminate any information pertaining to it.

#### Background

A key purpose of this standard is to establish an indexing system that references the geospatial location of every property, and links to the information pertaining to it. Whether the information is about the property boundary, utilities, or improvements, it is essential that it is geospatially located to be consistently referenced.

A property identification system currently in use and maintained by County governments throughout

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the United States, references tax records. The unique Parcel Identification (Parcel_ Id) assigned to every property in various counties could be used as an index to store and share stakeholder provisioned information via the Internet.  Building department records already reference these Parcel IDs, as do County Geospatial Information Systems (GIS).

In 2012, new generic Top Level Domains (gTLDs) will be awarded by the Internet Corporation for Assigned Names and Numbers (ICANN) for various industries and their respective information communities (for example, music, movies, sports, and hotels).  Just as the current gTLDs (.com, .net, .org, etc.) frame the internet today; these new domains will revolutionize the way users of the internet interface with content to unite community members using technology platforms that allow them to interact more efficiently with greater capabilities.

The architecture, engineering and construction (AEC) community could utilize a new gTLD to provide a more secure means for sharing BIM information between partners and stakeholders. Electronic commerce is facilitated using prioritized listings delivered with web searches via a new gTLD (for example, AEC community gTLD websites could display before any .com for AEC searches).

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## RELEVANCE TO USERS

Stakeholders need information that originates from a variety disciplines whose contact information may not be known to them.  The time spent determining what information is available, where it is located, and how to retrieve it, is a major contributor to waste and redundancy in the Industry.
An Indexing system that uses the Parcel_Ids, could direct internet searches to unique websites for every property, where stakeholders could provide their contact details and links to their related, provisioned information.  Additional resources contained on these property websites would be links to the county records and other public information, as well as log-in access by the registered AECgTLD community to access proprietary information. This resource would save stakeholders time and money.

## RELEVANCE TO NATIONAL BIM STANDARD

The purpose of Stakeholder Provisioned Internet Accessible Information is to establish guidelines for a minimum level of storing and sharing bim, and a system for locating and accessing it via the internet.

Five concepts proposed with this standard would streamline the process for stakeholders to locate bim, thus increasing efficiencies in the industry.

1. Architecture, Engineering, Construction Industry new generic Top Level Domain (AEC gTLD).
2. Registering a unique Website for every property and indexing the information pertaining to it.
3. Registering a Community of stakeholders having privileges to access proprietary information.
4. Collaborating on projects centralized around the property websites at the AECgTLD.
5. Defining “bim” for real property.

## DEFINITION

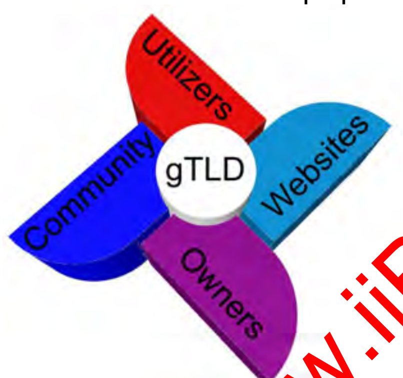
**Bim** is information about Real Property and its attributes, and the open process of originating, storing, updating and sharing this information.

Synonymous with the acronym (BIM) for Building Information Model, Building Information Modeling, and Building Information Management, which could be interpreted as being limited only to building; the word "bim" also includes information pertaining to all real property (land, structures, power poles, equipment, etc.).
This definition of bim is intended to remove the controversy regarding the words for the initials "BIM", as the term associated with the transformation of the Capital Facilities Industry which includes every stakeholder (Owner, Mortgage Lender, Title Agent, Developer, Planner, Surveyor, Architect, Engineer, Contractor, Builder, Manufacturer, Supplier, Facility Manager, Realtor, etc.) who have an interest in originating and sharing information about all types of real property.

## CONCEPTS

Four components that frame these concepts correspond to an adaptation of the "Tetralogy of Bim" being promoted by the building Smart Alliance (bSA).

1. Websites – *Assemble* information and Stakeholders at the new AEC gTLD.
2. Community – Registered Stakeholders with access privileges to collaborate on *Design*, etc.
3. Owners – *Operate* the access to their proprietary information.
4. Utilizers – *Procure* properties, goods, services and information.




*Adaptation of the BuildingSmart Alliance's Tetrology of BIM.*

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Websites

There are three classifications for the websites envisioned with this standard:

1. Property Websites (at the AEC gTLD)
2. Community Member Websites (at the AEC gTLD)
3. Utilizers Websites (at any gTLD)

*Property Websites (at the AEC gTLD):*

Every property on Earth has a geospatial relationship. Unique property websites supported by a unique identifier, can act as an *Assembly* where property information, across the lifecycle, may be accessible. In the United States of America, every County government maintains tax records utilizing unique Parcel Identifiers (Parcel_Id). The Parcel_Id, when prefaced by the state name and county name can uniquely identify that property, and can be used as a Uniform Resource Locator (URL) at the AEC gTLD, to direct Internet searches to a website that assemble information about it.
For example: www. State_County_(Parcel_Id).AECgTLD

These unique property websites would be registered, at the property owner's request, by a Registered AECgTLD Community Stakeholder (i.e. Realtor, Contractor, Architect, Insurance Company, etc.) having some involvement with the property; whether for the sale, development, construction, management, etc. Standardized templates are used to organize the information contained on the property websites for consistent storing and sharing via the internet. A history of these websites would be maintained at the 'Wayback machine" for achieving.

Collaboration among all disciplines during planning, design, analysis, bid proposals, permitting, construction, as-built records, maintenance, operation, and sale would be coordinated via property websites and their attendant service offerings to access Intellectual Property (IP), exchange vital documents, and receive notices of business opportunities, etc.

There are several functions of the property websites at the AECgTLD:

1. Display of Public Information
    a. Parcel_Id
    b. Property Address
    c. Owner name
    d. Location Map
    e. Every Stakeholders' contact details
    f. Utilizers' forum (public dialogs)
2. Links to Public Information
    a. County Records
    b. Building Department
    c. County GIS
    d. Stakeholders' Websites (public information)
    e. Utilizers' Websites (public information)
3. Login for Registered AECgTLD Community Members
    a. Proprietary Information Display
        i. Legal documents
        ii. Insurance papers
        iii. Appraisal
        iv. Real Estate listings
        v. Survey information
        vi. Utilities
        vii. Construction drawings
        viii. Permits
        ix. Systems monitoring
        x. Etc.
    b. Proprietary Information Upload
    c. Proprietary Information Download
    d. Stakeholders' forum (private dialogs)
    e. Work requests notifications to AECgTLD Community Members

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*Community Members Websites (at the AEC gTLD):*
Registered AECgTLD Community Members having any information pertaining to a property should, at a minimum, list their contact details on every property website that they have involvement. Additionally, stakeholders should add links on those property websites that direct Utilizers to publically accessible information and Community Members to the proprietary information on their Website. These links should be directed to URLs that follow the same indexing system.

For example: www. Stakeholder.AECgTLD/State/County/Parcel_Id/{bim}
The extent and manner to which stakeholders make the bim accessible to others via the internet is at their discretion. For example:

- Publically accessible Web pages
- Authorized FTP sites
- Virtual Private Networks (VPN)
- Etc.

Utilizers Websites (at any gTLD):
The general public and any business offering goods, services or information, may have websites that could be linked from the property websites. Utilizers having information pertaining to a specific property should store it in a manner that uses the indexing system, to be located by others via the internet.
For example: www. Utilizer.gTLD/State/County/Parcel_Id/{bim}.

Community
Any stakeholder may apply for an AECgTLD community domain, thereby creating a secure and authenticable place in the community, for advertising or simply storing records about their products and services. Registration provides a means for AECgTLD community members to enter standard codes identifying their type of business, granting them access privileges to proprietary information contained on other AECgTLD websites, and enabling them to receive notifications of projects posted on property websites.

Further registration criteria could require the AECgTLD community members to utilize, as much as possible, open standards and interoperability methods recommended by the bSA, in the National BIM Standard (NBIMS), to promote best practices, utilizing data exchange protocols and Integrated Project Delivery (IPD) processes.

Owners
Individuals and businesses who own proprietary information contained on AECgTLD websites.

Utilizers
Individuals and businesses who have access to public information contained on AECgTLD websites.

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## CONCLUSION

As the generation of information proliferates, a BIM standard defining how it is indexed for storing and sharing among stakeholders will greatly increase the efficiencies of those industries reliant upon that information.

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# THE EVOLUTION OF LEARNING: How Technology can Advance Corporate BIM Training Initiatives

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## ABSTRACT

There is no doubt that rapidly changing technology is shifting the methods for which people learn. With the information age comes new ways of pushing information to users, and new ways of pulling information when it's needed. By understanding the benefits these new training methods bring, we can restructure corporate BIM training and create an instructional approach which can also advance other types of training within an organization.

## INTRODUCTION

Innovation is causing a paradigm shift in the education system. Training methodologies which haven't changed in nearly 100 years are now being completely rethought due to advances in technology. Digital textbooks now incorporate multimedia, changing the way students learn and teachers teach. Instructor-led classroom training is being replaced by online eLearning and video training, giving students the ability to learn anywhere and anytime. Adaptive learning seeks to bring back the idea of personalized training customized to each individual student, but does so on a very large scale. Future corporate training methods should reflect these new ways of learning.

## FORMAL EDUCATION IN HISTORY

<u>From the one-room schoolhouse to industrialized education</u>

Learning, in its simplest terms, can be defined as gaining knowledge, or acquiring information. Learning didn't always equate to schooling - i.e. the formal education system we know today, and it may not always equate to formal education in the future.

Prior to the industrial revolution, learning was done more informally, through home schooling and apprenticeship. Early schools only had one room, and all children of all ages were taught together. Since books were scarce, the students weren't grouped by age; they were grouped by what book they were using.

In the late 19th century, educational changes were driven by a fundamental shift from family-centric production (farming) to manufacturing and industry. Rapid urbanization meant that the home, the workplace, and the church lost many of their earlier functions in the educational system. The school became a central institution in education, to the extent that we now often think that education equals schooling.

The "industrialized" education system is what prevails today. Students are taught at the pace of the teacher's instruction tempo rather than a pace more suitable to each individual learner's needs. They move sequentially through their classes, and no matter what is happening in a classroom, the class ends once the bell rings.

## EDUCATION IN THE INFORMATION AGE

Learning driven by technology

Now that the information age is upon us, formal learning environments are beginning to change again. In our schools, traditional classroom methods are shifting to instead use technology as the vehicle for driving instruction and training. Textbooks are going digital, which changes the "book" experience to include interactive animations, virtual interactive diagrams, and videos. Because the user interactivity in digital textbooks is immediate, multimedia can become an integral part of the "book" training lesson.

But even outside of the classroom, technology is driving knowledge itself. The internet makes information (i.e. knowledge) readily available to any person who knows how to run a Google search. Information is provided, or "pulled" when it is needed - also referred to as just-in-time (JIT) learning. These "students" are becoming self-taught learners. This is especially true among younger generations.

ELearning – the Virtual Classroom

The instructor-led classroom is also being replaced by eLearning, also known as online training. ELearning comes in two flavors: synchronous and asynchronous.

Synchronous eLearning is facilitated through "live" videoconference training, supported with live audio and/or live chat. Synchronous training is more social, allowing instant feedback and a deeper level of interaction between host and attendees - similar to instructor-led classroom training, but with the added benefit that students can be in multiple locations.

Asynchronous eLearning is usually facilitated by media, such as prerecorded videos with instructor-supported email and group discussion boards. The greatest benefit of asynchronous eLearning is that the whole of the training can be completed anytime and anywhere, making it easier for students to work around other commitments. Recorded video training can also be distributed to large numbers of people and reused over and over, reducing the cost of instructional development and delivery.

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## APPLICATION OF LEARNING METHODS

A good way to understand how to best implement eLearning or other options might be to take it away from the context of BIM training for a moment. What if we were trying to teach several thousand of our business colleagues all over the world how to correctly play the game of golf, including tee shots, chips, rules, putting, etc? What options do we have and how effective are those options?

<u>Traditional Immersion Training</u>

The immersion training one-day or two-day "workshop" is the most common method of corporate training, even though it is one of the most expensive and can be difficult to schedule. Immersion training has the advantage of incorporating the training, the application of the training, and the feedback all in one location. But on-site workshops also have a major disadvantage: applied to our golf instruction scenario, trainers would have to be found in, or sent to many different countries to give the training. Another disadvantage is retention: after the first day of training, users would have little time to practice, review, and apply what they have learned. By the second day there is usually significant overload.

### Training Manual Distribution

Emailing a "how to play golf manual" would certainly have the advantage of being far more cost effective, but the reality is that step-by-step written instructions would be hard to follow for most. While training manuals may be a good reference source, as the first point of learning it would be too hard to follow.

### "EBook" and Digital Training Manual

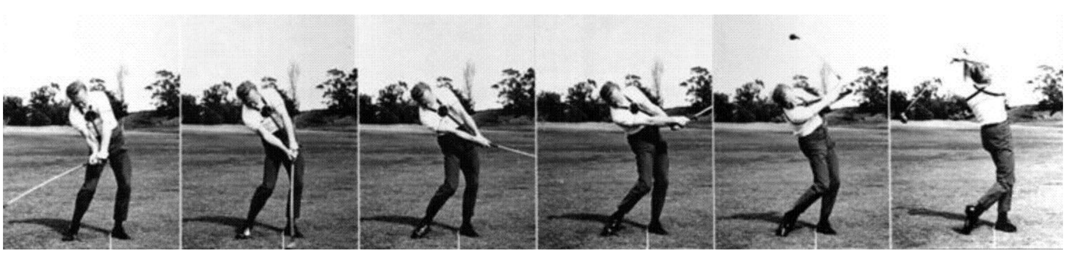
Combining a training manual along with interactive "snippet videos" covering single specific topics comes closer to the idea of information being "pulled", or used exactly when it is needed. As a reference this is a very good source – users could watch simple videos when they need answers to questions. While not "instant feedback" it is a 24/7/365 source for information closely related to the topic they need.

### Global Webinar

Another option might be to add a global webinar with a PowerPoint slide show of a proper golf swing, putting, etc.

Figure 1: The Proper Golf Swing in Pictures

A webinar also has the benefit of being cost effective and at the same time gives end-of-session feedback initially for questions, but once users begin working on their own they have little source for feedback. A webinar is also very one-dimensional, similar to watching a video.



### Synchronous eLearning Sessions

The synchronous eLearning option could be global golf online training sessions. Students could

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watch the trainer, and could ask questions and get instant feedback. There would need to be many sessions at various times to accommodate different time zones. There would also need to be time given between sessions to allow users to apply what they have learned, then return to get more feedback.

### Asynchronous eLearning "Sessions"

The asynchronous eLearning method would be to create and post detailed "how to golf" videos on YouTube, then respond to questions via email. Like a Webinar, asynchronous eLearning is passive. Users could watch the videos over and over for reinforcement, but feedback on questions or issues would not be instant, and therefore not as effective as active learning methods.

### Blending it all together

All of the various methods for learning have advantages and disadvantages when applied to BIM training. Used on their own, these methods would most likely be inadequate to teach Revit or another BIM application to most users. But what if the best parts from these methods could be combined to create a new type of training?

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In the summer of 2011, educator Salman Khan of the Khan Academy, a non-profit educational organization, took on the task of rethinking how eLearning training could be combined, or "blended" into traditional schoolwork within the Los Altos, CA school system. He switched the lecture-style classroom training time to be all video-based - happening outside of school. He also switched the time students worked on exercises to happen inside of school, during class time. This "flipping" of the traditional education model freed up time for teachers and students to work on exercises together. So in a sense, the students were doing their homework in class and their classwork at home. The results of this blended eLearning approach were positive overall – outshining even one-on-one tutoring for students.

Applying this education model of flipping user training to a corporate environment, we can restructure BIM training as a whole, and apply the optimum parts of the individual learning methods at the same time. Breaking the learning into its main parts: the **training**, the **application of training**, the **feedback**, and the **reference**, we can begin to see which methods might fit best.
Our new training model would look like this:

**Part 1 - A 15-25 minute video training lecture covering the technical aspects of a specific BIM topic.**
The video would be watched on the user's own time prior to attending the second part.

**Part 2 - A project-based "web workshop" online training class.**
The class would apply the technical methods from part 1 to an actual company project, putting them in a "real life" job-related context.

**Part 3 - Follow up reference materials, such as a BIM digital training manual or video links.**
Ideally this would include a training manual with embedded "snippet" videos (2-5 minutes in length), or at the very least a breakdown of the technical BIM training (part 1) into easily searchable, short video topic points. Users could reference a particular topic as needed, pulling information specific to their issue.

This training model provides the cost-effectiveness of eLearning while still providing trainer interaction, instant feedback, application to real projects, and reference materials. Following this model a trainer could provide BIM training globally without leaving the office. Training videos can also be used over and over, furthering the cost benefit.

For the students receiving the training, there are several advantages to this approach vs. the typical webinar or even onsite workshop:

- When watching a video, students can go at their own pace, and can pause or replay a video until they understand a concept.
- There can be a time gap between part one and part two of the training. This allows the students to watch the video, practice, and then meet online with a trainer to get immediate feedback.
- Focused attention by a trainer following a video training class should serve to reinforce the topic more than video or online training alone.
- Users receive training on both the technical mechanics of how to use the software, and the practical methods of applying what they learned.

Further improvements to this model could require specialty training software, but could also have a significant impact. The biggest enhancement missing from the prerecorded training would be the ability to quiz users to track progress. Quizzes not only validate that the training has been adequately completed; they also identify users who excel at a particular topic of training who could potentially tutor other users.

## FUTURE EDUCATION PRACTICES

### Adaptive Methodologies – from industrialized education back to personalized education

Looking forward, the next evolution of education as a result of technology may be what's called adaptive learning. Adaptive learning is an asynchronous teaching method which uses technology to deliver material in a way which responds to each individual's performance and activity within the system. Adaptive learning software watches a student's every move - quiz scores, speed, delays, keystrokes, etc. - and uses that data to customize the training's structure, format, and difficulty level. Recommendations are made, or "pushed" the instant a student uses the command or feature within the software.  Students go at their own pace, with the software analyzing and "tutoring" them along the way. The ultimate goal of the software is to figure out the method of teaching which works best for each individual.

The adaptive method of getting information to users has been around for a while – in the form of predictive analytics used for target marketing. Advertisers "push" recommendations for products all the time. A basic example of this is the "Customers Who Bought This Item Also Bought" section on Amazon.com.

What actions can we take to apply predictive analytics and target marketing to the next generation of corporate BIM training? While we may not have the ability to analyze employees' buying habits or internet social network updates, we can look at more straightforward ways to collect user data.

## APPLICATION OF ADAPTIVE METHODOLOGIES

Information gathering is the essential element of adaptive methodologies, but in a corporate world it may be difficult to acquire relevant information. Using an example of, say Revit technical training, there are several methods we can use to ascertain a user's competency level.

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**We can gather it** - The simplest way to achieve this may be an online survey. Questions could delve into learning styles preferred by users, or a user's overall technical aptitude related to the software. Other options might include the creation of a focus group to discuss options for learning, or a social network function within a company intranet. Once training is underway, simple quizzes can ascertain how the user is doing moving along the path of training.

**We can assume it** - Assuming there are going to be diverse levels of technical aptitude, we could provide multiple versions of the *same training class* – for example a slower "easy version" and a more tech-savvy "hard version" of Revit training.

**We can observe it** - Observable diversities, such as age demographics, could also be considered. Distinct generations of varying age ranges may work side-by-side, but learn at different rates and use technology in different ways. *Baby Boomers* (born between 1946 and 1964) enjoy interactive, structured training. *Generation Xers* (born between 1965 and 1980) put a greater emphasis on technology, personal freedom, and a self-directed schedule as part of a healthy work-life balance. *Generation Yers or Millennials* (born between 1981 and 1994) are effective multi-taskers who have known nothing but technology, but thrive best in a well-structured environment which keeps them busy. Applying different teaching styles to different generations could be more effective versus one training style for all.

**We can push it** - Adaptive technology training can even be carried into the level of day-to-day usage of the Revit software. If we could tie-in recommendations to watch training videos and embed them inside of the software itself, we could teach users as they interact with the software directly. Training would be pushed to you in much the same way Amazon.com recommends you to purchase a product...

## CONCLUSION

A lot can be learned from the technological advances happening in today's educational system. With technology come many benefits and many new ways in which to gain knowledge. By adopting these technological advances, we can restructure our corporate BIM training programs to provide better education for the end user, while at the same time saving money and limiting impact on work-schedule.

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# CUSTOMIZING BIM:
# Enhancing Efficiency and Capability with Application Programming

***Mario Guttman – Perkins+Will***

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## ABSTRACT

The use of an *Application Programming Interface* (API) with the widely used *Building Information Modeling* (BIM) authoring tool *Autodesk® Revit® Architecture®* to enhance common design processes is explored. Examples, based on a set of Revit add-in tools developed by the author, illustrate the potential for this kind of software development.

## INTRODUCTION

Although commercial applications for authoring *Building Information Modeling* (BIM) have grown increasingly powerful, they often lack critical features that are required for specific architectural design workflows. Custom tools, developed using an *Application Programming Interface* (API) that is provided with the BIM authoring tool, can help to mitigate this problem. *Figure 1* illustrates the Revit API being utilized within the *Microsoft® Visual Studio® Integrated Development Environment* (IDE).

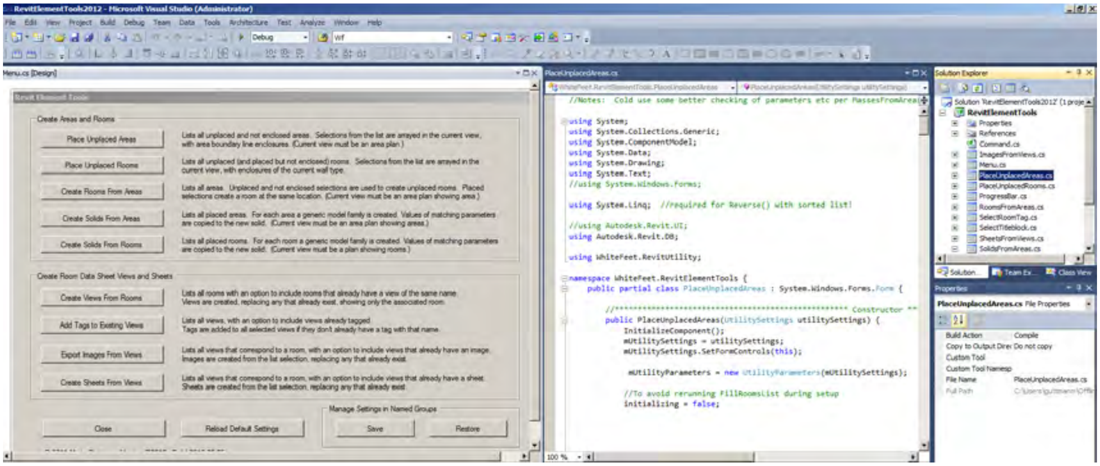

Figure 1:  Revit API using .NET in the Visual Studio Integrated Development Environment

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At the same time, the technology leadership of an architectural firm is typically concerned about the long-term risks of undertaking custom software development.  In addition, the API associated with Revit, has been difficult to work with.  Despite these objections, the author has continued to create tools, both as an employee of various small and large firms, and as an independent developer.  The long-term concerns about customization can largely be ignored as long as the focus is on achieving immediate results from a relatively modest investment.  *Figure 2* illustrates the results of the customized menus as they appear inside Revit.

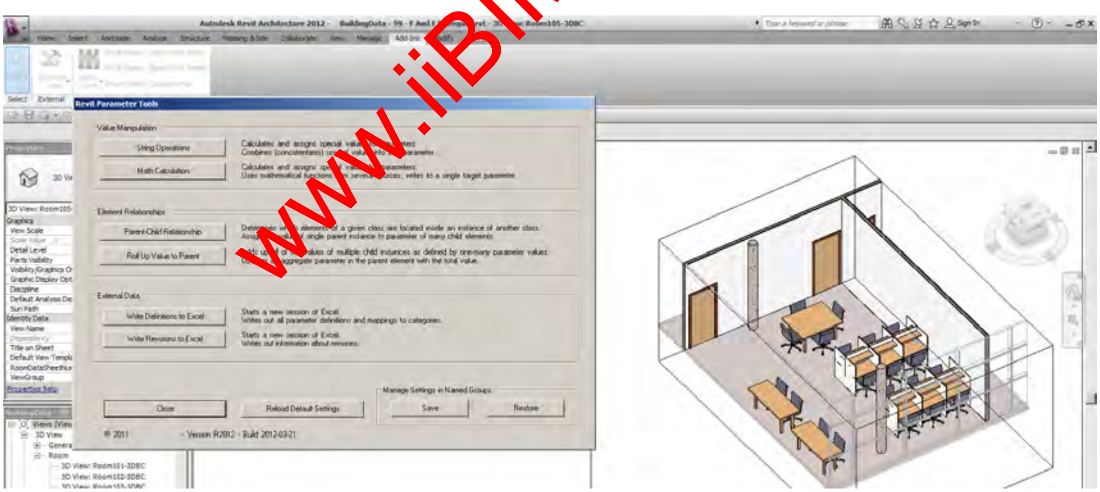

Figure 2:  A Custom Menu Accessed From the Revit Add-ins Ribbon Menu.

The use of an API does not require an overall change in the goals and strategies for using BIM.  The basic principles of API use with BIM are illustrated in this paper as a set of discrete solutions that can be used to address specific needs and opportunities.  Which solutions are used, and how they are prioritized, is typically based on how easily they can be applied and how well they can be expected to improve the effectiveness of project teams. In addition, automation is sometimes used to support advanced form-building, either as necessary to support ongoing work, or in support of a marketing position for the firm.

## ROUTINE TASKS

The automation of low value tasks provides the most direct benefit to project work, and is the most easily justified in terms of its return on investment.

### Managing Sheets

It is not unusual for a project document set to have hundreds, or even thousands of sheets. Moreover, these sheets have important attribute data that needs to be actively maintained over the life of the project. Even with the latest version of Revit, this process is very time consuming and prone to error.

The solution used was to create a bi-directional link to the *Excel*® spreadsheet program that is a component of *Microsoft*® Office®. At the start of a project, an Excel template, based on the office standards, is used to develop the planned sheet list for the project. When this is substantially complete, it is used to automatically build the sheets in Revit, based on a selected title block. Columns in the Excel file correspond to attributes in the title block so these are filled in automatically. *Figure 3* shows the dialog box interface of the custom functionality in Revit, an example of the associated Excel worksheet, and the resulting titleblock attributes.

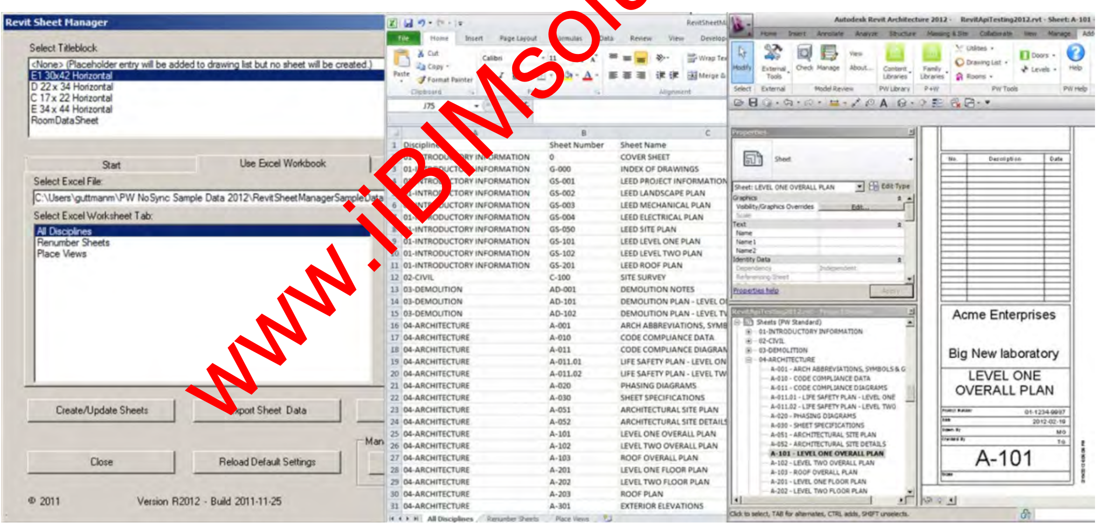


Figure 3: The SheetManager Tool Coordinates Revit Sheets with an Excel Worksheet

Revit also allows "placeholder" sheets – sheets that exist in the sheet list but do not exists as sheets in the model file. These are useful a way of incorporating consultant sheets in the master drawing index. The application includes an option to create these.

As the project progresses, sheets can be added, deleted, or have their attribute information modified, in either the Revit or Excel application, and then synchronized with data controlled by the other program. This includes the ability to renumber sheets, a surprisingly common requirement that is very difficult to accomplish without the automation.

### Bulk Processing Families



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Revit families need to be constructed carefully and maintained as a component of office and project BIM standards. In some cases this requires applying the same change to many of them and a bulk processing application is used for this. This example illustrates an advantage of developing this kind of solution in-house, since we do not know in advance what changes will be needed and it is difficult for a general purpose commercial application to anticipate every need.

In the author's experience the automation was used for four specific purposes:

**Updating Family Version:** With each new release of Revit the library of existing content must be updated to a new file format.

**Making a "Proof" Project:** A folder structure, containing many families, is scanned and a new Revit project is created for each folder. In each such project instances of each family is inserted on a separate row of a grid. Within each such row, an instance of each type of that family is placed. The grid is labeled with the family and type names, and other information. These projects are used a s a means of evaluating existing content and as a way of creating "container" projects that are used to deliver content to users.

**Fixing Preview Icons:** A known defect in the way Windows displays preview icons for files (based on functionality provided as part of the Revit installation) causes many families to appear with only a generic placeholder icon. This can be corrected by opening the families and saving them in a certain way.

**Creating Detailed Images:** Our family management tool includes an option to display an image that gives more information about the family than is possible in the small preview icons. The larger images, which can be as large as 1200 x 600 pixels, are created manually for special content but that process is too tedious to do for many families. The automatic process opens each family, and searches for a 3D view, a plan view, and an elevation or section view. These three views are combined into a single .JPG file with the same name as the family. This convention is understood by the content manager so it will then automatically display the image when one is available.

## DATABASE COORDINATION

The combination of BIM with a database enables the use of powerful database tools while maintaining a synchronized relationship with a model that provides complementary graphics.
Our solution utilizes a custom bidirectional connection between Revit and the Access® database that is part of the Microsoft Office suite. The relationship is based on a key correspondence between each single Revit instance of a given class, and a single row in a corresponding database table. In addition, other fields of the table are synchronized with corresponding parameter values in Revit.
There are many uses for this functionality. A few that have been particularly important to our early design process are:

### Architectural Programming

Data about space and equipment requirements, provided by building owners and operators, is usually structured in a way that does not correspond easily with the specific spaces developed in an architectural design. Custom database tools, including queries, reports, and VBA macros, are used to process the data into normalized database tables with one-to-many relationships, that can be used to develop the initial spaces and validate the program as the design evolves.

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## Defining Gross Building Areas

Typically, the detailed space requirements are too granular for early architectural design. The database is used to abstract groupings into fewer, larger areas, representing the major building elements. In some cases these are distributed over multiple buildings, wings, and floors as a purely data-driven exercise.

The application includes tools for importing the areas into the Revit model. The areas are created automatically, as unplaced areas, with their required area, use type and occupant group, as pre-assigned parameter values. *Figure 4* compares a scan of the older manual process with the fully digital one.

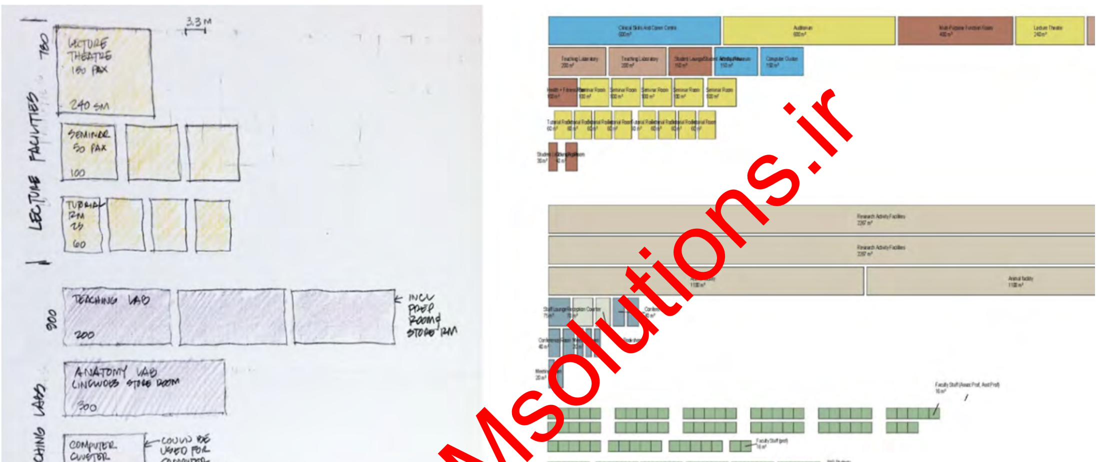


Figure 4: Replacing the Manual Definition of Space Requirements with Automatic Area Creation

The placement and manipulation of the areas is discussed in a following section of this document. The placed areas are continuously synchronized with the database tables in order to validate the overall areas and to record architectural programming decisions based on the work in the model.

## Managing Room Data

A custom program is used to develop a list of rooms in the database, including a separate instance for each individual room, based on the program requirements, the gross building spaces, and room identification conventions. These records include foreign key pointers to tables that record room use, organizational assignment, furniture and equipment needs, and other kinds of room requirements.

The Revit API application is then used to import rooms in a similar way as done with areas. These unplaced rooms also include their required area, use type, occupant group, and other values as pre-assigned parameter values. Their placement and manipulation is discussed in a following section of this document. *Figure 5* illustrates the user interface and a typical plan condition as the rooms are being placed within the building.

The coordination of the normalized database data, with the “flat” data in Revit, which cannot be normalized, is a source of difficulty. In general the strategy is to keep the best data (the “source of

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truth") in the database, and use flattened copies in the model to display it.

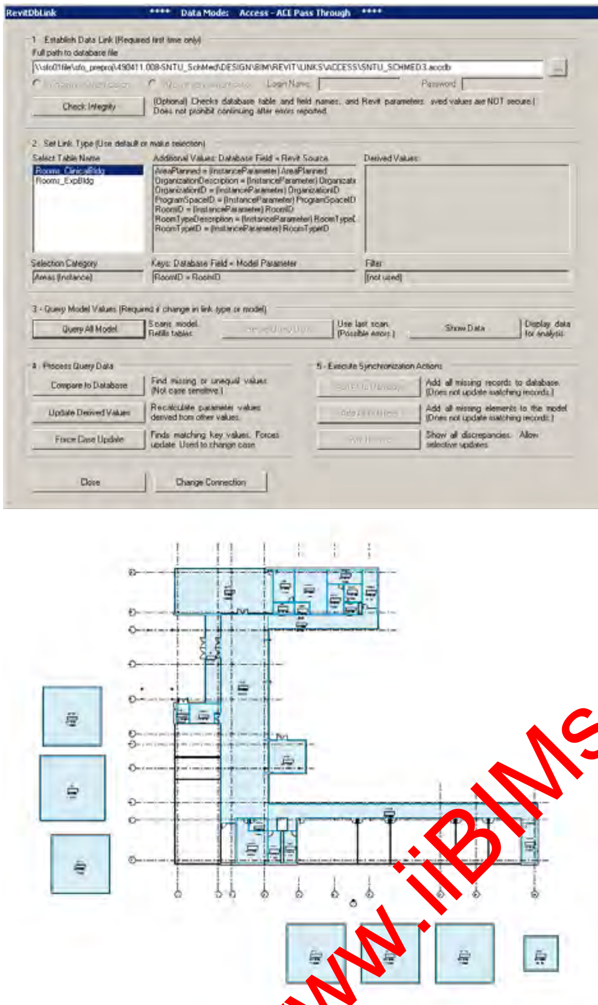


Figure 5: Rooms are Imported and Managed with a Bidirectional Database Link.

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### Supporting Construction Documentation

Ideally, data connected to rooms, doors, equipment, furnishings, and other element types, are maintained in the database during construction documentation. This supports a variety of ad hoc processes for bulk updates and quality control. For example, database queries can be used to select subsets of rooms and doors so that their parameters can be set as a group.

This is particularly useful in working with team members, such as a hardware consultant, who do not want to make edits directly in the Revit model. They can work in Excel, or another convenient tool, and then upload the values to the model.

**Providing a CAFM Deliverable**

Well maintained design data in a database, in combination with CAD output from the BIM, can be used to populate a building owner or operator's CAFM system when the construction is completed.

## MANIPULATION OF AREAS AND ROOMS

After the areas and rooms have been created as unplaced elements, the application can be used to place them in the model. If their required area has been included as a parameter, the new instances will be sized appropriately. Typically this is as a square shape. Alternatively, where a planning module is being used, they are placed with one fixed dimension and varied lengths. *Figure 4* illustrates the use of a planning module.

The areas are then further manipulated in Revit as a design technique. As schematic layouts are defined, with room separation lines, area boundary lines, or walls, the rooms or areas automatically fill to their new size, and their new area values are coordinated with the database.

Plans developed in this way can be represented with *Revit Color Plans*, which use a color legend to distinguish the use types, organizational assignments, or other values. In some cases it is necessary to use the database to flatten multilayered data into a form that overcomes the limitations of the Revit color plan functionality.

## MANIPULATION OF 3D SOLID FORMS

The application can also use areas and rooms to generate solid forms. Unfortunately, due to limitations of the API, it is not possible to create these as in-place mass families. Two options are offered in the application;

> One is to use a standard rectilinear solid family with height/width/depth parameters. These are set according to the corresponding size of the area/room, without regard to its shape. This method is efficient with blocking diagrams but cannot reflect angles or other irregular shapes. To some degree these solids can be further manipulated with shape handles and by editing the parameter values.
>
> An alternative method is to create a new family for each area/room, based on an extrusion of the area/room shape and a fixed height value. These can assume any plan shape but can be edited only by opening the family in the family editor and revising the sketch of the profile.

In both cases, subcategories and material are assigned to the solid forms, based on a parameter value, so that they can be colored according to a legend. Alternatively, the standard Revit view filters can also be used to accomplish this.
*Figure 6* shows some examples of how the tools are used to resolve the building massing.

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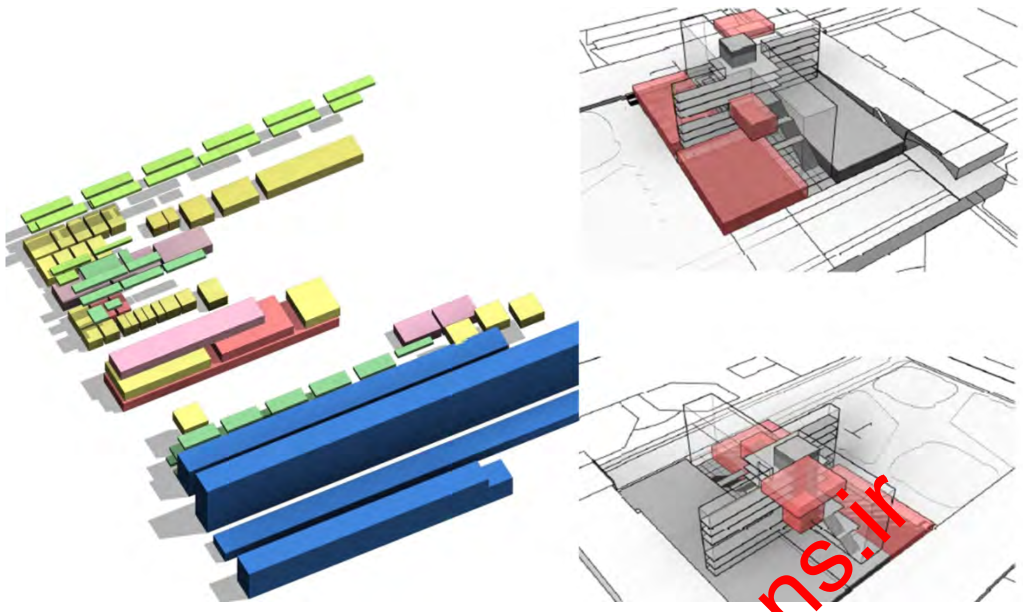

Figure 6: Solids Created from Areas for Form Generation.

## ROOM DATA SHEETS

It is typical in hospital and laboratory design to create a *Room Data Sheet* for each room. These record detailed requirements for fixtures, finishes, utility connections, and so on. It is often desirable to include plan and or 3D views of the room on the sheet.

Room data sheets are typically used at two stages of the design.

> Initially they define generic room types, representing many instances that will be created in the future. At this point they are drawn as complete rooms, often with equipment, cabinets, and other furnishings. Cost and area estimates are based on multiplying the values from each of these prototype rooms by the number of that type required by the architectural program.

> In the second stage, the prototype rooms, with their contents, may be copied as a means to generating the complete building. Alternatively, this can be done as a separate database activity, after which the room records are used to generate, or are linked to, newly created rooms in the model. At this point, each specific room instance may have its own data sheet, reflecting exactly the configuration of its walls and variations in its contents, utility connections, etc.

The application can support both of these phases in either or both of two automated workflows:

> One option is to create the reports entirely in Revit. Views of each room are tagged with the data to be displayed, and each tagged view is placed on its own sheet.

> The other is to create 2D and 3D views in Revit, export them as image files, and then to merge the images with the corresponding room data in an Access report.

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A comparison of the output of these two methods is shown in *Figure 7*.

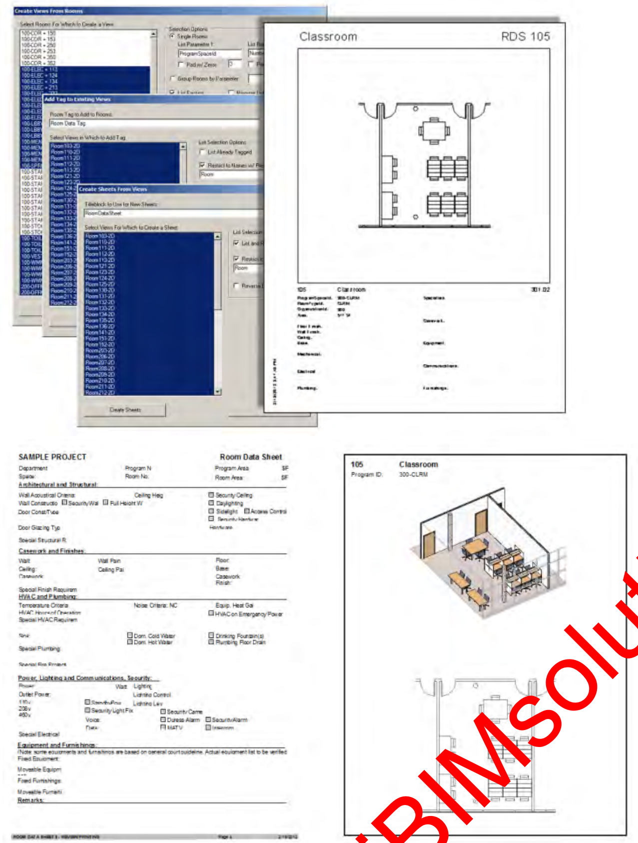


Figure 7: Room Data Sheets. Left: in Revit. Right: in Access.

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## Computational Design

Increasingly, as building forms become more complicated, there is interest in using computer programs to automatically generate unique building geometry, as an alternative to an equivalent manual process. In both the computational and the manual case the process utilizes a commercial digital design software tool. The distinction is that, in the computational case, the instructions are the result of an overlain computer program, whereas, in the manual case, they would be made by a human user.

*Computational Design* has not typically occurred within BIM applications, such as Revit. Although there are dedicated computational design applications, notably *GenerativeComponents*® from *Bentley*® and *Catia*® from *Dassault Systèmes*®, these are not widely used within the architectural community. Probably the most common tool that architects do use is the *Grasshopper*® plug-in to *Rhino*® from *McNeel and Associates*®, because it is an inexpensive and easily implemented complement to Revit. Unfortunately, however, its product is not directly integrated with the concurrent BIM work, which is problematic as the project moves forward.

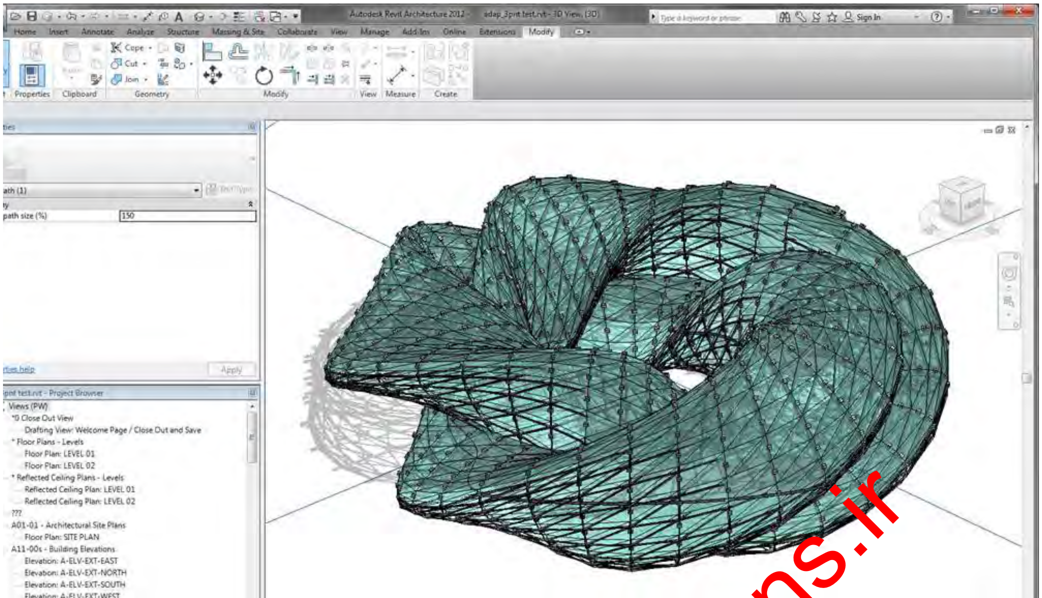

Figure 8:  3304 Adaptive Components in Revit Based on Geometry from Rhino

One reason that this kind of design does not occur within a BIM authoring tool is that it is focused on pure *form*, as distinguished from the *building components* that a BIM represents.  For example, tools like Rhino can represent a NURBS surface, and even contribute to a rendered visualization of the form, without having to define the form as a "roof" that is subject to parametric constraints. Often a designer will create a complex shape in Rhino, deferring until later the issue of how that form will be represented in Revit.

This separation may be entirely appropriate during certain design activities, but ultimately it is necessary to completely represent the form in Revit in order to address other architectural issues, refine the design, and create construction documents.  In some cases this is done by importing the geometry in a static form that is visible but does not have any of the parametric behavior of Revit objects.

As an alternative, the application developed by the author supports several methodologies for utilizing Excel as a bridge between other programs and Revit.  A standard syntax for the Excel workbook is defined so that Revit can build native objects from a list of directives.  The source for the Excel file may be output from Rhino, a specially-built C# program, an analysis program such as *Autodesk Ecotect®*, the open source *Process®* programming language, or another option.  An example of the power of these tools is illustrated in *Figure 8*.

## PARAMETER MANIPULATION

It is often useful to populate a Revit model parameter based on other model parameters.

> **Math Calculation:** A general purpose calculator utilizes up to three other parameter values or constants and an equation to populate a target parameter.  Options for summing based on groupings and rounding output values are also available.  Multiple calculations can be chained together as a way of performing more complex calculations.  An example of the use of the

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math calculation tool is shown in *Figure 9*.

**String Manipulation:** Text, from parameters or fixed values, can be concatenated and inserted into a target parameter. This is often useful as a means of flattening data into a form that is usable by the standard Revit color plan commands.

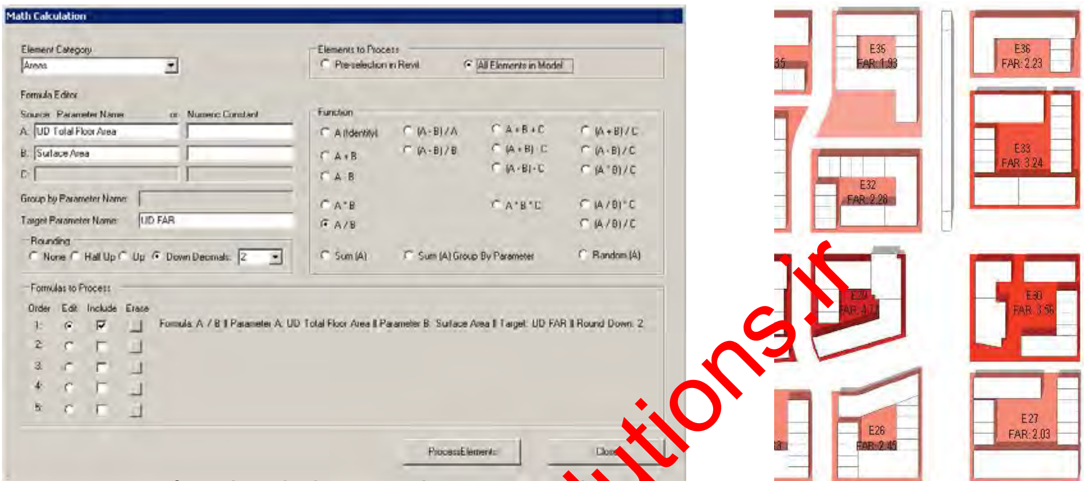


Figure 9: Use of Math Calculation Tool to Compute Floor-Area-Ratios.

## CONCLUSION

Commercial BIM applications, although increasingly powerful, often lack specific capabilities that can be corrected with customizations that utilize their API. The examples illustrate some potential solutions including: automation of routine tasks; bidirectional connectivity between a BIM model and a database; creation and manipulation of areas, rooms, and solid forms; creating room data sheets; manipulating parameters; and supporting computational design. Although there are difficulties associated with this development, the author's experience is that this development is both possible and useful.

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# BUILDING RELATIONSHIPS:
# Introducing Construction And Structural Logic Through Detailed Modeling

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## ABSTRACT

This paper summarizes a pedagogical approach for introducing second year architecture students to the logic of structure and construction through the parametric modeling of relationships between building components. By combining digital modeling with fundamental understanding of construction technologies, students discover how construction and design inform one another. A term-long process of virtual construction results in a detailed model that includes parametrically linked structural components. The paper suggests that this level and strategy of modeling is rapidly becoming an expectation of practice. Furthermore, it argues that students who are exposed to the logic of structure and construction through detailed parametric modeling are better prepared to grasp design logic which enhances their compositional acuity.

## INTRODUCTION

Architectural educators across the United States are altering curricula to address the industry's shift to a 3-D Building Information Modeling paradigm. This recalibration represents a unique opportunity to bridge an age-old chasm between compositional design and construction reality that are often taught independently from one another. The consequence of a disintegrated approach to teaching is that a fundamental aspect of architectural design—that structure and construction detailing are integral to design vocabulary—is typically lost on the student. To an inexperienced designer, design tends to follow a process that moves from abstract ideas to details as a one-way operation. Every tool within an architectural education must help students understand that discovery at the detail level can re-inform an early gesture, and that all tools are part of the iterative design process. Essays such as "The Tell-the-Tale-Detail" by Marco Frascari (Frascari, 1984) or exposure to the work and early design sketches of architects like Carlo Scarpa or Helmut Jahn (Herbert, 1993) demonstrate this concept.

In parallel, the elegance, efficiency and availability of digital fabrication have made it an expectation in industry rather than a luxury. This digital fabrication revolution has likewise exploded over the past decade with students expecting access to laser cutting, CNC milling and 3-D printing operations for expressing their ideas. With more and more of the construction industry heading in this direction, it is clear that schools of architecture must provide strong experiences for students to incorporate the new digital tools as an integral part of their basic disciplinary education.

The pedagogical approach presented in this paper takes into consideration the need to introduce students to the concepts of Building Information Modeling and parametric design with an eye to the eventual completion of a three-dimensional building model that would lend itself to direct digital fabrication processes. This approach assumes that BIM practiced at the level of modeling individual components of construction (Harfmann, 2004) is eventually inevitable and that the design process will include the modeling of design drivers that define the relationships between construction and design (Aish, 2005). The strategy presented herein articulates a practical methodology to move students with little to no construction or parametric computer modeling background to thinking parametrically and abstractly about first principles of structure, construction and design drivers, preparing them for advanced level coursework and the future BIM to digital fabrication practice reality.

The first section of the paper describes the curricular and class context of this effort then articulates the pedagogical instrument used to introduce concepts of structure and construction to a large class of second year architecture students. The second section focuses on the techniques and strategies used to integrate the concepts of structure and construction through a term-long modeling project to illustrate the strategies. The last section provides a summary and conclusion that incorporates examples of a student project.

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## CONTEXT AND INSTRUMENT

The first year at the University of Cincinnati School of Architecture and Interior Design focuses on the development of skills and principles of composition and representation. The second year is a complete immersion into architectural production with studios focusing on building and site design with a full array of history and technical support courses taught in parallel. Therefore, the second year is a critical year as it lays the architectural foundation for the rest of the curriculum building on the footing of the first year skills of representation and composition. As part of this immersive foundation, the introductory course in Design Science was constructed with the following learning objectives;

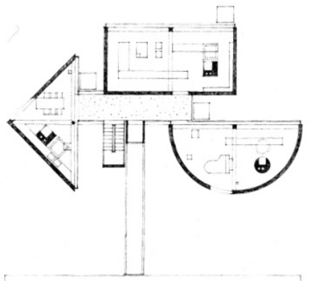
- Introduce students to simple principles of structure and structural systems
- Introduce students to basic materials and methods of construction
- Introduce the concepts of parametric Building Information Modeling

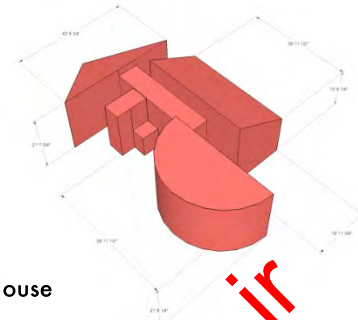
Providing 120 students with a tailored learning experience can be difficult to balance with a professor's desire for standardization of assessments. Providing a range of problems to solve in conjunction with learning the fundamentals of structure and construction led to the following criteria for selecting and designing the instrument. The instrument should;

- allow for the independent modeling of parts that correlate to construction type so students can focus on one particular set of problems at a time,
- provide varying complexities of form to force engagement with solving construction and modeling issues associated with non-orthogonal designs,
- lend itself to articulating a simple set of parameters that can drive the design,
- provide sufficient variation so that sharing digital files is discouraged,
- provide varying conditions between building and site to resolve, and
- provide opportunities to solve more complex problems as knowledge and skills

increase.

Based on the learning objectives and criteria outlined, the Half House by John Hejduk was chosen as the instrument for developing a parametric BIM construction experience. The plan of the house consists of three spaces in three separate geometric forms, a half circle, a triangle and a rectangle, connected by a hallway spine with a stairwell shown in Figure1a.





Figures 1a and 1b: Plan and variables of Hejduk Half House

The three separate geometries of the Hedjuk Half House lend themselves to independent modeling of three different construction types based on three different structural systems as well as the creation of several variables that give each student a unique building experience. Each student inherits a set of variables that is calculated based on their ID number and initials. The variables include alternative slopes for the site, differing sizes of geometry, varying the construction type by geometry to name a few and some of these are shown in Figure 1b.

With this number of variables an individual problem set for each student is ensured. The individual geometries facilitate the discrete and independent modeling of each shape in parallel with lecture and reading materials. The incremental building of the Half House is also coordinated with due dates to break up the term-long project into manageable pieces with significant class time devoted to in-class modeling to explain construction sequence and detailing. While this is not a computer modeling class, students learn to use the BIM software by modeling along in the class.

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## PEDAGOGICAL FRAMEWORK

With the learning objectives and the pedagogical instrument in place, the specific framework for orchestrating the path through the structure and construction content was developed. The overarching goal of the course is to continually reinforce the concept of modeling relationships rather than simply modeling components of construction as static elements. This relationship-building exposes students to the power and potential of parametric modeling with the expectation that construction and structural logic will inform design logic in the studio. The subsections are loosely organized according to the sequence in which they are introduced in the class using the Half House instrument as the vehicle for instruction. Classes typically alternate between lecture and demonstration on one day followed by an in-class "lab" the next where students follow the construction modeling process on their own laptops.

### Regulating Lines

Among the first items introduced is the concept of regulating lines (Kolarevick, 1994) and controlling a design with a set of rules and parameters (Woodbury 2010.) This concept builds on a rich history of analyses of form, (Baker, 1993) constraint based design (Gross, 1996) and the logic or architecture (Mitchel, 1989) and is not new to most seasoned architects with some background in design methods and precedent analysis. To the second year student, however, the concept of parametrically driven design lines is entirely foreign. Given the simplicity of the form, the first major regulating lines, driven by the individual student's dimensions, are produced directly as part of the project in both plan and elevation. Students do not often immediately grasp why they are asked to begin their model this way. But it becomes abundantly clear as soon as they need to adjust a major aspect of their construction. Figure 2 illustrates the basic form and regulating lines with critical dimensions articulated.

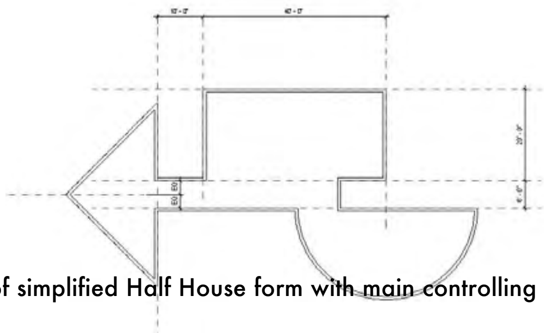

Figure 2: Plan of simplified Half House form with main controlling regulating lines.

<u>Material Distribution</u>

The first content area covered in the class is simple wood frame construction, which provides a relatively straightforward introduction to the complexity of structure and construction. On the first day of entering the class, students are asked to "walk the plank"—a 12′ long 2″ x 8″ supported at either end by a 4″ x 4″ block. This experience launches the discussion about the designer's responsibility for the distribution of material and the patterns of that distribution. After a brief foray into calculating the Moment of Inertia for simple rectangular beams to illustrate how the depth of material is related to its capacity to resist bending, the focus shifts to modeling this behavior parametrically. All second year students have access to introductory texts, in this case The Architect's Studio Companion (Allen, 2007), and are familiar with rules of thumb for assigning depth to structure. This behavior is modeled as a simple rectangular beam that grows in depth proportionally to the length of the span.

Since this course is obligated to introduce students to more depth with respect to structure and construction, the rules of thumb are set aside in favor of a more accurate approach to assigning depth to structure. Since this is quite simple for wood construction we use the Southern Pine Span Tables (http://www.southernpine.com/span-tables.asp) to size and model wood joist behavior. As a point of departure we consider and model a typical 16″ on-center deployment and discuss how the different spacing and grades of lumber in the table affect the joist's ability to span. The if-then statement that drives the depth parametrically based on the length utilizing values extracted from the Southern Pine table is shown in Figure 3.

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=IF(L<9’1”,5.5”,IF(L<11’11”,7.5”,IF(L<14’8”,9.25”,IF(L<17’2”,11.25”,0.1))))

**SOUTHERN PINE SPAN TABLES**

*Maximum spans given in feet and inches inside to inside of bearings*

**TABLE 3 FLOOR JOISTS – 50 PSF LIVE LOAD, 10 PSF DEAD LOAD, 360 DEFLECTION**

| Size (inches) | Spacing (inches on center) | Grade | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Visually Graded | | | | Machine Stress Rated (MSR) | | | Machine Evaluated Lumber (MEL) | | |
| | | SS | No.1 | No.2 | No.3 | 2400f - 2.0E | 2250f - 1.9E | 1950f - 1.7E | M-23 | M-14 | M-12 |
| 2x6 | 12.0 | 10-4 | 10-2 | 9-11 | 8-6 | 10-9 | 10-6 | 10-2 | 10-4 | 10-2 | 9-11 |
| | 16.0 | 9-5 | 9-3 | **9 -1** | 7-4 | 9-9 | 9-7 | 9-3 | 9-5 | 9-3 | 9-1 |
| | 19.2 | 8-10 | 8-8 | 8-6 | 6-9 | 9-2 | 9-0 | 8-8 | 8-10 | 8-8 | 8-6 |
| | 24.0 | 8-3 | 8-1 | 7-9 | 6-0 | 8-6 | 8-4 | 8-1 | 8-3 | 8-1 | 7-11 |
| 2x8 | 12.0 | 13-8 | 13-5 | 13-1 | 10-10 | 14-2 | 13-11 | 13-5 | 13-8 | 13-5 | 13-1 |
| | 16.0 | 12-5 | 12-2 | **11 - 11** | 9-5 | 12-10 | 12-7 | 12-2 | 12-5 | 12-2 | 11-11 |
| | 19.2 | 11-8 | 11-5 | 11-3 | 8-7 | 12-1 | 11-11 | 11-5 | 11-8 | 11-5 | 11-3 |
| | 24.0 | 10-10 | 10-8 | 10-0 | 7-8 | 11-3 | 11-0 | 10-8 | 10-10 | 10-8 | 10-5 |
| 2x10 | 12.0 | 17-5 | 17-1 | 16-9 | 12-10 | 18-0 | 17-9 | 17-1 | 17-5 | 17-1 | 16-9 |
| | 16.0 | 15-10 | 15-6 | **14 - 8** | 11-1 | 16-5 | 16-1 | 15-6 | 15-10 | 15-6 | 15-2 |
| | 19.2 | 14-11 | 14-7 | 13-5 | 10-1 | 15-5 | 15-2 | 14-7 | 14-11 | 14-7 | 14-4 |
| | 24.0 | 13-10 | 13-4 | 12-0 | 9-1 | 14-4 | 14-1 | 13-7 | 13-10 | 13-7 | 13-3 |
| 2x12 | 12.0 | 21-2 | 20-9 | 19-10 | 15-3 | 21-11 | 21-7 | 20-9 | 21-2 | [illegible] | 20-4 |
| | 16.0 | 19-3 | 18-10 | **17 - 2** | 13-2 | 19-11 | 19-7 | 18-10 | 19-3 | [illegible] | 18-6 |
| | 19.2 | 18-1 | 17-9 | 15-8 | 12-1 | 18-9 | 18-5 | 17-9 | 18-1 | [illegible] | 17-5 |
| | 24.0 | 16-10 | 15-11 | 14-0 | 10-9 | 17-5 | 17-1 | 16-6 | [illegible] | [illegible] | 16-2 |

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Figure 3: IF-THEN-ELSE formula driving joist depth based on Southern Pine Span Table

In the formula, “L” represents the length of the joist so if the span (L) is less than 9’1” then the joist depth equals 5.5”, else, if the span (L) is less than 11’ 11” then the joist depth is 7.5” and so on. An abnormally small value is entered if the span exceeds the 17’ – 2” maximum for the 2 x 12. If the student attempts to model a joist exceeding the maximum length, the conditional statement prevents the software from generating the joist. By experimenting with the dynamically adjusting joist, the student learns that the design must somehow address material distribution according to the principles of structure. The “honest” expressions in the use of both the rule-of-thumb and dimension lumber joist structures in the triangular portion of the Half House would require a varying bearing condition that becomes obvious when the structural system is placed relative to a foundation as seen in Figure 4. This experimentation provides students with a graphic, diagrammatic, intuitive understanding of a fundamental principle of beam theory and its relationship to design.

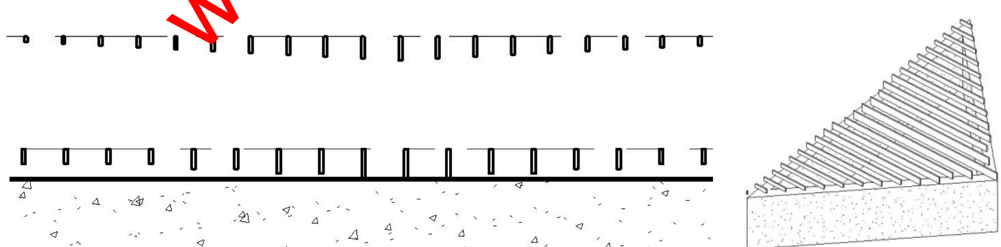

Figure 4: Varying joists depths based on length as part of structural logic

<u>References and Relationships</u>

Emphasis is continually placed on defining relationships rather than modeling static elements. The clear advantage of this approach is that if change is necessary (which it often is with inexperienced designers) it would not require complete remodeling or starting over. As an example of this approach, consider the relationship between a brick ledge and a sloping site. Since each student models their own slope it is unlikely that two slopes will be identical. Furthermore, the variability between the construction and foundation conditions for each of the forms makes it all but impossible to demonstrate a solution that fits every alternative in the class. Consequently, the focus shifts to defining the logic using reference planes to drive the conversation. As students follow along and model this logic, it is simple task then to “tune” their model according to their specific conditions and dimensions. To illustrate the concept, a simple parametric model is demonstrated that dynamically adjusts steps according to a slope. This allows students to develop an understanding of the logic and rules for the steps. For example, if standard bricks are used on the steps, the steps should be sensitive to the dimensional reality of the bricks resulting in steps that are in 8” vertical and horizontal increments. Once the logic is clear, students model their own references in order to associate a brick ledge appropriately in their model. Figure 5 illustrates the modeling of a brick ledge for the more challenging geometry of the circle. Shown in elevation are the vertical reference planes that drive the various depths of the ledge allowing students to adjust the relationship to the ground.

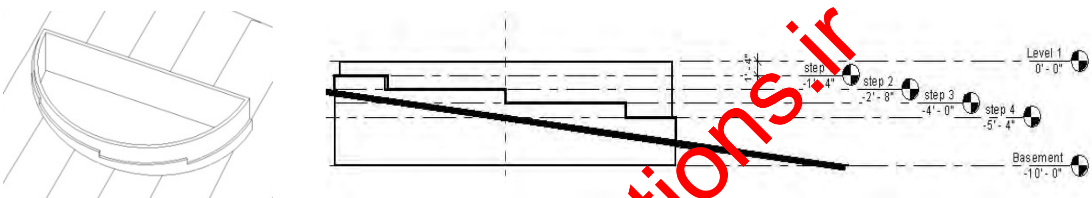


Figure 5: Axonometric and elevation with reference planes showing brick ledge to site

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Even though the foundation wall with a brick ledge would be poured in a single operation, the brick ledge here is modeled as an entirely separate wall. This technique is both easy to model in 3-D but more importantly, becomes the springboard to introduce the concept of “heavy” or self-supporting envelopes versus curtain wall or surface applied envelopes. Adding the wall in the 3-D model as a separate entity helps to explain the consequences of this act relative to design and construction.

Another example of the use of references used to articulate relationships is the distance between the exterior reference line that defines the form and the line of a structural bay. This relationship can vary greatly based on the specifics of the envelope, the size of the columns, or the depth of the girts to name a few. By modeling this relationship as variable, the students can quickly adjust the distance to accommodate the specifics of the envelope they choose to integrate. Figure 6 illustrates two examples of this variation—one with a storefront glass envelope, the other with a tilt-up concrete panel and interior wall.

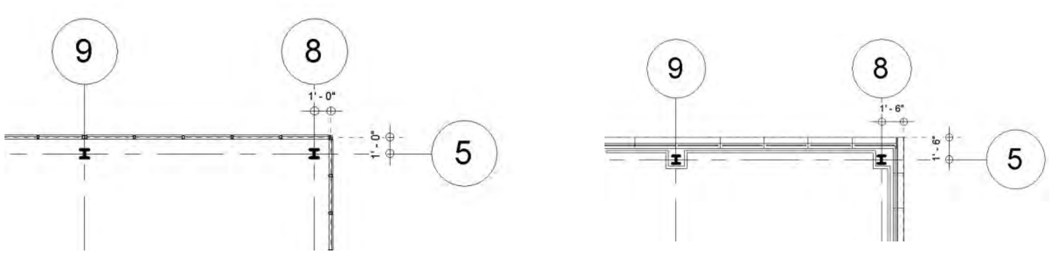


Figure 6: Plans showing outside reference line relative to structural grid

Everything is Structural

All construction obeys the laws of physics and as such, the logic of structure applies, whether it is a series of joists resisting gravity loads or a series of girts that withstand wind load. While it may seem unintuitive to model girts using the same strategy for a system of joists, the first principles and rules for distributing material apply to both. The same logic applies to the application of furring strips for drywall applied over a concrete masonry wall or stringers for suspending a ceiling structure. As the thickness of the final layer increases, its Moment of Inertia and capacity to span increases, which in turn allows the spacing of the girts, furring strips or stringers to increase. This increase in girt spacing also directly increases girt size so the exercise of exploring options gives students a first-hand experience with material distribution. From this, students quickly develop intuitive understanding of the inverse relationship between the size of members and the necessary number of members. They also see that this choice has a visual affect that may or may not be consistent with design aspirations. Figure 7 illustrates a structural logic for a girt system that spans between columns to support a simple, vertical metal panel exterior

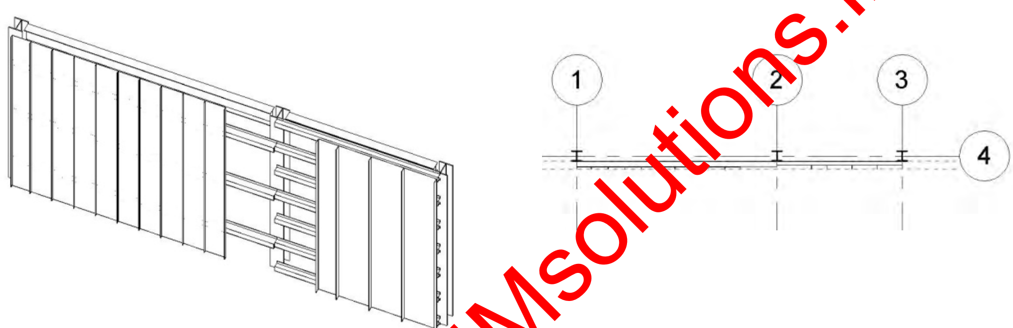


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Figure 7: Two different bays with girt systems for supporting metal panel cladding.

As shown in the figure, girts in this case are simple sections that dynamically adjust their depth based on span. Various spacing can be explored as well, resulting in girts with a different cross section that also vary in depth with changes in span. As the spacing between columns changes the girts grow in depth accordingly. The bay on the right shows panels with deeper ribs and closely spaced girts spanning between columns that are 10' apart. The bay on the left shows panels with shallower ribs and larger, less frequent girts spanning between columns spaced 16' apart. Since the line of the exterior envelope has already been related to the grid line that controls the position of the columns, it is an easy task to adjust the distance between them to accommodate the combined thicknesses of envelope and girt.

Modeling the Layers of Construction.

While architects customarily think of a wall assembly as a final unit, the reality of construction is that the layers in a typical wall section are assembled in a very particular order. There are several advantages to this approach; none the least of which is the ability to match the evolving model to photographs of construction as well as providing the ability to incrementally model aspects of construction as they are learned. Consequently, we model structure first, then outside envelope then interior lining. Another advantage of this method is the ability to define the relationship between the exterior skin, the structural wall, and the interior lining by tying them to reference lines as well. This separate modeling strategy forces a more conscious act of design than a single broad-brush stroke of a single wall. Furthermore, with all the layers separately built, it is a rather trivial task to adjust one layer of construction without remodeling or redefining the assembly. In this way, students are able to explore various envelope materials, bearing wall thicknesses or interior linings as separate design acts instead of modifying the composition of the entire assembly each time. As a teaching tool, this approach lends itself well to discussing the sequence of construction and introducing concepts such as rain screen technology. Figure 8 illustrates a partial sequence of modeling that parallels the sequence of construction with independent layers for walls, floor assemblies, and roofs.

Figure 8: Construction and modeling sequence of layered building.

At a more detailed level, consider the relationship between a concrete masonry bearing wall with a brick cavity and an interior finish of drywall over metal studs or furring strips. Independent and sequential modeling of the three layers and linking them to reference lines that allows for altering the relationships between them promotes the conscious placement in support of design. This is also significant to help explain certain logic of construction that would not be obvious if the walls were considered as one simple assembly. To illustrate this consider the placement of a window within the wall assembly described. Since conventional windows are typically hosted by a particular wall in most BIM environments, placement within walls that are independently modeled becomes cumbersome. Furthermore, these standard simplistic window tools do not provide any insight into the complex design and construction detailing questions that come with the act of punching a hole in a masonry wall. The insertion of a window in a wall is anything but trivial so the independent layering of the walls forces an alternative approach that offers a unique teachable moment to illustrate the choices for integrating a window within a complex wall assembly. Figure 9 illustrates the three layers of wall construction and the reference lines that determine their relationships. The reference lines that govern the positions of the walls are driven in the section and dimensioned relative to the exterior reference lines that govern the overall form of the building. The window in each wall section is a simple parametrically driven assembly that allows manipulation of the frame thickness and depth, sill height, and sash within the wall assembly. These conditions are modeled as instance parameters so that they can be adjusted in the section views dynamically to explore the design integration of the window in the wall. In the first section, the wall is modeled as a simple brick cavity with a 1" air space in front of a CMU bearing wall with drywall over furring strips with the window inserted in a rather conventional manner in the center of the wall. The second section illustrates a stud wall partition against the CMU wall to provide greater insulation opportunities. The window sash in this instance is pushed to the inside of the assembly in order to take advantage of the thick wall for some solar shading. The third section increases the cavity between the brick and CMU to accommodate insulation on the outside of the bearing wall and pushes the window through the exterior in order to provide a window seat or ledge on the interior. Once the relationships are established, dimensions can be locked so that a change in the exterior form will adjust the positions of all the elements without remodeling.

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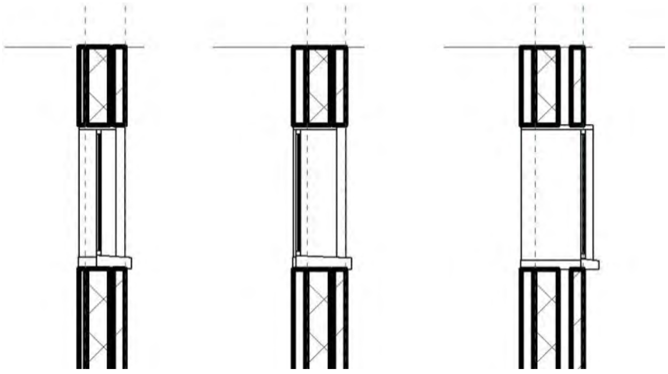

Figure 9: Three wall sections with reference lines and a window in three configurations

SUMMARY AND CONCLUSION

The best method for illustrating the effects of this pedagogical approach is through the use of a student project. The project presented is an 11-week effort with three interim submissions before the final submission. The submissions are cumulative beginning with the wood frame portion followed by submission of the masonry bearing portion of their house. The third submission is a pre-final submission that includes all three geometries and all three types of construction with a first attempt to resolve the connection of all three geometries with the hallway. The third submission is returned with redline comments and suggestions that students incorporate into their final submission. The final project includes opportunities to do extra credit and bonus work, such as modeling stairs, solving more complex details, etc. as a means to boost their overall performance in the class. The output for the final submission includes overall 3-D images of entire model as well as traditional plans, building sections, elevations and detailed wall sections of the wood frame, masonry bearing and steel frame portions of their house. Figures 10, 11, 12 and 13 illustrate 4 drawings of the coauthor's final submission for the class. These drawings are all produced from the 3-D model that emerged during the 11-week project.

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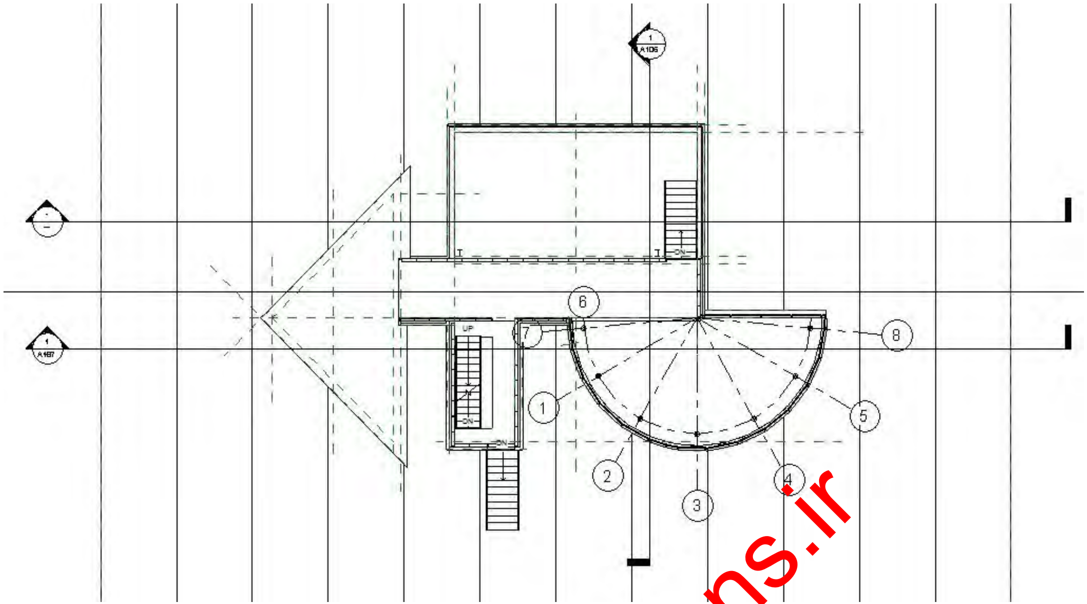

Figure 10: Plan of Half House model (courtesy Troy Newell)


Figure 11: Elevation of Half House model (courtesy Troy Newell)

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Figure 12: Building section of Half House model (courtesy Troy Newell)

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Figure 13: Wireframe axon of Half House component model (courtesy Troy Newell)

Admittedly, for experienced designers and architects the imagery and concepts presented herein are not extraordinary, remarkable or new. However the opportunity to combine principles of construction with digital modeling and parametric design directly correlates to the expectations of practice today. The modularity of the Half House, and the challenges of virtually constructing it with three different construction/structural systems, provides a series of opportunities to solve construction problems. The controlled variables provide a unique experience for each student within an overall instructional framework that permits structuring a rubric and assessments appropriate to a large class.

The next phase in implementing this pedagogy at the University of Cincinnati will include some degree of integration of parametric design directly into the second year design experience. The opportunity to combine principles of structure and construction with digital modeling and parametric design directly correlates to the expectations of contemporary practice. The modularity of the Half House, and the challenges of virtually constructing it with three different structural systems, provides a series of opportunities to solve construction problems. Digital modeling allows students to test and explore a multitude of construction conditions, especially because components generated according to parameters are adaptable to a variety of relationships. Furthermore within the scope of BIM, students are encouraged to design and employ their own parametric components. This can help them understand that the artistry of design results not only from a response to form and aesthetics, but also from a command of data, parameters, construction, structure and the relationships among these elements.

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# AECOsim BUILDING DESIGNER: New BIM Software Integrates All Disciplines

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## Abstract

This paper discusses AECOsim Building Designer, a new BIM (Building Information Modeling) software from Bentley Systems, Inc. that integrates all the disciplines necessary for design of a building, including architectural, mechanical, piping, plumbing, structural, electrical, visualization and drafting. Clash Detection is also built-in, enabling the author of a building to check the integrity.

## History

While the integrated program is new, the components within it have been used individually for years to make some very impressive designs by well-known architects who have won awards for their designs[1]. Among them are: Arup, CH2MHILL, Foster, Henning & Larsen, HOK, LJB, Morphosis, UN Studios, Warren-Mahoney, and many more. Examples of their work are depicted below.

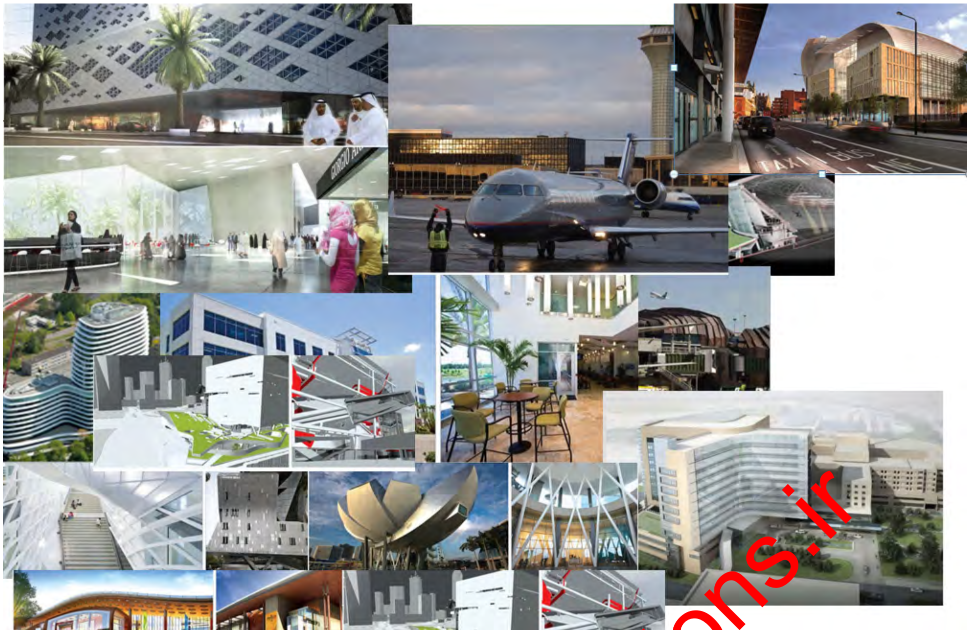

Figure 1. Collage of projects which used the components of AECOsim Building Designer

### Advantages

The advantage of AECOsim Building Designer is that all disciplines are integrated around one database with a consistent user interface. All built on the concept of a single platform using a federated database. This contrasts with software offered as a "bundle" or a "suite" which require separate installations and often have diverse user interfaces and databases. The single platform, interoperability and federated database all contribute toward more efficient workflow, especially for Design Build and Integrated Project Delivery, large BIM based projects.

AECOsim Building Designer is built around the best available standards including the National CAD Standards and the proposed National BIM Standard, and data is included with the product. Consequently, if a firm has no standards, or can change their standards, they are way ahead by going with the National Standards, since these standards have been developed and tested over the years, initially by the US Army Corp of Engineers.

### How does it work

Here is how AECOsim Building Designer works. The example is a 14 story 70,000 square foot high-rise building. Eight of the floors are the same. Through the Federated Data concept, one floor can be designed and then the composite model built up by referencing the common design. If something changes in the common design, it is reflected on all the floors.

The user interface is shown in the figure below. Tasks on the left are for each discipline and expand as they are selected.

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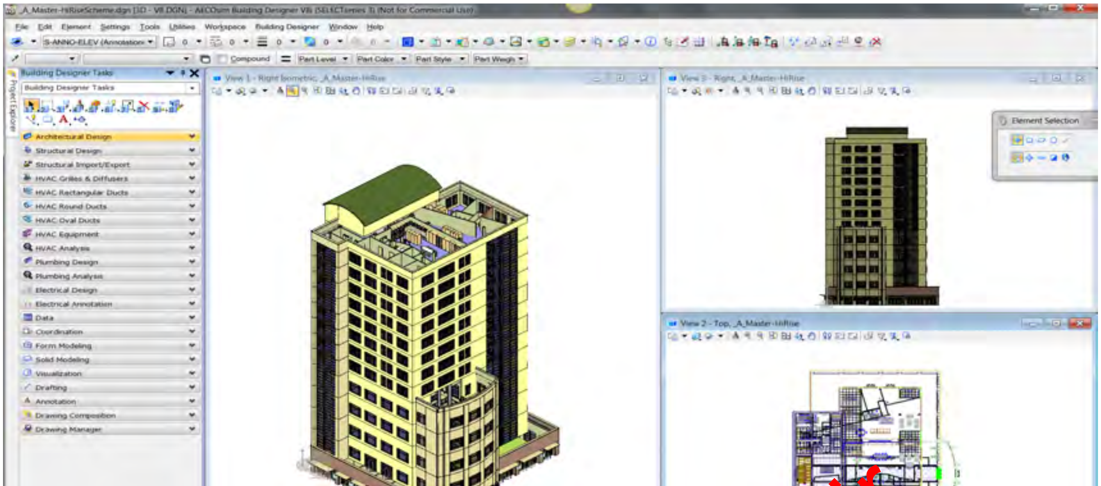

Figure 2. User Interface

AECOsim Building Designer can interoperate with nearly all popular BIM software such as AutoCAD or Revit based. Figure 3. is a view of the file reference dialog showing the variety of formats:

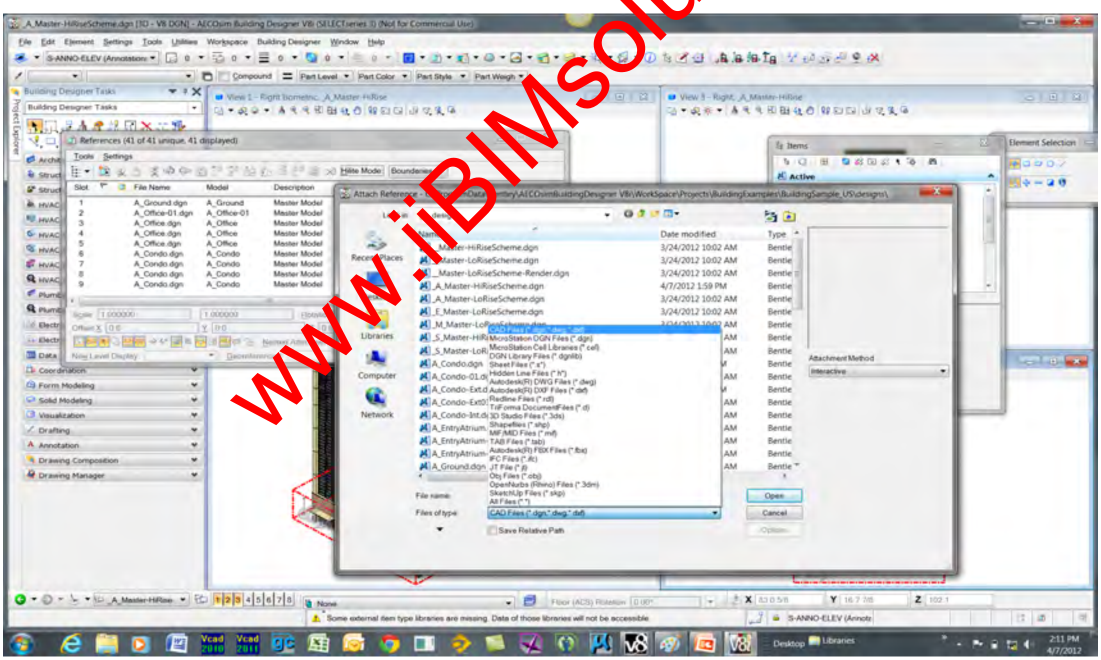

Figure 3. File formats which can be opened or referenced

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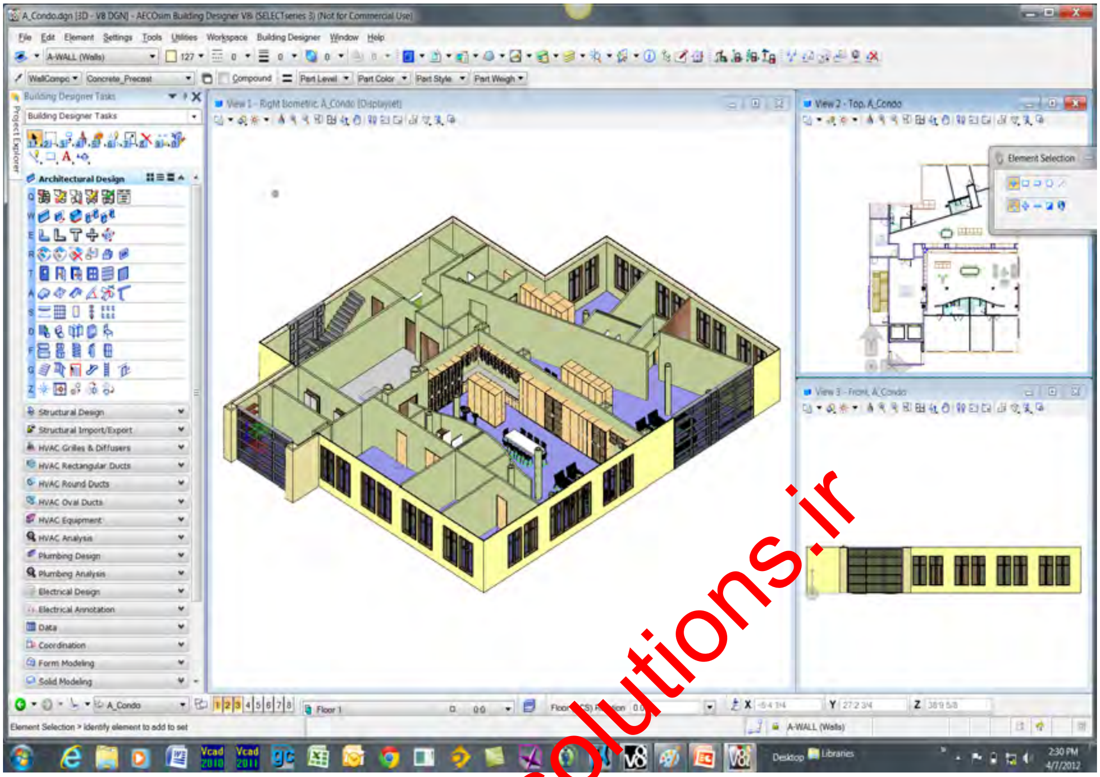

Figure 4. Common floors can be referenced into the composite design

## Handling Non-Graphic (text) information

The “I” in BIM, that is the text information, is every bit as important as the graphics. AECOsim Building Designer accommodates the “I” by automatically building a material and equipment list as a model is built or as it comes from output created by a free plug-in for Revit. Each BIM software has its own “Schema” for recording text information. AECOsim Building Designer knows most and can determine the schema used by others on-the-fly. Here is the item list for the high-rise example:

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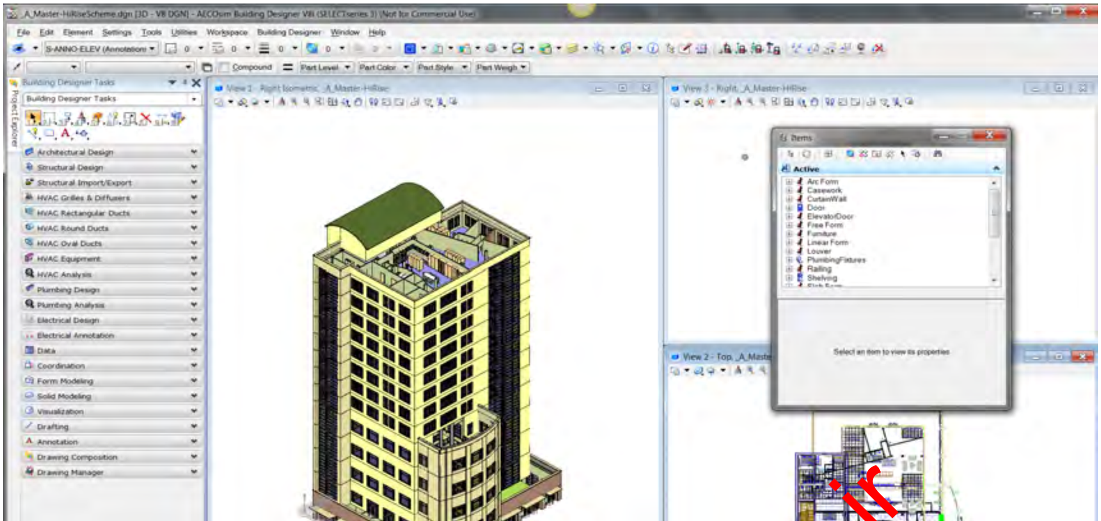

Figure 5. Item list

After a search for a particular window the model can be made transparent so the window stands out:

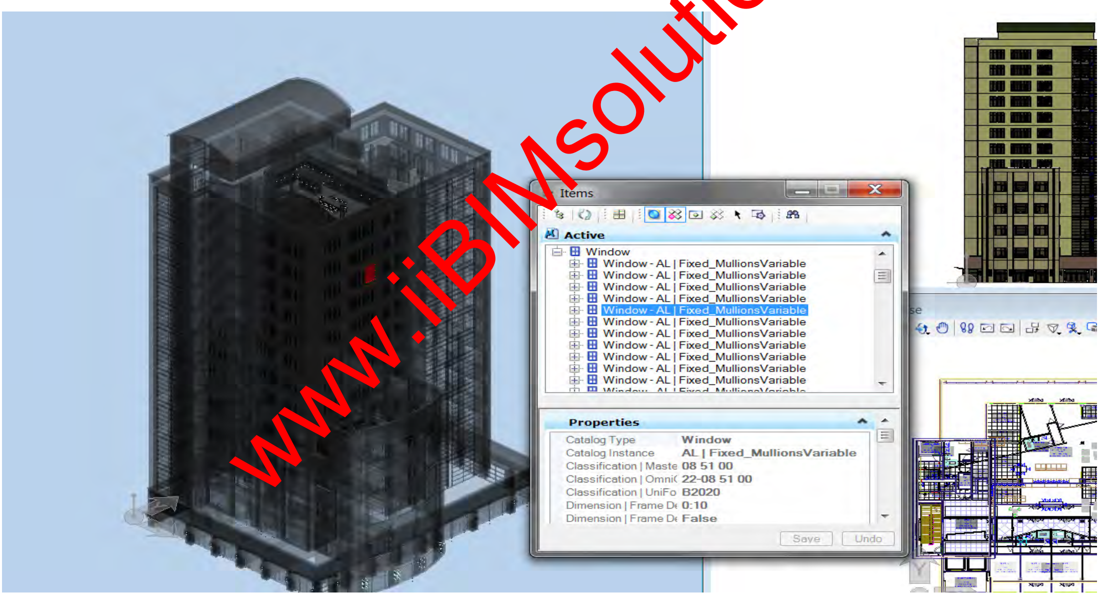


Figure 6. Transparent model to help locate an item such as a particular window

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## Visualization and Clash Detection

Complete visualization tools are incorporated inside AECOsim Building Designer so there is no need to export to separate visualization software.

Clash Detection is an integral function within AECOsim Building Designer. This function enables the Design-Build team leader, or the manager of an IPD project, or the owner or lead architect to bring models in from any BIM software, make a composite model and check for interference between the works of the various disciplines. Cost savings result by eliminating conflicts at design time rather than in the field. Also, there is no need to convert the files and send to an external clash detection software, saving valuable man-hours and schedule time. The clash detection function is outstanding. Built on Parasolid and DCubed, the same kernel used by major mechanical software, it offers the highest precision and the fastest speed in the highly complex mathematics involved, such as that required in designing machines.

Additionally, the clash function is very easy to use, making it a productive part of any workflow. Here is how it works. First drag one discipline into "Set A", then another into "Set B" and press "Process".

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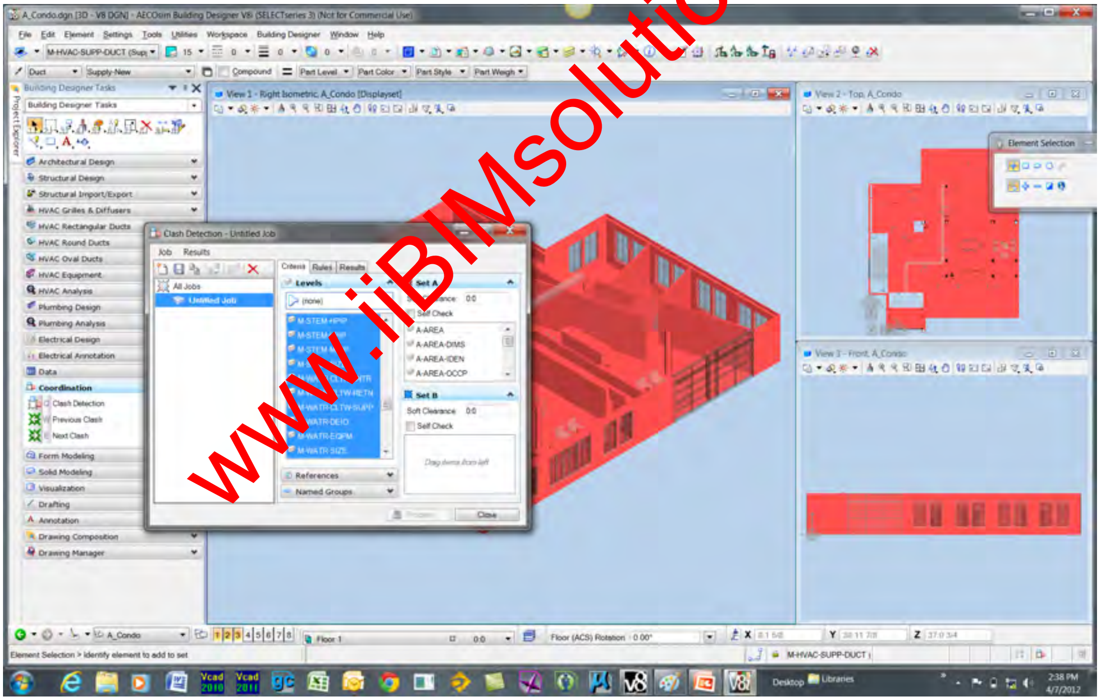


Figure 7. Red set of objects clashed against the blue set (files, levels or named groups)

The process takes place very quickly and then the first clash is displayed as shown in the figure below. The drawing of the clash is made automatically and can be sent to the proper discipline for correction. In this case, the HVAC duct interferes with a column, so the duct will need to be raised a bit higher.

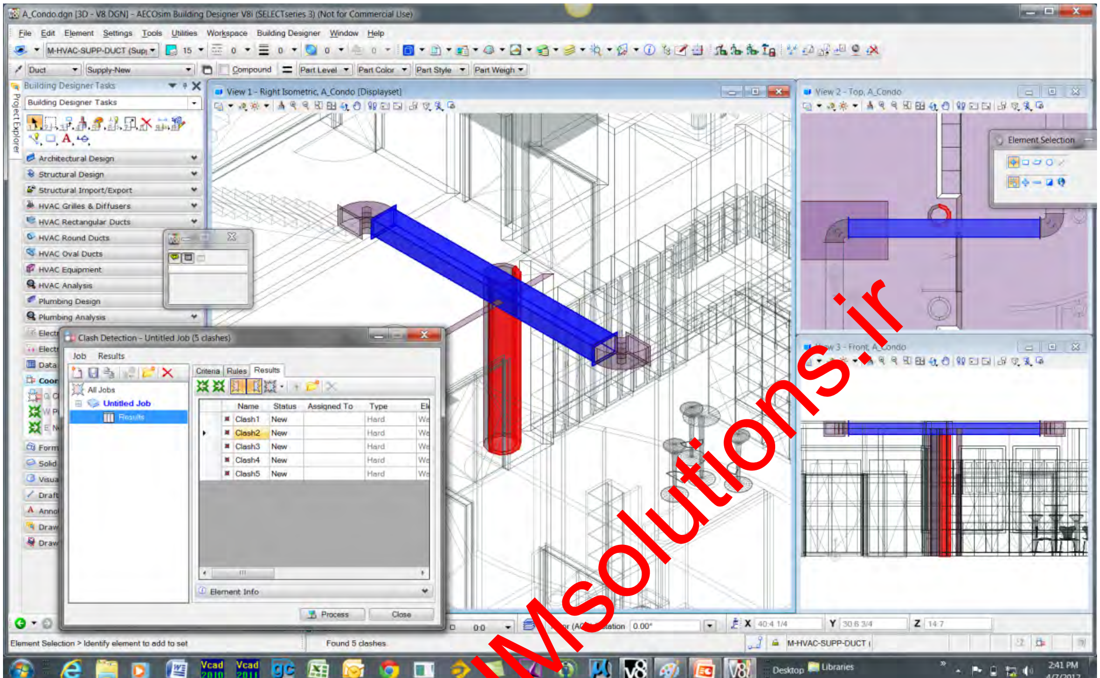


Figure 8. Clash between column and HVAC duct is shown.

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## Construction Documents

Drawing sets are easily created semi-automatically for any or all disciplines, all using the same user interface and the same database.

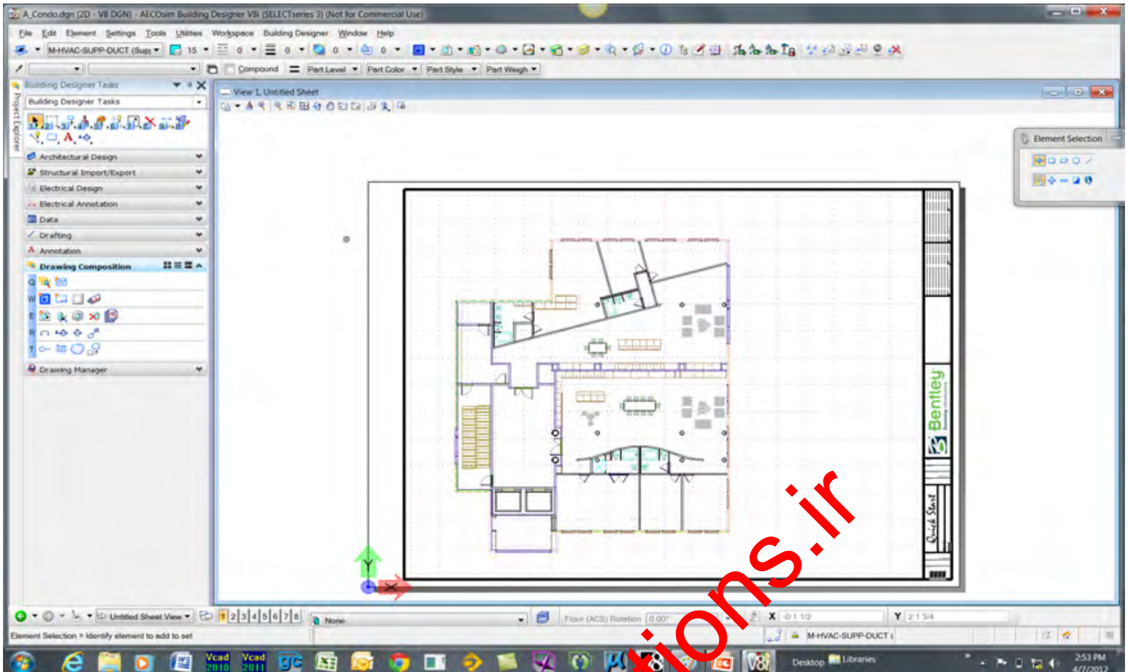

Figure 9. Construction documents created from specified points in the model

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### Where do we go from here?

There is always more that can be done. For example, AECOsim Building Designer comes with a great "QuickStart" manual. However some of the sections are not complete and need more work. Much work has been done on integrating analysis such as the "ductalator", "duct sizer", electrical energy required, etc. And, there is a separate AECOsim Energy Simulator. Additionally, the structural modeler has a link called "Integrated Structural Modeling" which links the design to STAAD or RAM or other popular engineering analysis software for "round tripping" between the designer and engineer. More work on integrating the analytical software is in order.

### Conclusion

AECOsim Building Designer is a giant step forward in BIM, increasing productivity by increasing integration and interoperability, as well as facilitating the move towards Design-Build and Integrated Project Delivery. While a new product, the components and technology have been in development and use on some of the most demanding projects in the world, including the USACE's work, the Crossrail Project in London, the London Olympic venues, and more.

### Citations:

1. The Year in Infrastructure, http://www.bentley.com/en-PH/Corporate/Publications/The+Project+Yearbook/

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# A MORE PRACTICAL BIM:
## Geospatially Re-structuring BIM to Sustain the Built Environment

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### ABSTRACT
At present, the buildings industry is still biased toward a paper-driven model, or one with unstructured digital data having no real connection or spatial context to the world at large. This paper discusses some of the negative impacts over the last three decades to the built environment from the continued use of unstructured building information from two dimensional (2D) systems, and even highly structured 2D and three dimensional (3D) technologies that are difficult to integrate with other systems. One impact is the persistence of erroneous building data within authoritative systems for businesses and cities. Another is the difficulty accessing and integrating it across multiple systems. This paper argues that to truly understand and resolve the challenges facing those managing and living within the urban form, systems providing greater context for individual building objects are critical. It also discusses how restructuring Building Information Model (BIM) technology to take advantage of the inherent spatial relationships in a Geographic Information System (GIS) allows building information (BI) to be aggregated at all scales and integrated with other management systems throughout the building lifecycle. Finally, the paper takes the position that by geospatially restructuring BIM technology it becomes possible to provide tools to forecast development impacts through time and across all scales, so that the market and consumers are better informed regarding more sustainable alternatives.

### THE SCALABLE CITY

The US is now 81 percent urbanized (Census Bureau, 2010) and the world is about 50 percent urbanized—by 2050 it is projected that the world will be 66 percent urbanized (United Nations Population Fund, 2011). Given the growing global population rate and the accumulation of wealth and resources in cities, the trend is towards increased urbanization. Recent findings by physicists and economists, not urban theorists or architects, show there is a sub-linear correlation between city population size and its infrastructure, and that there is an inverse super-linear correlation to city size and socio-economic factors like wealth, innovation, number of police, crime, disease, etc.... For example, as a city population doubles it requires only about 85 percent more infrastructure, and is 15 percent wealthier and energy efficient on a per capita basis. What is fascinating is that this is a universal law that seemingly "transcends history and geography." (Bettencourt & West, A unified theory of urban living, 2010)

"The general regularity of urban scaling laws and of the statistics of their deviations point to the possibility of a general theory of cities that can account for the essence of these interactions and predict a small set of fundamental scaling regularities common to all urban systems." (Bettencourt, Lobo, Strumsky, & West, 2010)

Evidence of this power-law is found in existing building industry data, which reveals a correlation "between project size and construction cost..." where per unit costs "generally are lower for larger projects due to greater opportunities for material quantity discounts and for spreading mobilization, demobilization and general overhead costs over a greater number of units." (Department of Defense, 2007, p. 4) It is further evident in the work of architects and engineers who know by experience there is an economy of scale if site infrastructure is already in place. With suburban development, there is no savings or efficiency to be gained, and total costs could well exceed 100 percent of comparable development in cities, given that sewer, road networks, water, and power will all have to be extended to this newly developed area. So, it not surprising that this scaling bears out with cities as well as buildings. However, if buildings can be thought of as trees, architects, engineers and developers are having trouble seeing the urban forest.

Two generations of poor development choices have left the United States (US) unable to realize these potential savings. While the population of US central cities has doubled over the last 60 years, their land area has grown an additional 427 percent (**Table 1**). Development practices in the US have become inefficient. Using 1950 US city density rates as a benchmark (7,517 persons per square mile), nearly 21,000 square miles of land have been wasted in today's cities on less dense development (Minnesota Population Center, 2012). This is enough land area to support 211 of the US's most populous cities—encompassing a total population of nearly 73 million persons (Minnesota Population Center, 2012). To compound this problem, the growth of new suburban and exurban areas outside these central cities has been just as dramatic–up 336 percent in land area and 348 percent in population since 1950 and has been to the detriment of prime agricultural land, green-fields, riparian zones, and other rural areas surrounding US cities. Clearly, existing infrastructure in such areas is minimal. Consequently, development and sustainment costs are comparatively high to bring supporting infrastructure to these 'greenfield' sites.

**Table 1: US Census Trends in Land Area, Population and Population Density, 1950 - 2010**

| Census Year | Category | Land Area (SQMI) | Delta | Population (Millions) | Delta | Persons per SQMI | Delta |
|---|---|---|---|---|---|---|---|
| **2010[1]** | **Total** | **3,531,905** | **(7,384)** | **309** | **82** | **87** | **23** |
| | Metropolitan | 912,992 | 346,844 | 258 | 89 | 283 | (16) |
| | Central Cities | *34,794* | *12,214* | *101* | *33* | *2,895* | *(114)* |
| | *Suburbs/Exurbs | *878,198* | *334,630* | *158* | *56* | *179* | *(7)* |
| | **Outside SMAs | 2,618,913 | (354,228) | 50 | 1 | 19 | 3 |
| **1980[2]** | **Total** | **3,539,289** | **(12,909)** | **227** | **75** | **64** | **21** |
| | Metropolitan | 566,148 | 357,975 | 169 | 85 | 299 | (108) |
| | Central Cities | *22,580* | *15,974* | *68* | *18* | *3,009* | *(4,508)* |



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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Suburbs/Exurbs | *543,568* | *342,001* | *101* | *66* | *187* | *12* |
| | ***Outside SMAs | 2,973,141 | (370,884) | 49 | (17) | 16 | (3) |
| 1950[3] | ****Total | **3,552,198** | **-** | **151** | **-** | **43** | **-** |
| | Metropolitan | 208,173 | - | 85 | - | 408 | - |
| | *****Central Cities | *6,606* | - | *50* | - | *7,517* | - |
| | Suburbs/Exurbs | *201,567* | - | *35* | - | *175* | - |
| | ***Outside SMAs | 3,344,025 | - | 66 | - | 20 | - |

[1] (Census Bureau, 2012; Minnesota Population Center, 2012)
[2] (Census Bureau, 1980, pp. Table 2, 30)
[3] (Census Bureau, 1950, pp. Table 2, 29)
*Includes urban areas outside the central city and within the same metropolitan area
**Metropolitan Statistical Area, 2010 definition with principal cities >= 50K, http://www.census.gov/population/metro/data/pastmetro.html
***Standard Metropolitan Area, 1950-80 definition with principal cities >= 50K
****Includes Alaskan and Hawaiian Territories
*****Land Area is based upon dividing the known population by the known density

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## IMPACTS OF DE-DENSIFICATION

The de-densification of US cities is troubling since it is the increased interactions among a city's populace that lead to the collaboration and innovation required to sustain and grow cities (New York Times, 2010).

"As highly skilled people concentrate in [cities], the rate of innovation accelerates, new businesses are created, and productivity—and, ultimately, pay—grows... Jobs requiring physical skill cluster in small and medium-size metro areas—industrial centers where land for factories is relatively inexpensive. Jobs featuring analytic skill are sparse in these places, and heavily concentrated in larger metro areas—indicating the rising benefits of having high numbers of well-educated, highly intelligent people working close together. And jobs requiring the highest level of social skill are the most concentrated in the very largest metro areas—where, combined with the high prevalence of analytic skill, they underpin faster rates of innovation and growth." (Florida, 2011)

So, without continued technological advances cities will be depleted of critical resources, and in highly populated areas typical results (among others) include more frequent use of unpleasant words like disaster, riots, death and disease.

These lighter development patterns were not only an inefficient use of land, but they resulted in a less efficient use of energy. Using the scaling law for city growth one would expect a 15 percent reduction in energy consumption per capita every time a city's population doubles. However, by researching the energy used by facilities over the last thirty years, it becomes evident that total US residential and commercial energy consumption has not met expectations for energy efficiency (US Energy Information Administration (EIA), 2010, p. 40). In total, and considering that only 40 percent of population growth was in central cities and that their density decreased by four percent during this period (

nearly 167 quintillion joules of energy were wasted by not focusing new development within existing central cities. This is enough energy to have powered the entire US commercial and residential sectors at their present rates for the last 30 months. It is also an amount 500 times greater than the most powerful nuclear bomb ever detonated, the Tsar Bomba. This device was detonated by the USSR in 1961, and the resulting mushroom cloud was more than 40 miles high and 25 miles wide. (Wellerstein, 13)

## HUMAN NATURE, NATURE, AND THE BUILDINGS INDUSTRY

So then, peering through the lens of the last sixty years what really is the current relationship between humans and their environment? Generally, even the most generous descriptions reveal it as another domain and world from what is human, e.g. humanity as progressive leaders and stewards of the environment. This is a self-validating epistemological error that will continue to work right up until it does not (Bateson, 1972), and by all appearances these beliefs are being challenged daily by contradictory evidence. For example, the measurable and growing suburbanization of the US outside its central cities demonstrates a very real disregard for the natural environment. If it was not before, it certainly is now evident that key practices within the buildings industry for shaping and managing the built environment are unsustainable.

The industry is no doubt integral to the US economy, having accounted for nearly nine percent of all US gross domestic product (GDP) during the same period (Pacific Northwest National Laboratory, 2010, 1.3.1, 1.3.2). It's also an industry where the output (buildings) accounts for almost half the country's greenhouse gas emissions and energy use (National Research Council (NRC), 2011, pp. S-2). However, with tools to forecast the short- and long-term impacts of proposed development, the market and consumers would have been better informed regarding more sustainable alternatives. In this manner, it would have been possible for developers and architects to configure more efficient layouts to achieve the same net square feet (NSF) as other alternatives with more gross square feet (GSF) for the purpose of increasing profitability for developers and reducing energy costs for consumers.

One barrier to achieving greater sustainability has been the high level of industry fragmentation. This is due to the large number of stakeholders (owners, designers, regulators, etc...) and whether their focus was strategic or tactical (National Institute of Science and Technology (NIST), 2004, pp. iii-iv). The other barrier is that the buildings industry is still biased toward a paper-driven model, or one with unstructured digital data having no real connection or spatial context to the world at large. One impact is the persistence of erroneous building data within authoritative systems for businesses and cities. Another is the difficulty accessing and integrating it across multiple systems. This certainly is not helpful when efficient and instant access to accurate building information is required (National Institute of Science and Technology (NIST), 2004, pp. 3-1 - 3-6).

Buildings and cities are inherently 3D, so the foundation for smarter buildings and cities will not be based on paper, unstructured 2D systems, or even highly structured 3D technologies that are difficult to integrate with other systems. To understand and resolve the challenges facing those managing and living within the urban form, systems providing greater context for individual building objects are critical. This then should be the buildings industry view, given that today's advanced technology (including cities) allows humanity to extend its reach beyond the body and virtually across the globe, right? The irony is that it is not. In point of fact, it could take days, weeks or months to assemble the drawings and data required to adequately represent an existing building, much less integrate that data with other systems to provide required context.

## AN ECO-MENTAL SYSTEM

One of the few explanations for the persistent use of unstructured buildings data and/or the failure



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to integrate that data with other systems used for managing the built environment is that the industry's project based focus on a building or handful of buildings prevents it from seeing the urban forest. It is almost like a Cartesian plague forcing humanity (in this instance, architects and engineers) to view itself in one domain, technology in another and nature in still another, and that all these parts somehow equal the whole. What's missing is the realization that this hybrid existence, human/ machine/environment, is a system organized by a series of relationships and intensities rather than individual parts.

What is required is the understanding that this system incorporates the perspectives of the actors participating in it (Haraway, 1991, p. 154), expanding the realm of possible experience in ways previously unimaginable. In this manner, the system can respond to phenomena observed by whole system, as well as self-correct in a manner similar to sentient life. "Together these are characteristics of the mind...," though this is not a mind trapped within the confines of one's head, this is a virtual, hybrid mind and it forms the basis of an "eco-mental" system that maintains balance between humanity and its environment, preventing humanity's self-destruction (Bateson, 1972).

"...the lines between man, computer, and environment are purely artificial, fictitious lines. They are lines across the pathways along which information or difference is transmitted. They are not boundaries of the thinking system. What thinks is the total system which engages in trial and error, which is man plus environment."

The territory of this eco-mental system is a "matrix in which all scales of existence come together to sustain (or undermine) life..." (Holmes & Pentecost, 2011) from intimate, to local, to global. What then are the roles of architects and engineers at each of these scales, and how can this territory be reconfigured to better sustain the world, nature, its cities, and its people? What is needed is an epistemology that fosters the discovery and creation of relationships—according to this way of understanding, perception of patterns is the key to achieving wisdom. This pursuit begins by utilizing the combined and enlarged perspective of the eco-mental system to impose a reconfigured order onto the field of existence, e.g. Kant's 'thing-in-itself, allowing for perception of new patterns and reception of new information. Thus enabling the system to differentiate and understand the phenomena around it. These "patterns are everywhere, anywhere, and nowhere...[they] are in-between, ephemeral, yet real." (Cholodenko & Shapiro, 2009)

The key then, at least for architects and engineers, is to stop conceptualizing the world as the sum of its parts, but rather as an overlay of systems and relationships between the actors within it, as well as to comprehend the criticality of discerning patterns within this world. With this as the epistemological underpinning, it becomes critical to collect buildings data in a more structured way. The stakes are now too high, and there can no longer be tolerance for BIM, CAD and other buildings data that cannot connect to the world at large. This is necessary so that it can be integrated and aggregated into larger systems to provide those managing the built environment insight and a level of predictive capability needing for optimizing performance and course correction when needed.

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## PROMISES AND PROBLEMS OF BUILDING TECHNOLOGY

In the early 1990's visionaries within fields as disparate as philosophy and architecture saw past this lingering reluctance, to a time where advanced technologies would converge to produce a better and more sustainable urban form. It was in 1993 that theorist and urbanist Paul Virilio, foresaw a convergence of technological capability enabling us to "see, to hear, to perceive, and thus, to conceive more intensely the present world." He coined the term "telepresent" to convey the compression of intervals of time and space via advanced technologies—being simultaneously "here" and elsewhere. His view was that these new technological capabilities signaled a radical reconfiguration of "traditional human relationships with the environment." (Virilio, 1993)

To gain some insight to the extent to which technology is leveraged to make our modern lives possible, think about if suddenly space is compressed to near nothing in the equation Work = force * distance (W=f*d), but the output remains the same. So, while distance (space) is near nothing, the force through which work is delivered increases almost exponentially. Also, the virtual proximity of data and systems enabling these results means that data from once distant systems can now be 'mashed up' in a unified way, creating a virtual system of systems for providing better and more rapid results. These systems can be ad-hoc and temporary, meeting exigent operational needs, or more durable with an eye towards needing longstanding organizational and programmatic requirements. While these changes have brought great efficiency in the delivery of information used for decision-making, it also demonstrates how flawed data can create errors that rapidly propagate and cascade, producing calamitous and disastrous results in the physical world, e.g. the US Northeast blackout of 2003.

Most often, traditional paper or computer-aided drafting (CAD) based systems are used to design and store data about buildings. For high cost building acquisitions, recent trends have been towards modeling technologies that operate in a robust structured data environment such as building information models (BIM); however, the predominant mode is still a mix of 2D and 3D CAD. For run-of-the-mill design and acquisition projects, 2D CAD is still customary. In the case of cities, most building information is derived from entitlement process submittals, which are usually unstructured paper submittals. The result being that most building information is still unstructured and disconnected at best, and error prone at worst. Without smarter ways to design, construct and manage our buildings and cities, the risk of unintended and negative consequences remains a very real threat to a more sustainable future.

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Interestingly, it was simultaneous to Virilio's reflection on telepresent technology that architect Frank Gehry first developed Digital Project, an early BIM program—providing designers, engineers, and cross-disciplinary project teams powerful simulation tools for shaping the urban form (New York Times, 2009). BIM provides needed structure to the voluminous reams of data and drawings documenting the built environment, allowing greater control of project schedules and budgets. While BIM technology does provide structure, each model exists in its own universe with no real connection to other buildings managed within the same city or the world at large. This functionality gap prevents BIM from being truly practical for use across stakeholder groups, throughout their business processes and throughout the building lifecycle.

## CONNECTING BIM TO THE REST OF THE WORLD WITH GIS

By importing and aggregating BIM geometries and tabular data into a GIS, BIM can be leveraged, extended, and connected to other relevant site, neighborhood, municipal, and regional data. BIM, via GIS, can be exploited to provide key information to decision makers when they need it to answer questions regarding the best manner to develop and manage the urban form. This ability is largely a result of its capacity to identify spatially related objects using global coordinate systems, as well as the server and relational database technology underlying it. Spatial relationships allow GIS to merge different worlds of knowledge—it is significant because it exposes related patterns that would otherwise go undiscovered. Finding these patterns helps ensure the future viability of our buildings and cities as it allows decision makers to formulate plans and take corrective action—see

For example, it enables managers to abandon run-to-failure maintenance strategies and instead adopt strategies for preventive and reliability-centered maintenance, which can dramatically lengthen facility service lives, as well as reduce capital costs and operating costs. It's no surprise then that GIS is rapidly emerging in a new role within the industry as an enabling technology for better communication, analysis, and interoperability.

Leveraging BIM to ensure the future viability of the built environment requires a union with GIS. This means more than the ability to view BIM derived objects in GIS as part of a 'one-off' simulated fly-through. The ability to conduct typical GIS analysis on these objects is also required—tasks like spatial querying (e.g. how far? within? contains? etc...), as well as geoprocessing routines like buffer, intersect, hot spot analysis, routing, tracking, exploratory regression, line of sight, view-shed, shadow surface, etc...

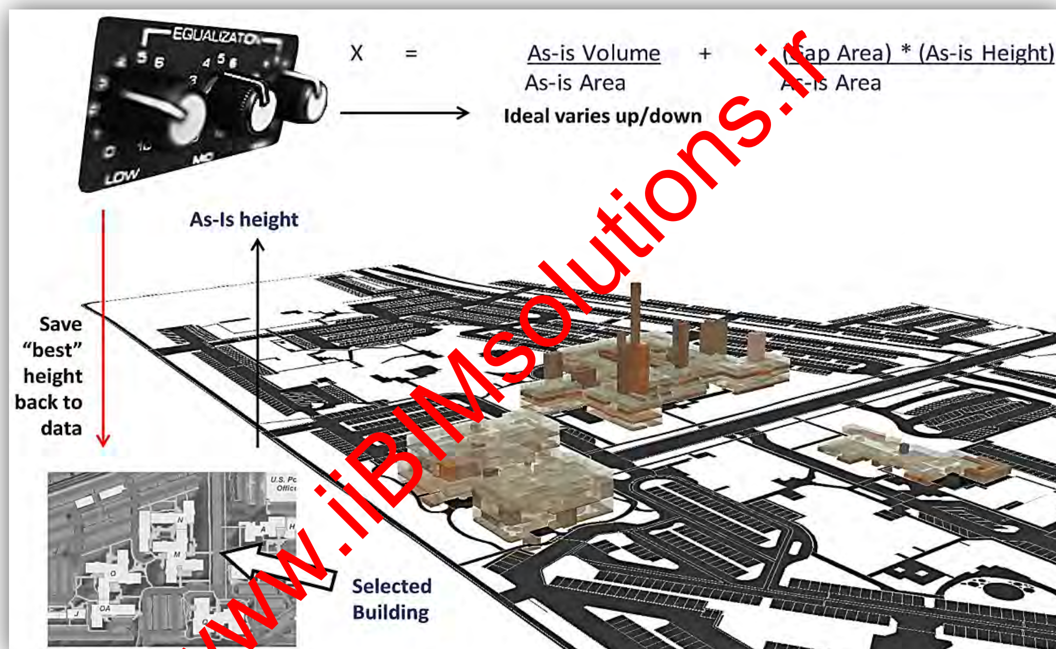

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Figure 1: Tracking Building Performance with GIS
(Produced by the author using Esri ArcScene software)

## RECOMMENDATIONS FOR A GEOSPATIALLY RE-STRUCTURED BIM

A number of recommendations need to be implemented to make BIM more practical and useful within the range of systems used to manage and sustain the built environment:

1) Presently, high or low level interoperability requirements cannot truly be expressed since there just is not enough representation on national standards committees, e.g. National BIM Standards, from key stakeholder groups like facility planners, portfolio managers, urban planners, etc...
2) BIM geometries, attributes and associated indexes need to be able to be aggregated and decomposed of at different Levels of Detail (LOD). For example, after building commissioning, most use cases do not require high LOD—most often LOD 300 or less will

suffice.

3) Current 2D exports to formats like .dwg do not maintain the rich attribute data found in BIM. Consequently, their use as foundational data within an enterprise system is limited. 'Smart' 3D, 2D and 2.5D views of IFC data need to be exported in a structured manner. If this capability was compatible with GIS, building and city managers would be able to quickly answer questions like: Is building A next to building Z? What is total volume of conditioned space in this region? etc....
4) IFC boundary representations need to be exported for each spatial container: site, space, building, floor, zone, space. It's hard to manage a building without the ability to spatially capture equipment and components by the appropriate container in technologies such as GIS.
5) Designers and engineers need to actually populate key IFC attributes. "Null" values in key fields are not helpful when downstream users need to integrate with BIM to manage their buildings.
6) IFC needs to allow updates to non-geometric attributes from non-BIM interfaces, e.g. spreadsheets and databases. There is an intense focus by standards bodies on information exchange from BIM, e.g. COBie, but there needs to be an equally strenuous effort importing updates back to .ifc files.
7) Common semantic structures that extend past BIM attributes, down to attribute domains, are required. Without this, BIM will not plug and play with configurable applications used by stakeholders to manage their buildings and the cost for useful applications will be too high. For example, standard pick lists for critical data such as storey, space, etc... are needed. There will remain differences between the first floor in NYC and Paris, but there's no reason this could not be accounted for in a locally editable alias field, i.e. 1 in NYC and 0 in Paris agree on the same "z" value.

In conclusion, the past generation of ineffective communications and data interoperability has been a big resource drain for building owners and managers, as well as for the cities where these buildings are located. Enabling smarter buildings and cities requires us to correct these deficiencies. Forecasting the future is generally a fuzzy science, but one clear step to reverse old and unfavorable trends is to realize that a more practical BIM, one with better GIS interoperability, can and should play a key role in managing and sustaining the built environment and the world.

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# PRACTICAL BIM EXECUTION PLANS:
# A Guide to Building a Practical Plan for Your Projects

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## ABSTRACT

This paper presents a concept of building a practical BIM Execution Plan for everyday BIM projects. The concept originated from approaching BIM projects as an MEP engineering firm and finding that the existing available BIM Execution Plans are overly large in scope and cumbersome to use on typical, day to day projects that my firm encounters. These existing BIM Execution Plans that are available from government agencies, large companies, and public consortiums were developed for use with large, complex BIM projects and are found to be overkill for typical BIM projects that most companies are working on daily. The desire to build a BIM Execution Plan that would identify the key areas of communication and workflow for BIM projects led to building a more practical BIM Execution Plan for my firm, which can be used on the majority of projects.

## INTRODUCTION

Over the past decade or so, BIM has gone from being barely known and/or considered a trend, to now being accepted by most in the AEC industry as the default system for building, coordinating, and documenting a building project. In the past few years, some different entities have built and published documentation for running BIM projects called a BIM Execution Plan. Some of the more recognized BIM Execution Plans have come from Penn State University, Indiana University, State of Ohio, and the US Army Corp of Engineers (USACE), amongst others. While these plans are well put together they are very inclusive and rather difficult to use on typical, day to day BIM projects that most AEC firms currently do.

The goal for most companies should be to cover the main points of these plans and to build a document that satisfies the types and sizes of projects they do. The practical use of a custom, in-house design BIM Execution Plan will be much more beneficial to a project versus trying to fit your projects into one of the available plans.

Having recently gone through the process of defining and building a BIM Execution Plan for my firm, I have outlined what I have found to be the core areas to establish for a practical and successful BIM Execution Plan.

## CONTEXT

The four (4) core areas I found for a practical BIM Execution Plan are Project Info, Model Exchange, Model Workflow, and Model Expectations (Level of Development).

### Project Info

This section contains project information for all companies and its team members that are involved with managing and/or exchanging their models. It is important to distribute this info to all those involved with the BIM project so they can contact the appropriate people in reference to their models. Additional information included is the BIM software and version that all companies involved in modeling should use for compatibility purposes; also information like project name, number, client info, etc; and any other pertinent project information that all team members should be aware of.

#### A. Project Information

| | |
|---|---|
| Project Name: | |
| Project Number: | |
| Revit Model Location: | |
| Revit Version Number*: | |

* All companies should discuss upgrading the model to a newer version of Revit prior to any company upgrading theirs as it will impact all models in the project.

#### B. Company Contacts for BIM / Revit Management

| Model Manager Name | Title / Role | Company | Email |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

Figure 1: Sample Project Information tables

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### Model Exchange

This section outlines who, when, where, and how models will be exchanged. Answering these questions early on in the BIM project will help to save time trying to track the information down later in the busy project schedule. Who will be uploading and downloading the models? This question helps to identify the person you would need to contact for model availability. When will the models be exchanged? Definitely try to set a schedule if possible so that you can be sure to hit those deadlines. Where will the models be hosted? Will one company host the models or each company individually? This is something that will need to be coordinated and documented along with any login and password information. How will the models be upon delivery? Highly suggested that models be purged and optionally views and sheets removed for a smaller file size.

### A. Model Hosting Location

| | |
|---|---|
| Company hosting models: | |
| Login info (if needed): | |

### B. Model Upload Schedule

| Discipline | Schedule | First Model Phase / Date |
|---|---|---|
| Arch | | |
| Struct | | |
| MEP | | |
| Equipment | | |

### C. Model Conditions upon Upload

- All models should be detached from their central models
- Model views to remain in model (checked):
  - ☐ Sheets
  - ☐ Schedules
  - ☐ Legends
  - ☐ Drafting Views
  - ☐ Sections
  - ☐ Elevations
  - ☐ Ceiling Plans
  - ☐ Floor Plans
- All models should be purged before uploading

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Figure 2: Sample tables and checklist for model exchange

Model Workflow

While there are several different BIM tools, each has areas that when setup correctly helps the workflow between companies as you share models. Spending time discussing and documenting the following areas will ensure that all members of the team produce good, coordinated models. My company currently uses Revit, but these areas can generally apply to any BIM software.

Areas for consideration include file naming, coordinate system, linking models, view setup, matchlines, grids, and levels; as well as phases, sheet setup, and project parameters. Other things to consider are line weights, symbols, and Revit specific areas like worksets, design options, etc.

Model Expectations

Model expectations should be discussed and documented very early in the project. Model expectations should include Level of Development (LoD) information. Having these model expectations outlined allows everyone on the project team to know to what level each model will be developed. Object ownership is also an important discussion to have as it will affect who should build and maintain certain objects like lights and plumbing fixtures. Discipline specific information should be discussed for LoD planning and expectation between the discipline models.

## SUMMARY AND CONCLUSION

There is no "one size fits all" when it comes to building a solid, practical BIM Execution Plan for your company and BIM projects. But with some time and effort a good, practical plan can be built that will help your BIM projects to be better organized, more consistent and hopefully prevent issues by documenting the four core areas; Project Info, Model Exchange, Model Workflow, and Model Expectations.

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Dept. of Veterans Affairs - http://www.cfm.va.gov/til/bim/BIMGuide/

US Army Corps of Engineers –
http://mrsi.usace.army.mil/rfp/Shared%20Documents/USACE_BIM_PXP_TEMPLATE_V1.0.pdf

The American Institute of Architects (BIM Protocol E202) –
http://www.aia.org/contractdocs/training/bim/AIAS078742


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# RESTRUCTURING THE ARCHITECTURAL PRACTICE:
# AEC Success in BIM, IPD and Beyond

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## Restructuring for BIM Success

*To find success with BIM, firms need to look beyond the CAD processes that staff are comfortable with using. Assessment, planning, and communication are key.*

The transition into BIM is a foregone conclusion for A/E/C firms large and small. But once they make the decision to implement BIM, firms are left with new software and old processes; therefore, creating BIM processes is fundamental for successful transition.

CAD processes don't require that architectural practices be good, but BIM does because without structured teamwork, communication, and defined processes, firms cannot realize the full benefits of BIM.

Firms that have found success using BIM have done so in large part due to creating and following clearly defined, rigorous, and robust processes. BIM project success requires much more than simply excelling at software. Getting the right work done at the right time with BIM requires a highly organized practice.

In an architectural team, each person has specific tasks and responsibilities. When everyone is performing their tasks, it's smooth sailing toward project completion, but if one team member fails to deliver – say a designer doesn't meet an important deadline – then the team can expect cascading, negative and costly impacts.

A winning environment is created when thorough process plans are in place for each aspect of the team and timelines and responsibilities are clearly defined and followed. There are always outside forces acting against our plans, so flexibility is necessary too, but with effective communication, active management, and coordinated efforts, the promise of BIM can be achieved.

Many of the workflows that have typically been employed for CAD are now considered inefficient. One that masks its own inefficiency is the throw-extra-staff-at-it workflow. That's not a production failure; it's a management failure. And if that approach is used on BIM projects, the inefficiency becomes a glaring indicator that effective management processes weren't followed. Throwing extra staff at BIM production without the new team members understanding the project can be dicey; the result can be an enormous amount of time spent fixing avoidable mistakes. If there are struggles or failures on BIM projects, they need to be captured and used to benefit future projects, not simply hidden away and ignored.

There are potential pitfalls in BIM processes, as well. Modeling can be a hypnotic endeavor. Teams can find themselves meandering back and forth in the model, losing sight of the bigger picture such as schedules, time, and money. Rigorous processes can keep that problem in check.

### Transitioning to BIM

How does a firm become successful at transforming its processes for BIM implementation? It must begin by being clear about what currently works and what doesn't in the organization. Its leadership must be willing to embrace new ways of production, coordination and presentation. The creation of project guidelines and systems that will help teams manage project objectives and overall firm goals is also necessary.

What to focus on is important, but doing so at the proper time is equally important. Change can come in many ways, such as allowing existing processes to evolve. For example, chasing CAD symbologies is not always recommended; rather, allowing an evolution of symbololgy in BIM is more desirable, especially since tags, keynotes, and such can be associated to actual building elements. This gives the project better data with less need for QA/QC compared to CAD.

It can be posed that he shape of a tag never made a firm any money but blindly chasing them around, especially at the wrong time sure has lost them money.

BIM output is another evolution that while it can be distinct from the look of CAD in many ways, it can also be extraordinarily better, providing more informational and coordinational value. BIM can tell a better story than CAD.

People will often say things like "You can't do that in BIM." While it is natural for humans to resist change, it's a mind-set that needs to be eradicated. Such roadblocks are simply excuses for people to remain on an inefficient yet comfortable path. The truth is that anything done in CAD can be done in BIM. Anyone who claims otherwise is simply unaware of how to do it or they are trying to stall the inevitable. Firms may need to learn new approaches for BIM, but that is what will enable growth of our industries and allow better projects to be built. BIM authoring tools work just fine. It's mainly inexperience that creates problems and confusion.

The addiction to CAD is perhaps the single most difficult obstacle that BIM adopters will encounter when transitioning. If a full BIM transformation is to take place, then CAD addiction needs to be acknowledged and mitigated. The same kind of transition was necessary when firms and individuals hesitated to adapt CAD at the expense of hand drafting. But where are all the hand drafters today? They are either using CAD or they're in other lines of work.

CAD may be around in many industries for a long time to come, but in A/E/C, CAD will be replaced by BIM. For many firms, it already has.

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## Restructuring for BIM

We cannot effectively create a better future if we don't understand the past and present. Assessment will give insight into what is necessary to change or refine during the transition and restructuring process. Assess the staff, existing systems and infrastructure, as well as project procedures. These assessments will be used as a baseline of the state of the firm, its capacity to absorb change, fiscal impacts, and staff mind-set.

To assess personnel, create a 10-question interview that will be given to all staff and managers. Ask then what works in the current process, what doesn't, who they think are the best teammates, how they like the infrastructure, who they feel may hold the process back, etc. Make the interview setting safe and confidential. The goal is to get honest input on the state of affairs, not to interrogate. These assessments will help you identify potential champions as well as gatekeepers by connecting actions to issues.

Since the goal is to restructure A/E/C processes for BIM, the next step is to assess and define objectives. This is the point to review current processes and map them out visually so the current approaches can be used to influence BIM approaches.

Providing an interactive, live assessment can be done in several ways: digital tools such as traditional process maps or mind-mapping software can be used, although I suggest starting off by using index cards posted on a wall. Digital process maps can be created later on, but the storyboard approach adds benefits such as immediate collaboration that allows people to add all variety of documents, notes, and drawings. Include the entire staff in divining the process maps so expertise at all levels is included and every possible measure is addressed.

Set up the storyboards and refine the map until it addresses the entirety of the firm's current processes. After each process is fully vetted, input it into a digital process map for use in later phases of restructuring and documenting.

Process maps will include all the steps taken to complete an A/E/C project in your firm, practice area, or team structure. Provide time to review these, and color-code them for prioritization, distinguishing what works and where the pain points are.

The BIM process map can be started by using copies of some of the items from the current process map: Colored strings can define critical paths, connections, etc., and those paths can be translated to the digital copies.

The BIM process plans will require different input than the CAD processes did. People who have extensive knowledge of both BIM production and project execution will be included, for example. The team that creates the new processes should incorporate all levels of project execution, including technical and managerial. If there is no one on staff with BIM leadership experience on the kinds of projects your firm produces, then get some. Not knowing what you do not know can create failure, so bring in staff or consultants if necessary to help you understand BIM processes.

## Transformation

A key to transformation is determining the goals then creating plans intended to accomplish those goals and completing the necessary actions in the plans.

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Restructuring a practice to incorporate new processes requires many levels of buy-in and transformation. People will have varying degrees of willingness to change, and that needs to be figured in to the restructuring plans. If staff openly agrees that they want to be part of the firm's success and the leadership publicly states that they want to better the firm by refining its processes for BIM, then it becomes natural for the staff to do what it takes to accomplish that goal – namely, following the plans that are being created. If there is no implicit, open, and public agreement between leadership and staff, then the restructuring itself may not be efficient and may speak to how future projects will run.

The public nature of these agreements can provide an environment of empowerment and self-oversight. Conversely, if people say they accept the plan yet don't follow through on their agreement, then there is a need and an opportunity to deal with whatever issues are lingering.

If it comes to pass that there are any parts to the plan that have not been as scheduled, then these objectives need to be completed or, if found to be unnecessary, dropped from the plan. Either way, there is a mechanism for responsible and managed follow through.

A structured plan is necessary for success in anything, and BIM is no exception. An implementation plan is used to provide on-demand insight into where the project is at any moment and can be developed into a recipe for project performance. This plan should encompass the gamut of necessities from an overall strategic plan down to task lists. The plan should include infrastructure, staffing, training, implementation timelines, and fiscal plans – all of the what's, when's and who's.

Successful BIM projects have team members with intimate knowledge of the design, production, and documentation processes used. By documenting the project execution tasks, the management can predict staffing needs and budget impacts proactively with more predictable results. Unplanned up-staffing can throw unnecessary trouble into the mix and should be avoided.

With the completed assessments directing an understanding of what to plan, a host of documentation can be created to explain what needs to be done, when, and by whom, as well as to provide management with tools to keep items from falling through the cracks. Good planning documents will enable prioritized workflows, tighter timelines, and overall project health since knowing what still needs to be done at any one time is critical.

BIM and IPD projects benefit from process maps and demand that granular plans be generated throughout the project lifecycle from preliminary submissions onward. The better we get at planning, the better our potential for success will be.

The AIA E202 Building Information Modeling Protocol Exhibit is one of the great starting points for helpful, if not necessary, documents that BIM teams use. Similar types of matrixes can be used to create overall project checklists as well as team-specific plans. Creating a team toolset that uses task lists interlinked with project schedules offers even greater opportunities to manage projects and teams and to keep everything running smoothly.

Once the plan is in place, it is time to do. Implement the plan, making everything necessary for staff to understand what the goals are, then validate the plan for future repetition, and you're on your way to restructuring from old processes to new. Built on good planning, teamwork, management, communication, and follow-through, a BIM process can realize successes for the entire A/E/C team.

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## BIM Planning Resources

| | |
|---|---|
| NIBS Resources | http://www.nibs.org/index.php/resources/ |
| AIA E202 BIM Exhibit: | http://www.aia.org/contractdocs/training/bim/AIAS078742 |
| BIM Execution, Planning: | http://bim.psu.edu/ |

http://bim.psu.edu/Intro/Resources/default.aspx http://www.indiana.edu/~uao/iubim.html

| | |
|---|---|
| COBIE Tools: | http://www.wbdg.org/tools/cobiex.php |
| IDM Process Mapping: | www.iai.no/idm<br>http://www.iai.no/idm/idm_learning/idm_learning.htm |
| IPD Guide: | http://www.aia.org/contractdocs/AIAS077630 |

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# SHARING BUILDING INFORMATION MODELS:
## Best practices for collaborating between all team members

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Critical Issues and Best Business Practices in order to have a successful BIM Project
PART 1 Managing Expectations

1. Establishing and understanding expectations from each team member

A successful Revit project goes beyond knowing the technical side of the BIM software. There are important topics that need to be considered at the beginning of each project long before the first element is even modeled in the BIM software. Some of these important topics and questions are listed below.

BIM models contain extensive amounts of rich and intelligent data and the use and application of these BIM models are virtually endless. Therefore, it is extremely important to establish boundaries for the BIM models with the architect, owner and contractor. This means that you will need to come to some understanding and agreement on the expectations of the team members for what the BIM model contains and what it is to be used for.

2. Critical questions to ask at the beginning of each project

What is the intended use of the BIM Model?

Coming to an agreement on the use of the BIM model with the architect, owner and contractor will establish how much modeling effort there will need to be. Is the BIM model to be used just for architectural and structural coordination or are there other disciplines involved in the 3D coordination effort? Will the BIM model be part of the deliverable as a contract document in which the contractor uses it to build off of?

What is required to be submitted at each phase of the project?

Is the BIM model expected to be delivered with the 2D drawings at schematic design? What about

at development design and construction document phases?
Who is modeling what between the architect and the structural engineer?
The architect, structural engineer, and other design team members will need to come to an understanding on who is modeling what elements in each of their respective models. This will also help establish who is ultimately responsible for the size and location of the elements in the 3D models.

Is the management, organization and exchanging of the architectural and structural BIM models planned in advance?

A well planned program between the architect, structural engineer and other design professionals that establishes how each model is organized and how each BIM model is to be exchanged will help the coordination process and eventually create smooth a well-coordinated set of 2D documents.

Part 2 Coordination

1. What software are your clients/consultants using?

The ideal model setup for coordination is for each consultant to use the same software (Revit). At the outset of a project it would be best to identify what software each design team member intends to use so that any problems with interoperability can be foreseen. During the course of a project upgrades or changes to the version of a software package can occur and it is best practice to allow for this when dealing with consultants that may not want to upgrade to newer software.

If a design team member is still using something as basic as 2d cad, it is still perfectly feasible to make use of this kind of information in a Revit model, either as background line work or else as lines upon which to trace particular items using some of the native tools for items such as grids, levels, wall, and beams.

When discussing the software choices of all the design team members it is best to bear in mind that some software programs do not offer the same level of interoperability as others. Examples of this are some of the specialist structural analysis programs that do not export information to cad or to Revit very easily. With this in mind it may be necessary to develop custom routines or scripts to make particular software's talk to each other.

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2. What design information do you need to communicate?
At the outset of a project it is highly recommended to start communicating what major elements will need interference checking. Some parts of a building or structure can have more complexities than others and therefore can take better advantage of the more sophisticated tools that Revit has to offer. Some of the best practices for this type of coordination are:

- Coordination setup of model extents or zones with design team
- Use grids, reference planes, levels or wireframes to communicate complex geometry
- Use naming conventions across all disciplines drawing sheets.
- Establish a standard level of detail.

- Use clash checking for coordination.

3. What is the easiest way to achieve coordination?

The easiest way to achieve efficient coordination is to get all of the design team to agree on a logical structure for the BIM model. Creating project standards for items such as the software in use, file naming, sheet naming etc. can all go a long way in creating a more efficient environment for the coordination efforts on a large job.

Establishing ownership of items such as gridlines or levels for example can really help as the responsibility is maintained by one member. To extend this level of accuracy, using Revit's tools for copy/monitor or clash detection, the other design team members can maintain the same geometry without any errors.

4. How can this all be recorded when using Revit?

Recording all of this information is made very simple based on the fact that Revit is a single file model, there is not the complication of having hundreds or possibly thousands of dwg files which would be typical of traditional Cad programs. Saving a copy of the model at benchmark issues is definitely a best practice and is very easy to perform as only one file needs to be saved.

When working on very large Revit models that may be setup with Worksharing or Worksets, it is a very good practice to include comments when performing a "Save to Central" so that at particular times the model can be saved to another copy or rolled back if necessary.


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Another method to record the evolution of the BIM model is to using reporting tools within Revit to save html reports of the interferences in the model. These can be useful to send to consultants to communicate where potential clashes are occurring. The consultant can then use tools such as "Select by ID" to find the pertinent members in the model.

5. Coordinating designs with non-Revit consultants?

For very large BIM models the combination of all discipline's models may require neutral model management software such as Navisworks. The use of such software can make it easier to clash check and visualize very large or complex models, especially if some of the design team members are not using the Revit platform.

One of the many useful tools that Revit has for coordination in conditions where a multi-platform BIM is in effect is the use of the 3d Dwf file which is a very lightweight file that can be emailed if necessary.
Revit is able to batch export 2d or 3d cad files from the model, this can make it very easy to work with non-Revit consultants that require dwg or dgn files for coordination. The export of such files is very streamlined and should be tailored to suit the standard layer and linetype setup for the company cad standards.

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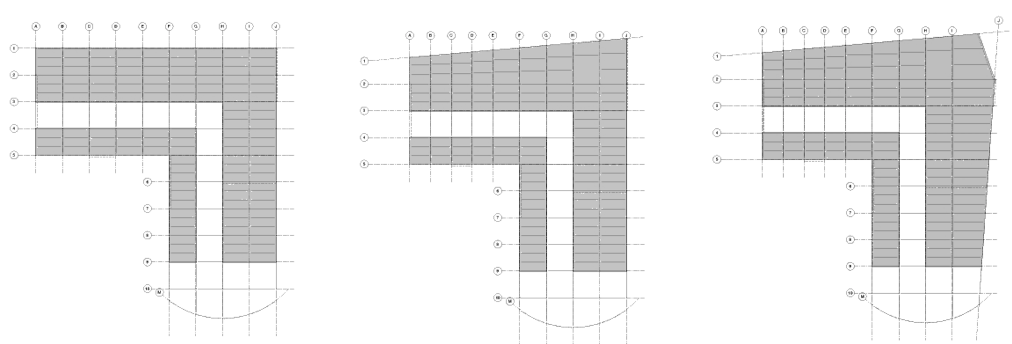
6. How do you deal with changes?

Dealing with changes in Revit is what the software is designed to do. Using the native tools such as Copy Monitor makes it extremely efficient to modify the design to match new geometry or design options. Setting up the Revit model to look for the latest linked models can make reloading the latest version of consultant's models very simple and efficient. This can be done very simply in the Revit software and basically involves using the "Manage Links" tool to point the linked model at the latest version of a consultant's model.

When working with a new model from a consultant it is definitely a best practice to utilize whatever new grids or levels that have been created or modified in their model. These items are the cornerstones of the BIM and should be maintained very accurately which is very easy to do if using Copy Monitor.



7. Who owns what, the new area of BIM contracts?

With this new BIM technology maturing new issues are appearing such as who owns the final BIM model? Deciding who will be ultimately responsible for the complete model at the conclusion of a project, or who will be maintaining as-built models for the project is very important, so as to avoid repeat work or unnecessary survey work.

Other decisions that are critical to efficiency are items such as whether the fabricator or detailer will be working from the model? Also the consequences of sharing the digital model with the contractor could have a very positive influence on the communication of the design and execution on site.

These issues should be covered in the contracts for BIM projects so that lines of demarcation are setup for each member of the design team.

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8. Tools & Methods to achieve well coordinated documents in Revit

   I Compatible Platforms

   1. For the maximum efficiency of tools, Revit Architecture and Revit Structure should be used simultaneously (same version)
   2. 2D drawings can be linked/imported so working with a design team member that uses 2D is not out of the question
   3. 2D drawings can in fact be used for tracing once linked/imported
   4. Linking rather than importing allows cleaner purge when the link/import is removed
   5. Do not "explode" CAD files unless absolutely necessary
   6. Trace standard details with Native Revit Linework to form a Revit details library.
   7. Depending on project size and intent, breakdown of imported/linked 3D model by category may be needed
   8. 3D dwg, Bentley and Sketchup files can be imported, but you lose capability of some tools. Being aware of the capabilities will be helpful in the long run.

      a. Symbolic representation will not work
      b. Automatic hatching & recognition of material will not work
      c. Sections and elevations will still work.

ii. Linking/Importing Files

1. Consider project size before linking/importing
2. Project director/manger should have input on what files are linked and imported because this will affect the project model in the long run
3. The modeler should be aware of the frequency of revisions (weekly, bi-weekly?) of the other models
4. Origin (0,0,0) should be maintained throughout all design team member's drawings. This is much more crucial than in 2D drawings.

iii. Geometry Constraints

1. Geometry constraints are a significant part of BIM models and so should not be ignored.
2. Consider the size and complexity of project before deciding on how far to take advantage
3. Manager input and more detailed knowledge of design and construction is necessary to take full advantage of geometry constraints.
4. Constraints must be consistent and accurate to be effective.

iv. View Browser Organization

1. All views and sheets are in one file, so organization is key.
2. The standard organization can work for smaller projects, but custom organization may be necessary for larger, more complex projects.
3. Customize for intuitive understanding for others that may work on the model.
4. Use "Project Parameters" and apply to Views for custom organization. (i.e. "For Reference Only" or a separation of "Perspective" and "Orthographic" for 3D views may be necessary)

v. Structural Analysis Coordination

1. For engineers, importing the model from 3rd party analysis programs can save redundant modeling time, leaving more time to design and coordinate project.
2. The question really is if a bi-directional link should be maintained between the analysis programs and Revit. The issues to consider with bi-directional linking include:
   a. Multiple analysis programs may be used on one project
   b. Accuracy between import and export
   c. Large file size and complex geometry transfer
   d. Accuracy standard difference between analysis model and Revit model
3. Depending on project, one way import may be more useful.
4. Level of accuracy is based on Engineer's attention to detail during analysis modeling
5. Consider the Engineer's modeling role
6. Custom interoperability between programs will be necessary at some point.
7. Some designs & building types do not lend themselves to this process.

vi. Copy Monitor – Coordination Review

1. Only 5 types of model elements can be shared – levels, floors, walls, columns & grids
2. Keep in mind that copy/monitoring elements depends on the project and that there is no absolute standard.
3. This tool can be a managerial tool as much as it is a "drafting" tool
4. Consider the fact that the party responsible for the geometry (i.e. slab outline - architect)

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may be different than the party responsible for its properties (slab thickness and reinforcement – engineer).

5. Coordination Review can be used only after copy/monitoring is set up and there will even be an automatic notification.
6. Create/save HTML Coordination Review Report once Coordination Review is completed then export to Excel format – since the Excel format allows better organization and manipulation of data.
7. Identify person responsible for the "actions" (manager or modeler).
8. Do not ignore the "add comments" option for record keeping purposes.

vii. Interference Check

1. Similar to the Coordination Review Report, copy the HTML Interference Check Report to Excel format for better organization.
2. There is no need to select all element types when doing coordination report.
3. Communicate between design team, what elements can and can't be checked for interference (i.e. gusset plates, connections, etc.)
4. Once in Excel format, separate instances to be ignored that are common modeling practices (i.e. standard practice with columns and slabs)
5. It is also good practice to separate instances of error in modeling and interferences that arise from design issues.

Viii. Export to AutoCAD or other programs

1. Exporting to AutoCAD is useful for design team member that does not use Revit and for visualization purposes
2. Creation of Xrefs, Layers, and titleblocks with viewports are automated, but keep in mind that customization and back-check might be necessary
3. 2D DWF may work better for simpler viewing and printing (no worry about Xrefs)
4. When exporting to 3D, check level of detail (i.e. Coarse, Medium & Fine – structural members in fine detail show even the fillet radius adding additional geometry that may not be necessary)

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1 http://www.En.wikipedia.org/wiki/Frame_rate: Frame rates in video games.

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# THE BIM BANDWAGON:
## The Time To Jump Is Now

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### ABSTRACT

The following paper summarizes one firm's trials and tribulations adapting to Building Information Modeling (BIM) requirements and the urgency placed on employees to adapt to this new method of production, construction, and thought. One case study is reviewed in which the client requested a BIM Execution Plan (BEP), Construction Operations Building Information Exchange (COBie) outputs, specific levels of detail (LOD), and numerous parametric functions associated with built components. Despite the requirements being unprecedented to the firm, and despite initial internal pushback, the firm has been successful in not only fulfilling its contractual obligations, but also in educating its own staff.


### INTRODUCTION

Building Information Modeling is an axiom of the future of architecture. Within a few short years, the building industry has been turned on its side. Gone are the days of two-dimensional plans drafted in AutoCAD with two poly-lines representing the thickness of a wall. Welcome to the future, where walls are assemblies of studs, insulation and gypsum that span from the floor to the underside of deck above.

The National BIM Standard-United States (NBIMS) states that "A BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward." [ii] This definition has made it to the mass of people not only within the design and construction industry, but outside of it as well. Clients are demanding three-dimensional representations of their projects and are no longer settling for lone sets of drawings. Additionally, they have become much savvier and are well aware that a 3D representation is not the end result, but rather, a smart, fully-integrated simulated representation with flexibility for future use and modifications by facility maintenance personal is rapidly approaching the deliverable norm.

Now, more than ever, with the BIM bandwagon on the move, all architectural disciplines, owners and contractors must jump on board, lest they be at risk of being left behind in its dust.

## BIM EXECUTION PLAN

In every awarded project, BIM requirements seem to be ever affected by scope creep. In 2007, Penn State's the Computer Integrated Construction (CIC) Research Program was awarded a grant to develop a BIM Execution Plan (BEP).iii Though our office has yet to see widespread use of this document, larger entities have come to the table demanding that this become part of the contractual language. For a large civic facility, the document, which required input from the client, architect, general contractor and subs, is comprehensive. It not only delineates dedicated BIM staff, required software, and both informal and formal deliverables; but it also outlines schedules and milestones, file naming conventions and schema, data security, methodology for ensuring field installation accuracy and validation of as-built models, and the physical characteristics of the BIM work room, where all disciplines work on-site to run through real-time clash detection.

Though the final BEP agrees to a BIM scope well outside of those in our previous projects, we remain forthright in our quest to achieve great success under these stringent guidelines. In general, this civic endeavor is an unprecedented one for our office. It consists of an entire campus: roads, space planning, landscaping and underground utilities - all of which lay the foundation for over two dozen buildings, totaling approximately 1.1 million square feet of built space. Bound to a fast-track schedule, successful completion of such a large project began with years of comprehensive management meetings, outlining the proper workflow to achieve the desired end-result. BIM management was one subsector.

## PROCESS AND DELIVERABLES

Because the project falls prey to a design-build contract, our deliverables were not only to the intended occupant, but also to the general contractor (GC). While a complete construction document model was turned over to the GC, our tasks continued just as they would with any project entering construction administration. The future end result is to provide a single federated model, per building, over at the close of the project. This federated model is to include documentation of shop drawings and change orders, fabrication, assembly and detailing; field modification; reviews by owners representatives; and compacted file-sharing. This deliverable does not only apply to the building, but also to the site and all utilities. Not unlike any other project, everything is to have true geo-reference controls.

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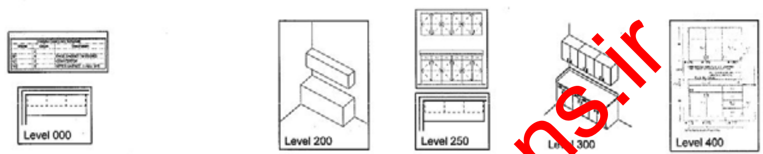
BIM work started with a civil survey. This file was turned over to us to create a site file that would house all buildings within Revit and serve as the author of all geo-coordinates. Because many of the buildings are prototypical and will have duplicates on site, it was paramount that this site file was managed by experienced personal, as shared coordinates between the site file and single building models were published numerous times, for each instance on the site. Each export and "DEAD" model that was shared was published with the shared coordinates so that the receiving discipline would receive true backgrounds to reference.

Though the final submittal is required to be a fully-integrated digital model, not all of the authoring design disciplines worked in three-dimensions. While civil, landscape, structural, equipment planning, interiors, and architecture all designed and coordinated within Revit and Civil 3D, mechanical, electrical, and plumbing continued to operate in AutoCAD MEP. Once the completed CD model was issued to the GC, they, in turn, hired sub-contractors to transform the flat drawings into digital models. These living models, in combination with the submitted ones, were imported into

Navisworks for collision detection. Due to the fast-pace of the project, a BIM room was constructed on the project site for live coordination sessions. Led by the GC, daily reviews take place on a large projection screen. Designers, foremen, and subs all participate in the meetings to review current construction issues and solve future conflicts.

## LEVEL OF DETAIL AND PARAMETERS

One of the greatest challenges the design team faced was adhering to the level of detail (LOD). During pre-production meetings, the general consensus was that LOD 100 and 200 were still programming and planning levels. This meant that the requirements and preliminary schematic design documents handed over to the designers already met these requirements. LOD 300, 400, and 500 were design, construction and as-built levels, respectively. Everything from the 300 level and beyond was to be a modeled object.




| | Level 000 | Level 100 | Level 200 | Level 250 | Level 300 | Level 400 | Level 500 |
|---|---|---|---|---|---|---|---|
| Description | 2D drafting including lines and schedules. Also includes BIM objects created as 2D objects. | 3D Overall building massing and/or other geometric data. | 3D Place Holder | Simple 3D Obje[illegible] with [illegible]dded 2D linew[illegible] 2 1/2 | [illegible]D Actual Object | 3D Actual Object with fabrication details | 3D As built objects |
| [redacted] Description in Spec 01 35 54 | | Programming Level. Buildings and/or structures will be modeled as masses indicative of area, height, volume, spatial location, and orientation. | Planning Level. Buildings and/or structures including major architectural, structural, mechanical, electrical, and plumbing objects will be modeled as generalize[illegible] systems or assemblies [illegible]ith approximate qua[illegible]es, approximate [illegible]nfiguration, spat[illegible]catio[illegible] orien[illegible] | | Design Level. Buildings and/or structures including all objects will be modeled as specific systems or assemblies with accurate quantities, recognizable configuration, spatial location, and orientation. | Construction Level. Buildings and/or structures including all objects will be modeled as specific systems or assemblies with accurate quantities, recognizable configuration, spatial location, and orientation, with complete fabrication, assembly, and detailing information. | As-Built Level. Buildings and/or structures including all objects will be modeled as constructed systems or assemblies with accurate quantities, shape, spatial location, and orientation, with complete fabrication, assembly, and detailing information. |
| Design and Coordination | Data may also be attached to the 2D BIM objects for scheduling purposes. | Massing and/or other geometric data representing areas, volumes, zones, information, etc… | Generic [illegible] shown in th[illegible] dimensions plus [illegible]ximum [illegible]e purpose ma[illegible]al- rating element ID | Generic 3D object representing maximum size: 2D line work adds detail representing elements; purpose; material; rating; element ID | Specific elements Confirmed 3D Object Geometry dimensions capacities connections- | Shop drawing/ fabrication. Purchase manufacture install specified | |
| AIA E202 | None | Overall buil[illegible]ng m[illegible]sing indicative of [illegible], he[illegible] volume, [illegible]ation and orientation [illegible] be modeled in [illegible]D or represe[illegible]d by other [illegible]a | Model Elements are modeled as generalized systems or assemblies with approximate quantities, size, shape, location, and orientation. Non geometric information may also be attached to Model Elements | | Model Elements are modeled as specific assemblies accurate in terms of quantity, size, shape, location, and orientation. Non geometric information may also be attached to Model Elements | Model Elements are modeled as specific assemblies accurate in terms of quantity, size, shape, location, and orientation with complete fabrication, assembly, and detailing information. Non geometric information may also be attached to Model Elements | |

Figure 1: LOD matrix[iv]

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With a limited company library, dedicated team members were put to work to create families that conformed to the LOD requirements set forth by the users. Standardized template families were built with shared parameters that would fulfill requirements across all disciplines. These included, but were not limited to: general construction constraints, dimensions and clearances; construction weight, mounting type and installation; materials and finishes; electrical power, phasing, and data; hot and cold plumbing supply, vent, and drainage; mechanical supply, return, and loads; structural and seismic information; and tracking identity data – spec number, team responsibility, item number and description, equipment number, assembly codes, manufacturer, warranty, and cost. While many of these fields still remain blank and are not relevant to all family types, they not only provide consistency across all linked BIM models, but are also fully equipped for future use and flexibility.

## THIRD PARTY SOFTWARE AND PLUG-INS

Many of the parameters were driven by Construction Operations Building Information Exchange (COBie)v. The client requested that this U.S. Army Corps of Engineers data management system be a required deliverable for facility operation and maintenance of the completed project. New to our company, managing the numerous excel spreadsheets proved to be a daunting task. Though the project team was used to exporting schedules into Excel from Revit-created spreadsheets and using BIMLink for more complex information exchanges, pushing all pertinent information for every modeled instance proved to be cumbersome with the known methods. By using the Revit extension DB Link, all smart building information is pushed from the model into a created database, similar to SQL. This database can then be sorted and refined to showcase only the desired data. This database is hosted to a Sharepoint site that can be viewed by not only the design disciplines, but also by the contractor and user. By the end of construction, when the as-built model exists, the file export will provide the client with a comprehensive list that will be used by facility management and operations. Unlike BIMLink that allows the user to push and pull information between Revit and Excel, DB Link is only one directional. The uni-directional approach allows for the mass exodus of data that provides a snapshot in modeling time and does not allow alterations by viewers to affect the actual model.

Though not used for any deliverable, BIMLink was an imperative coordination tool for us. Due to the nature of this civic project, user security was of the utmost concern. In addition to using general space planning and wall assembly construction to secure areas, doors become very complex, very quickly. With thousands of doors on site, all with differing frame, panel, and hardware sets, management of the door schedule demanded a smart workflow.

From the Revit model, we were able to push out a door schedule with all pertinent parameters (height, width, frame type and finish, panel type and finish, glazing material, fire information, and hardware sets) to Excel to then be updated by the security consultant. These parameters were both type and instance based. For those type-based instances that could not be readily altered by the security consultant, we had "dummy" instance parameters that could be updated. By writing some rudimentary scripts, any discrepancies between these parameters were flagged for review by the architect. Once the security consultant had updated the Excel spreadsheet, we were able to pull the updated information into the model and update all doors via their unique ID's. We created quality assurance and quality controls (QA/QC) views within the model, formatted in such a way that every time an update was recognized by the pulled information, the filter would graphically flag changes. This method of data exchange was not readily embraced by the non-BIM-using security consultant and required some education sessions. Once the time- and error-saving benefits were proven, the BIMLink method proved to be the only way we could accomplish our task at hand.

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Figure 2: In this axonometric, each door is highlighted in a color corresponding to a change that was documented in the door schedule. This allowed for easy filtering between affected doors and those already approved.

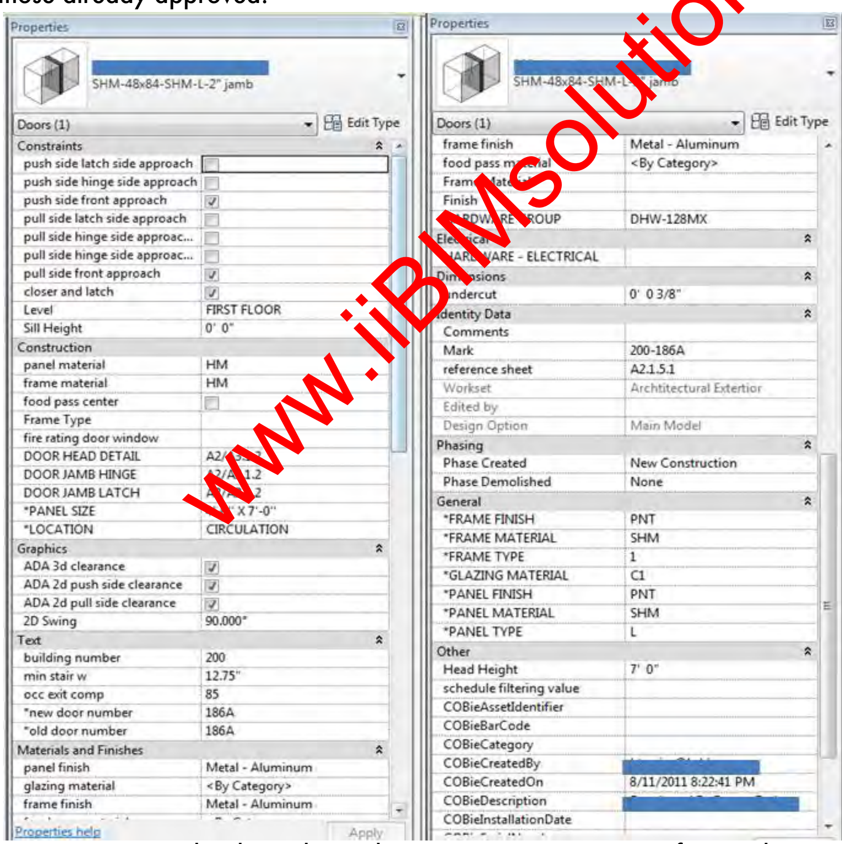


Figure 3: Each door housed numerous parameters for architectural code compliancy, constructability reference, and general identity. Those parameters prefaced with "*" were "dummy" instance parameters used as a coordination tool between us (the architect) and the security consultant working the Excel file.

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## SUMMARY

We are now in the midst of construction and are still learning which workflows are successful and which ones are proving to be less than optimal. We are continually updating our company's family library and are still striving to fully understand how to respond to Requests for Proposals and how to write and interpret a BEP and its affected specification section. Though we still have a long way to go in some areas, understanding the true meaning and intent of an LOD matrix, for example, we have jumped a hurdle. Our greatest achievement, as seen with the security consultant, however, is beginning to take shape. A production team that was once only trained in CAD, now has the ability to produce and design in three dimensions. Senior architects are beginning to understand that a Request for Information is no longer a hand sketch, but rather a coordination discussion in front of a projection screen. The realm of BIM is taking a definitive shape and is no longer a conceptual train of thought only followed by "those other firms." There is no doubt: our firm has successfully jumped on the BIM bandwagon.

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# WEB ENABLED CAD, A FRAMEWORK

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## ABSTRACT

Building Information Modeling is the technology that is reshaping the CAD paradigm, and with the launch of new online services that provide content directly to the BIM CAD solutions, a new era of empowerment to the architect and the AEC related product vendors has begun. The potentials offered now in the new environment of the web would be far beyond those offered before. However, the disparate file format array that is being used limits its potentials.

The research describes and evaluates the potentials of the amalgamation of current web technologies and also suggests restructuring the data distributed in many file formats based on a phase related need basis.

The proposed restructure will result in a streamlined electronic procurement of building components and should turn CAD files into pointers to the data rather than the carriers of the data which leads eventually to the reduction of paper drawings.

## INTRODUCTION

Collaboration on AEC projects over the Internet has been sought since the early days of the web; from emailing to simple file sharing, to the more sophisticated technologies, among others, such as the older/original DWF format, the discontinued "i-drop" technology from Autodesk, and the GDL technology from Graphisoft. AEC product vendors and users were always engaged in a rather rudimentary level of collaboration across the web.

The basic model was to create content by product vendors that can be implemented directly into CAD platforms of the architects.

Throughout the years, no significant change to this model has been introduced. Basically, content is created by CAD users or product vendors around the world, and distributed over the internet either through direct sharing or by submitting content files to dedicated service providers who organize and categorize them for downloading, either paid or free. Since the architectural profession depends on vendor and manufacturer catalogues for product details and specifications, this model of data exchange makes it convenient to both the architect who seeks the information and the vendor who likes to introduce his products.

## CURRENT WEB TECHNOLOGIES AND ITS IMPLEMENTATION IN CAD

The development of the Internet technologies since the dot-com bubble burst had made grounds for many new mature models to realize. And like other industries, the AEC industry has been following and making use of the following technologies: Web 2.0, Cloud Computing, and "Software as a service" (SaaS).

**Web 2.0**: without debating the name, or its real meaning (Ulanoff), Web 2.0 refers to a perceived second generation of web development and design; that facilitates communication; secure information sharing, interoperability, and collaboration on the World Wide Web. Web 2.0 concepts have led to the development and evolution of web-based communities, hosted services, and applications; such as social-networking sites, video-sharing sites, wikis and blogs. (“Web 2.0 - Wikipedia, the free encyclopaedia,” http://en.wikipedia.org/wiki/Web_2.0#cite_note-6)

Web 2.0 does not refer to an update to any technical specifications, but rather to cumulative changes in the ways software developers and end-users utilize the Web. It is the business revolution in the computer industry caused by the move to the Internet as a platform (Torkington 2006).

Web 2.0 technology encourages lightweight business models that are enabled by syndication of content and of service.

**Cloud Computing**: The concept is a direct result of the Web 2.0 technology where the word Cloud refers to the Internet. The services provided in such a technology has no centralized infrastructure and are accessible anywhere that has access to networking infrastructure. The Cloud appears as a single point of access for all the computing needs of consumers (Chappell 2008). It usually provides online common business applications that are accessed from a web browser, while the software and data are stored on the servers (Buyya, Venugopal, et al 2008) The technology is based on what is known as SaaS or Software as a Service

**Software as a service (SaaS)**: is a model of software deployment where a provider licenses an application to customers for use as a service on demand. SaaS software vendors may host the application on their own web servers or download the application to the consumer device, disabling it after use or after the on-demand contract expires (Bennett 2000).

## ONLINE CAD/BIM OR RELATED WEB SERVICES

Aside from general simple drafting, very few web based services currently provide true CAD or BIM capabilities online, partly due to the inherent complexity of the programs required and partly due to the issue of handling massive amount of information, graphical or not, online together with the issue of bandwidth. There are several dominant service models available right now:

1. **The product depository model**, that is providing content for CAD users. Content is usually developed by other users or product manufacturers. The service rigorously sorts and organizes the content to be searchable and downloadable to users. Many successful sites from big providers such as McGraw Hill fall in this category namely: Sweets network which is a long running service that extended its paper based catalogue of the United

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States vendors and manufacturers into the digital world by making the data available online in a searchable and well classified format. Specifications and details drawings of products can be directly downloaded to end users for incorporation in their CAD drawings or their specifications books.

GDL Technologies: out of necessity Graphisoft had to provide a service that would compensate for the relatively difficult to create content for their flag ship product ArchiCAD. The GDL technology itself contains all the information necessary to completely describe building elements to use in drawings, presentations and quantity calculations.

Autodesk Seek: is another free online source for architects to search and download manufacturer design information quite similar to the Sweets Catalogues.

Google 3D Warehouse: with the acquisition of @last software and making SketchUp part of Google arsenal to model the world, came the Google 3D warehouse as a searchable, online repository of 3D models. The main pitfall of this service is its focus on geometry. The service is organized to allow description information to show with the model in its web page, however, when downloaded and incorporated in user's model, the attached information is not transferred.

The way these services presented information did not fundamentally change over the years. A facelift to the interface is the only change beside the inclusion of more and more CAD formats. Instead of the older DWF, there is a DWG or DGN file of the same detail. And despite the inclusion of some BIM formats such as RVT or RFA, textual data is still distributed separately in DOC, XLS and CSV files.

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2. **The product depository facilitator model**; the best example of this model is some plug-ins that run inside CAD systems and enable searching the previous model. Natively, very few CAD systems support this feature. By delivering relevant building product content directly to the CAD/BIM environment, designers should be able to spend less time searching for products and more time to explore design scenarios.

3. **The online CAD environment model**; where the whole modeling is executed online with a client application running at the user end. Few products of this model have been realized, and most of them provide only viewing capabilities rather than full editing tools. Sharing objects can be achieved along with online collaborative modeling.

4. **Cloud computing CAD**; CAD packages hosted entirely online. Cloud computing is a model that has prevailed recently and has been utilized successfully with document creation and photo editing. CAD systems running entirely online encourages lightweight business models, however, it is difficult to compete with conventional solution mainly due to the complexity of the applications. Autodesk has recently tested few solutions for this model.

## THE UNFULFILLED PROMISE, HOW DID IT FAIL?

Can we consider what we have today a success? In comparison with other advancements that we see with other daily used software, what we have now cannot be considered successful. The industry is still fragmented around different formats, and the parametric models, once inserted, lack any update mechanism from their creators.

Although the current different models have been well utilized to a certain degree, they stopped short from realizing their real potentials. What we use today has several shortcomings:

1. **The disparate file formats problem**; what users can obtain now is a collection of unrelated files with different formats. There is no way to choose which or when to use except for the users experience with those formats. Translating from one format to the other remains a problem. A simple search for a "Door" would return the following formats: PDF, RVT, RFA, DWG, DWF, DOC, SKP, DGN, CSV, TXT, IES, ZIP. Each file is valuable, but many of them are specific to a particular platform. Also, the data is not reflected among the different types, mostly due to the format not supporting that particular type of data.

   For example, data found in a PDF file is not necessarily available as family properties in a RVT Revit file. This deficiency hinders the expected benefits of such a service from being fully realized.

2. **The lack for CAD/BIM ontology**; Ontology defines a common vocabulary for users who need to share information in a particular domain. It includes machine-interpretable definitions of basic concepts in the domain and relations among them. Ontology for a domain forms the heart of any system of knowledge representation for that domain. Without ontology, or the conceptualizations that underlines knowledge, there cannot be a vocabulary for representing knowledge. Industry Foundation Classes, IFC, are expected to bridge one aspect of the problem by providing ontological description of the objects used within BIM but not the processes, it falls short in describing the intent and the experience used in decision making.

3. **The incomplete IFC (buildingSMART data model) and IFD**; The BuildingSMART alliance is a global standards-setting organization representing widely diverse constituencies; all members are committed to promoting effective means of exchanging information among different software platforms and applications serving the AEC industry. The success of the alliance would be the publishing of specifications for Industry Foundation Classes or IFC. The promise of the IFC has been only partially realized today. Most of the major BIM software vendors support the standard, and their applications can read and write IFC with different degrees of success. However, it has been clearly declared that IFCs cannot be used in data roundtrips between different applications. Therefore, the best method to benefit from the technology is by having a third application to work as a viewer where all models from different applications can be open, read and coordinated inside it rather than inside their original creation package. The recent introduction of data dictionary; International Framework for Dictionaries or IFD is one step in helping achieve interoperability. IFD creates a catalogue, a "vocabulary", of what objects are called and brings together disparate sets of data into a common view. But despite the fact that this will enable an open BIM model to be linked to data from many source, it might not help aggregate the data for the different phases where it is needed.

4. **The offline disconnection of product data**; once a piece of information have been downloaded and incorporated into the CAD/BIM model, it becomes part of that model and does not have a link to its original creator. This deprives the user from any future updates that might be introduced to this piece of data. There is no implementation of mechanisms that links inserted model with their distributor. This deficiency deprives the user from any updates that might take place on the developer side.

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## A FRAMEWORK

The proposed development to CAD/BIM systems is a framework for future research. The ontology development is an area that requires better understanding, documentation and development.

### The vendor on one side, the user on the other, a link in between:

This relationship has always governed the AEC business model. Vendors do their best to update users with their product information in order to insure a constant demand. Users seek updated information in order to insure best technical practice and best price. As stated above, once a piece of information has been incorporated in the model, there is no way with the current implementation of the technology to automatically update it when an update is available. For example, if price information has been embedded with the BIM object of a door has changed over the course of a project, there is no way for that BIM object to automatically update. The user has to insure the update of his objects data manually.

If that object has been constantly connected to its provider, it would be possible to automatically update itself, or notify the user of an update. The propagation of this example would also mean acquiring different versions of the same model that better responds to the different phases of the project development.

### The Peer to Peer (P2P) technology analogy:

There are many technologies used today that depend on a provider on one side, a user on the other side and a server in between providing updates to both parties. In the example of the Bit-torrent technology, we find no single server that keep the provided material, but there are servers that are tracking the provided material location and keeping a log of where to find it.

On the user end, applications that request that material are consulting those servers as of where to find them.

### The model: Distributed object technology and tracking technology.

The proposed framework is to build a service that would provide tracking to linked objects. It should be able to notify every user that has used a particular object if it gets updated or changed which should lead to an always updated model at the user side.

Vendors should host their own content and submit them to servers' database where they would be only pointers to their permanent location. Users can search the servers, find related content, and download a pointer to the permanent location of the content; the CAD/BIM system will link to the permanent location and download the object itself.

The layer that identifies the location will keep checking for any update to the downloaded object. The content server will update its pointers when an update is detected. [Figure 1]

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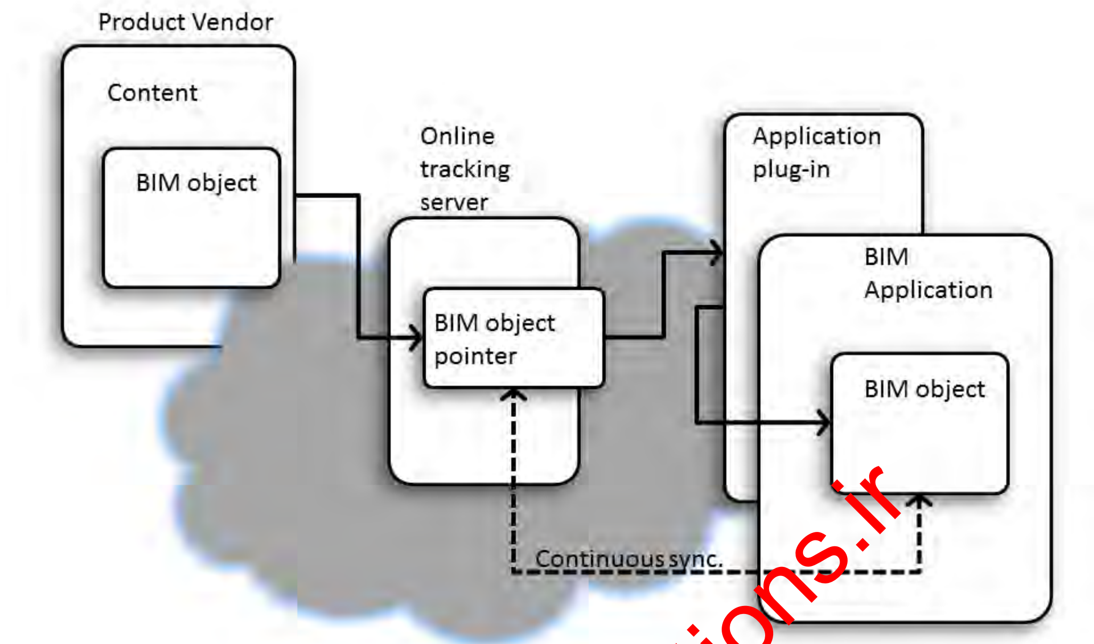


Figure 1: The proposed model

**Possible future applications:**

With a better semantic web, searching for relevant content can be greatly enhanced. Adhering to a strict ontology will enable similar products to be easily compared and evaluated by users before a decision is made to incorporate them.

Not only products but also processes can be shared among professionals. In architecture design there are so many situations pertaining to code and best practice that can be described and shared

## CONCLUSION

The way the web developed had changed the way we consume information on a daily basis, and has changed the way we interact with each other as well. That change should also encourage AEC industry to make a similar leap toward online collaboration beyond the classical means.

Despite of the advancement of the current CAD and BIM systems, the current content creation and dissemination process still lacks a coherent solution that would unleash its potentials. The web services that capitalized on managing and disseminating content are only working as a searchable storage areas, which is the least they can provide.

The potentials of harnessing today's web capabilities are enormous such as sharing experiences between users, finding relevant information from within applications, locating common solutions to common problems, working collaboratively to enhance a particular solution of a problem, finding historical data about items, getting detailed live information about items, just to name a few. All this has not been realized yet. The efforts done today are plausible; however, a substantial change should be considered to realize these possibilities.

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# GREEN BIM & LEED CERTIFICATION

*Karen M. Kensek, USC, School of Architecture*

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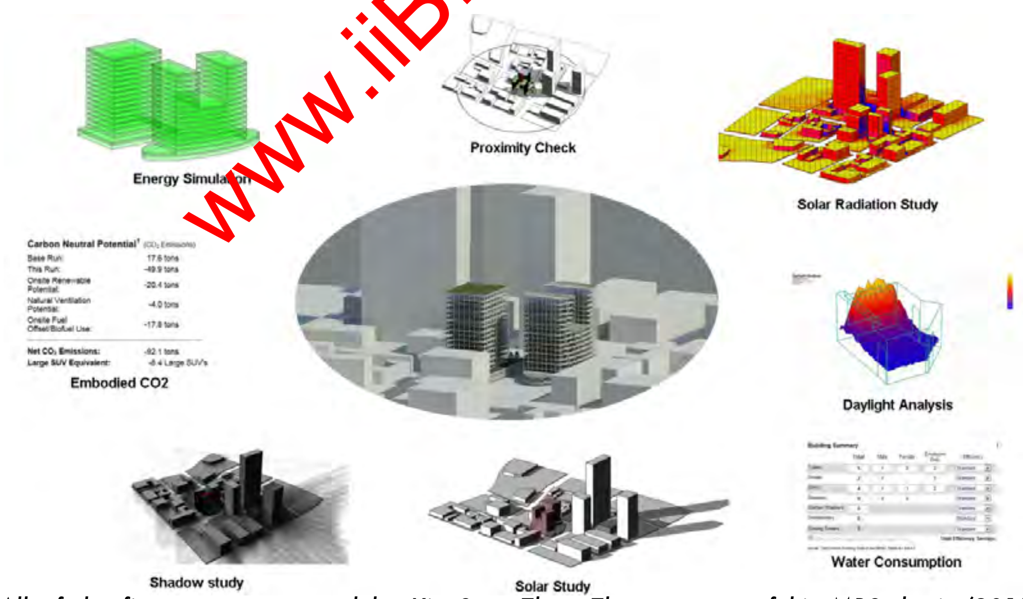
## Introduction

Many software programs exist that help inform the designer and predict the future performance of the building, and BIM can be used to provide data to these programs. A subset of these programs have to do with those used for sustainable design, for code compliance such as energy modeling, LEED compliance verification, and overall just to produce buildings that respond to the environment with less impact. This paper will explore several of these programs.




*All of the figures were created by Xin Stan Zhao Zhao as part of his MBS thesis (2011), An Investigation on using BIM for Sustainability Analysis Using the LEED Rating System. Committee: Karen Kensek (Chair), Greg Otto, Edwin Woll, Eve Lin.*

## Background

It would be inaccurate to say that these performance concerns are new, and that software writers are just now responding a demand by the architecture profession. Murray Milne wrote a white paper on building performance simulation models in January 2008, that provided a chronology of computer simulation and design tools that were intended to help architects "better understand the performance of their building designs in terms of heat, light, energy, and greenhouse gas production." It listed energy simulation programs from 1967, a set of thermal loads calculation programs contracted for by the Post Office Department, to some of his own software, including HEED, Home Energy Efficiency Design, in 2001. Many programs used today were developed from the early 70s to the 90s.

## Relationship to BIM

Typically simulation software was developed to be standalone. Data about the building was entered directly within the program; with the earlier programs this was done with a clunky text or command based interface. With the rise of CAD systems and then other 3d software, especially when designers rather than specialized consultants were using the software, it became apparent that modeling the building once and then importing it into the simulation program had many advantages in time savings, potential accuracy, and consistency across the models. However, it also become obvious that the data needed by simulation programs and that provided by 3d software were not the same. There were overlaps, especially with regards to the geometric description of the building, but different expectations made true interoperability difficult. BIM, with its emphasis on building components and complete 3d depiction, has helped resolve some of these problems, but has caused others.
A simple example of this relates to how space is represented. In many simulation programs when calculating heating and cooling loads, the representation of the 3d space bounded by the walls, roof, and ceiling or roof is critical. Many 3d CAD systems do not have a concept for this bounded volume although most BIM programs do, and some file formats (such as gbXML) will export that information. On the other hand, the simple concept of wall has evolved drastically over the years, but still is not sophisticated enough for thermal calculations. Walls have transformed from double lines in CAD to parametric, layered objects, but often still do not contain information such as R-value or solve the more complex problem of actually calculating this value. In fact, in some programs, one can only choose a wall assemblage from a list. Although this makes it easier for a novice, it is more difficult to achieve accurate results with non-standard wall types, and it can be confusing that the wall might be drawn one way yet is chosen for energy simulations to be something else.

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One huge advantage that BIM allows is that by having the 3d model started earlier in the design process, there is the opportunity for more analysis to be done earlier in the design process. Patrick MacLeamy of HOK diagrammed this in his famous MacLeamy Curve. It summarizes that the cost of design change increases in time. Hence it is better to put effort in the early design stage where the ability to impact cost and functional capabilities is higher and analysis opportunities can have the most significance. Although sustainable design decisions need to be made throughout the process, often it is the early choices that have the most impact, and by using BIM, one can take the 3d models more quickly into simulation programs for studying options.

## Not only energy simulation

A large amount of development has gone into writing software for energy simulation. Predicting energy consumption is especially critical because many building codes have requirements that must be met. Other simulation software, as discussed in the previous chapter, can also be used that fit under the category of sustainable design. Some of them do not need a 3d model at all: climate and weather data analysis, thermal comfort, understanding the local geography, renewable energy calculations from solar, wind, tidal, and geothermal sources. Other software programs could readily benefit from using the 3d model, especially if the architect has already created one: shadow studies, daylight harvesting, water resource management, energy and cooling load calculations. Others could use the "information" characteristic of BIM. For example, BIM could be used by the contractor for tracking recycled materials and carbon accounting. The BIM could also be linked to the manufacturer's material safety data sheets (MSDS) to show compliance with specific code, safety, or certification systems. LEED will be used an example of how BIM can be used to help achieve or document sustainable goals.

### LEED and BIM

The U.S. Green Building Council (USGBC) through its Leadership in Energy & Environmental Design (LEED) building certification system "encourages and accelerates global adoption of sustainable green building and development practices through a suite of rating systems that recognize projects that implement strategies for better environmental and health performance" (USGBC website 2010). BIM can help with LEED certification. It can serve as a depository of project information for the design team, consultants, contractors, and potentially operations and maintenance staff. Using BIM in this approach could allow designers to study green alternatives more quickly, make timely decisions, and communicate effectively both during design and construction. BIM could also assist in fulfilling requirements for LEED points and creating documentation for the LEED worksheets. It could assist project stakeholders in making decisions for new and existing buildings and determining the best value with regard to the applicable green building rating system score.

### Benefits and limitations

LEED is an internationally recognized green building rating system, which was developed and is continuously refined by the U.S. Green Building Council. Although LEED does not guarantee excellent sustainable design, it is one method towards this goal, and BIM can make the process of achieving certification easier and more transparent. LEED is not the only rating system, and BIM can also be used to help in the process of achieving other sustainable design certifications as well.

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### Review of LEED point structure

The most frequently used LEED rating systems are LEED NC (new construction), CS (core and shell), and K-12 schools. All the three rating systems have 7 categories: Sustainable Site, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation in Design, and Regional Priority. The total number of points in these three rating systems is 110. If a project earns more than 40 points, it will receive LEED certified, if 50 points or above, silver, 60 points or above gold, and above 80 points a platinum rating. This and the following examples use LEED NC 2009 as the basis for discussion.

To achieve each credit, the AEC team must fulfill the requirements of the credit, fill out the appropriate LEED templates online, and submit appropriate other documentation as specified. For example, to earn the 1 or 2 points for Material Resources credit 4, Recycled Content, the final building must use materials with recycled content of at least 10%, based on cost of the total value of the materials in the project. This will earn one point. If 20% of recycled content is used, 2 points can be earned. To achieve this credit, the design team must list all the required materials and their information in the table in the LEED template. Then the materials will be summed and calculated in another table in the LEED template, to see if the project meets the requirement in this credit. This is one example where a building information model could not only keep track of the materials that were used on a project including cost and recycled content, but also produce a schedule that matches the one online.

### Explanation of the Table of BIM Enabled LEED

The following table lists all the potential LEED points and possible methods where BIM could be used to enhance the process of achieving the credit. Cut sheets were also developed by Zhao in his thesis with more details about the requirements for fulfilling each credit and a proposed method to use BIM if it was appropriate.

LEED 2009 for New Construction and Major Renovation
Project Checklist

*The location of the Smith Slip Logos give an idea where Smith Slips could be checked on the Checklist*

Project Name
Date

| Y | N | ? | | Sustainable Sites | Possible Points: 26 |
|---|---|---|---|---|---|
| Y | | | Prereq 1 | Construction Activity Pollution Prevention | |
| | | | Credit 1 | Site Selection | 1 |
| | | | Credit 2 | Development Density and Community Connectivity | 5 |
| | | | Credit 3 | Brownfield Redevelopment | 1 |
| | | | Credit 4.1 | Alternative Transportation—Public Transportation Access | 6 |
| | | | Credit 4.2 | Alternative Transportation—Bicycle Storage and Changing Rooms | 1 |
| | | | Credit 4.3 | Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles | 3 |
| | | | Credit 4.4 | Alternative Transportation—Parking Capacity | 2 |
| | | | Credit 5.1 | Site Development—Protect or Restore Habitat | 1 |
| | | | Credit 5.2 | Site Development—Maximize Open Space | 1 |
| | | | Credit 6.1 | Stormwater Design—Quantity Control | 1 |
| | | | Credit 6.2 | Stormwater Design—Quality Control | 1 |
| | | | Credit 7.1 | Heat Island Effect—Non-roof | 1 |
| | | | Credit 7.2 | Heat Island Effect—Roof | 1 |
| | | | Credit 8 | Light Pollution Reduction | 1 |

| Y | N | ? | | Water Efficiency | Possible Points: 10 |
|---|---|---|---|---|---|
| Y | | | Prereq 1 | Water Use Reduction—20% Reduction | |
| | | | Credit 1 | Water Efficient Landscaping | 2 to 4 |
| | | | Credit 2 | Innovative Wastewater Technologies | 2 |
| | | | Credit 3 | Water Use Reduction | 2 to 4 |

| Y | N | ? | | Energy and Atmosphere | Possible Points: 35 |
|---|---|---|---|---|---|
| Y | | | Prereq 1 | Fundamental Commissioning of Building Energy Systems | |
| Y | | | Prereq 2 | Minimum Energy Performance | |
| Y | | | Prereq 3 | Fundamental Refrigerant Management | |
| | | | Credit 1 | Optimize Energy Performance | 1 to 19 |
| | | | Credit 2 | On-Site Renewable Energy | 1 to 7 |
| | | | Credit 3 | Enhanced Commissioning | 2 |
| | | | Credit 4 | Enhanced Refrigerant Management | 2 |
| | | | Credit 5 | Measurement and Verification | 3 |
| | | | Credit 6 | Green Power | 2 |

| Y | N | ? | | Materials and Resources | Possible Points: 14 |
|---|---|---|---|---|---|
| Y | | | Prereq 1 | Storage and Collection of Recyclables | |
| | | | Credit 1.1 | Building Reuse—Maintain Existing Walls, Floors, and Roof | 1 to 3 |
| | | | Credit 1.2 | Building Reuse—Maintain 50% of Interior Non-Structural Elements | 1 |
| | | | Credit 2 | Construction Waste Management | 1 to 2 |
| | | | Credit 3 | Materials Reuse | 1 to 2 |

| Y | N | ? | | Materials and Resources, Continued | |
|---|---|---|---|---|---|
| | | | Credit 4 | Recycled Content | 1 to 2 |
| | | | Credit 5 | Regional Materials | 1 to 2 |
| | | | Credit 6 | Rapidly Renewable Materials | 1 |
| | | | Credit 7 | Certified Wood | 1 |

| Y | N | ? | | Indoor Environmental Quality | Possible Points: 15 |
|---|---|---|---|---|---|
| Y | | | Prereq 1 | Minimum Indoor Air Quality Performance | |
| Y | | | Prereq 2 | Environmental Tobacco Smoke (ETS) Control | |
| | | | Credit 1 | Outdoor Air Delivery Monitoring | 1 |
| | | | Credit 2 | Increased Ventilation | 1 |
| | | | Credit 3.1 | Construction IAQ Management Plan—During Construction | 1 |
| | | | Credit 3.2 | Construction IAQ Management Plan—Before Occupancy | 1 |
| | | | Credit 4.1 | Low-Emitting Materials—Adhesives and Sealants | 1 |
| | | | Credit 4.2 | Low-Emitting Materials—Paints and Coatings | 1 |
| | | | Credit 4.3 | Low-Emitting Materials—Flooring Systems | 1 |
| | | | Credit 4.4 | Low-Emitting Materials—Composite Wood and Agrifiber Products | 1 |
| | | | Credit 5 | Indoor Chemical and Pollutant Source Control | 1 |
| | | | Credit 6.1 | Controllability of Systems—Lighting | 1 |
| | | | Credit 6.2 | Controllability of Systems—Thermal Comfort | 1 |
| | | | Credit 7.1 | Thermal Comfort—Design | 1 |
| | | | Credit 7.2 | Thermal Comfort—Verification | 1 |
| | | | Credit 8.1 | Daylight and Views—Daylight | 1 |
| | | | Credit 8.2 | Daylight and Views—Views | 1 |

| Y | N | ? | | Innovation and Design Process | Possible Points: 6 |
|---|---|---|---|---|---|
| | | | Credit 1.1 | Innovation in Design: Specific Title | 1 |
| | | | Credit 1.2 | Innovation in Design: Specific Title | 1 |
| | | | Credit 1.3 | Innovation in Design: Specific Title | 1 |
| | | | Credit 1.4 | Innovation in Design: Specific Title | 1 |
| | | | Credit 1.5 | Innovation in Design: Specific Title | 1 |
| | | | Credit 2 | LEED Accredited Professional | 1 |

| Y | N | ? | | Regional Priority Credits | Possible Points: 4 |
|---|---|---|---|---|---|
| | | | Credit 1.1 | Regional Priority: Specific Credit | 1 |
| | | | Credit 1.2 | Regional Priority: Specific Credit | 1 |
| | | | Credit 1.3 | Regional Priority: Specific Credit | 1 |
| | | | Credit 1.4 | Regional Priority: Specific Credit | 1 |

| Y | N | ? | | Total | Possible Points: 110 |
|---|---|---|---|---|---|

Silver 50 to 59 points Gold 60 to 79 points Platinum 80 to 110

Schedules and Parameters
3rd Part Software
Directly and Editing Families
To be determined

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OPTION 1:
Construct or renovate a building on a previously developed site AND in a community with a minimum density of 60,000 square feet per acre net.

**Directly calculate and construct building on previously developed site.**

OPTION 2:
Construct or renovate a building on a site which is located on a previously developed site and is within 1/2 mile of a residential area or neighborhood with an average density of 10 units per acre net.
And within 1/2 mile of at least 10 basic services, has pedestrian access between the builidng and the services.

**Method:**
**This credit requires designers to submitt a site plan showing building is within 1/2 mile of at least 10 basic services.**

**A 1/2 mile radius circle can be added into entrance door's family, then load into project,the circle will be shown in project. Mark and note the service buildings in site plan. Copy this site plan to this cut sheet.**

**File the table below**

| Number | Business Name | Service Type |
|---|---|---|
| 1 | Restaurant 1 | Restaurant |
| 2 | Grocery 1 | Convenience Grocery |
| 3 | Urgent Care 1 | Medical |
| 4 | Pharmacy 1 | Pharmacy |
| 5 | Gym 1 | Fitness |
| 6 | Hair Care 1 | Beauty |
| 7 | Bank 1 | Bank |
| 8 | Restaurant 2 | Restaurant |
| 9 | Cleaners 1 | Cleaners |
| 10 | Post Office 1 | Post Office |


1 Site Plan

**University of Souther California**
Master of Building Science Thesis
**LEED NC 2009**
**Templates for Revit**
Chair:Karen Kensek
2nd Committee: Ed Woll
3rd Committee:Eve Lin
Author:Stanley Zhao
**Development Density and Community Connectivity**
Total scores: 5
Applying Method: Method 3
**SS Credit 2**

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OPTION:

Employ strategies that in aggregate use 20% less water than the water use baseline calculated for the building (not including irrigation).
Calculate the baseline according to the commercial and/or residential baselines outlined below.1 Calculations are based on estimated occupant usage and must include only the following fixtures and fixture fittings (as applicable to the project scope): water closets, urinals, lavatory faucets, showers, kitchen sink faucets and prerinse spray valves.

**Method 1:**

designers export their model to Green Building Studio, it will automatically calculate the design base line of irrigation, flush fixture and total water consumption, based on basic project information from Revit, like building type, building footage, site area, location, etc. Then as figure show below, designers can input the basic fixture information and rainfall harvest information, and GBS will calculate the actual annual total water and portable water consumptions. Compared with design baseline, GBS will tell designers how much water they are saving.

**Building Summary**

| | Total | Male | Female | Employee Only | Efficiency |
|---|---|---|---|---|---|
| Toilets: | 5 | 1 | 2 | 2 | Standard |
| Urinals: | 2 | 1 | | 1 | Standard |
| Sinks: | 4 | 1 | 1 | 2 | Standard |
| Showers: | 0 | 0 | 0 | | Standard |
| Clothes Washers: | 0 | | | | Standard |
| Dishwashers: | 0 | | | | Standard |
| Cooling Towers: | 0 | | | | Standard |

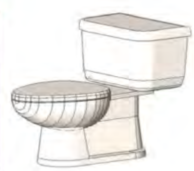
☑ Include cooling tower blowdown in sewer costs
**Total Efficiency Savings:**

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3

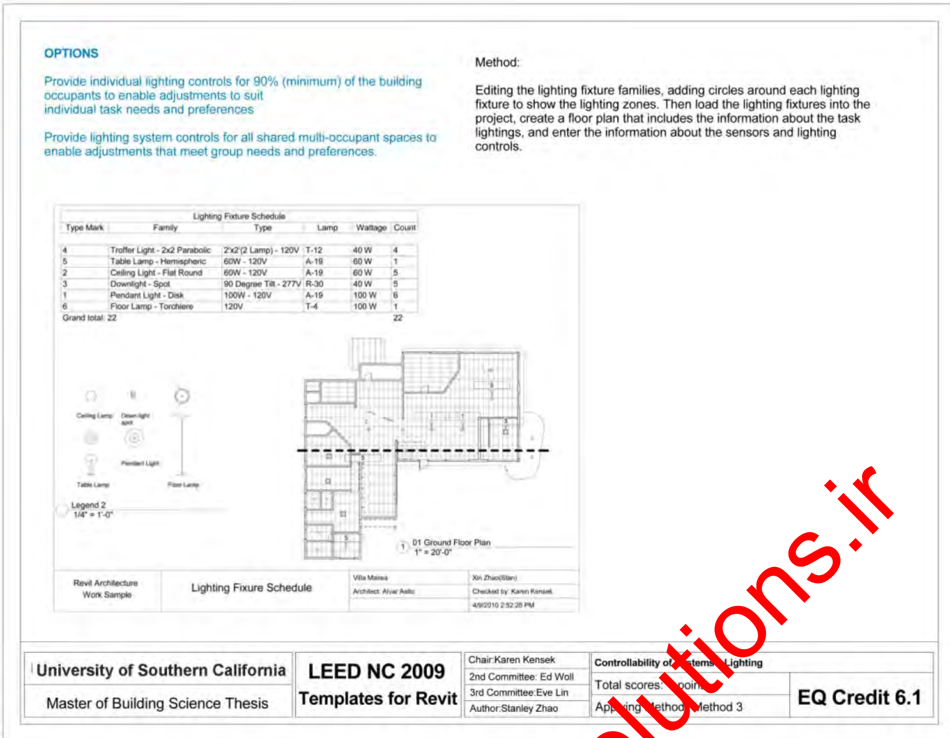
**Method 2:**

**Using the water fixtures directly from the family library. Fill the fixture information in the properties, create a water fixture schedule.**

**Recommend the Method 1.**



**University of Southern California**
Master of Building Science Thesis
**LEED NC 2009**
**Templates for Revit**
Chair:Karen Kensek
2nd Committee: Ed Woll
3rd Committee:Eve Lin
Author:Stanley Zhao
**Water Use Reduction**
Total scores: 0 points
Applying Method: Method 2,3
**WE Prereq. 1**




## Classification

Depending on the requirements of each LEED credit, different methods can be applied towards achieving it. The credits were classified into five categories of overall methods to help achieve compliance with BIM:

- interoperability with third party software
- scheduling parameters
- adding graphic information and custom parameters to objects
- to be determined
- BIM isn't helpful

Some of the credits require performance based simulation, for example, Energy & Atmosphere Credit 1, Optimize Energy Performance, and Indoor Environment Quantity Credit 8.1, Daylight and Views. These credits can be evaluated by transferring information from the BIM to third party analytical software. Many credits in LEED are similar to LEED NC Material Resources Credit 4, which are based on documentation and simple calculations. For these types of credits, one could create relevant parameters in he BIM, enter the appropriate data, and create schedules that use formula functions to show that compliance has been met. Some credits can be directly evaluated by design or constructions. They don't need computer simulations as proof of achieving the LEED requirement. Specialized components could be created to help in demonstrating that the design is compliant. Other credits can be achieved by providing supporting documents, like design drawings, photos during construction, and building site maps. These are not necessary helped by using a BIM. Of course, customized software could also be developed to assist the process.

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## Example using third party software

There are about 32 points that can be evaluated by third party software. Usually the design team would make separate models in each simulation program to evaluate these credits; the use of the BIM affords the opportunity to reuse data. For example, LEED NC Energy & Atmosphere Credit 1 requires a whole building energy simulation that demonstrates a percentage improvement in the proposed building performance rating compared with the baseline building performance rating. Often a consultant firm or engineer partner would be hired to do this, effectively modeling the building again in their preferred software. Yet if the design team had a BIM, it could be used as a source of the proposed building geometry for the simulation software. Sometimes, not only the geometry but also the information and building data contained could be transferred into gbXML, IFC, and other file transfer protocols, which can be shared and used between different BIM software and other programs. For example, one workflow is for the design team to transfer their BIM model into gbXML, open it in Green Building Studio, and export it to a DOE-2 file. The DOE-2 file can be opened in Excel where all the information and design data would be listed. One could edit the HVAC, internal heat load, and other information in Excel and save it. Then the file is re-opened in a DOE-2 software program, like eQuest, to calculate the final results. Although a bit cumbersome, this method is often easier than creating the model directly in eQuest.

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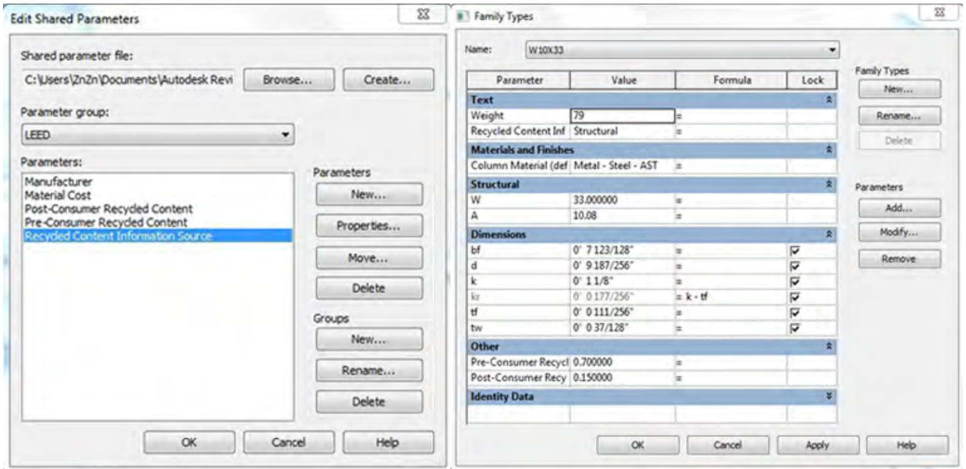
The third party software does the specific task that it is designed to do, in this case, energy calculations. All the other information needed by simulation is generated and stored inside the BIM, added in Excel, or input into eQuest. This workflow has the potential to save time and might have fewer inconsistancies with the original design geometry.

## Example using scheduling parameters

There are about 20 points in LEED that are based on simple documentation and calculation. To evaluate these credits, the project team may use Excel or other forms of tabulation to store building component data and then make calculations on the data according to formulas provided by LEED. Instead, they could add the data required by LEED into their BIM and then use schedules and the calculation functions of the BIM to document these components.

For example, the LEED NC Material Resources Credit 4 concerns itself with construction materials' recycled content and requires that the project use materials with recycled content at least 10% or 20%, based on cost, of the total value of the materials in the project. In LEED, the design team needs to document the following information to achieve this credit: Material Name, Manufacturer, Material Cost, Post Consumer Recycled Content, Pre-Consumer Recycled Content, and Recycled Content Information Source. It is possible to add fields for this data as shared parameters inside BIM and give values to these parameters according to manufacturers' specifications.




Then a schedule can be created with the appropriate categories and formulas. The figure shows a sample completed schedule in BIM and the schedule that LEED requires. When the design changes, for example, a concrete wall is added or a steel column is removed, the schedules and calculations will automatically update. One current downside is that the information has to be manually input into the LEED template.

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| LEED NC MR credit 4 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Family and Type | Material: Nam | Manufacture | Material Cost | PostConsume | Pre[illegible] | Recycled Content | Recycled Per |
| W-Wide Flange-C | Metal - Steel | Stanley | $2000 | 30% | 15% | $750 | 37.5% |
| W-Wide Flange-C | Metal - Steel | Stanley | $2000 | [illegible] | 15% | $750 | 37.5% |
| W-Wide Flange-C | Metal - Steel | Stanley | $2000 | [illegible] | 15% | $750 | 37.5% |
| W-Wide Flange-C | Metal - Steel | Stanley | $2000 | [illegible] | 15% | $750 | 37.5% |
| W-Wide Flange-C | Metal - Steel | Stanley | $2000 | 30% | 15% | $750 | 37.5% |
| W-Wide Flange-C | Metal - Steel | Stanley | [illegible] | 30% | 15% | $750 | 37.5% |
| W-Wide Flange-C | Metal - Steel | Stanley | [illegible] | 30% | 15% | $750 | 37.5% |
| W-Wide Flange-C | Metal - Steel | Stanley | [illegible] | 30% | 15% | $750 | 37.5% |
| W-Wide Flange: | Metal - Steel | USC | [illegible] | 25% | 20% | $1050 | 35.0% |
| W-Wide Flange: | Metal - Steel | USC | $3000 | 25% | 20% | $1050 | 35.0% |
| W-Wide Flange: | Metal - Steel | USC | $3000 | 25% | 20% | $1050 | 35.0% |
| W-Wide Flange: | Metal - Steel | USC | $3000 | 25% | 20% | $1050 | 35.0% |
| W-Wide Flange: | Metal - Steel | USC | $3000 | 25% | 20% | $1050 | 35.0% |
| W-Wide Flange: | Metal - Steel | USC | $3000 | 25% | 20% | $1050 | 35.0% |
| W-Wide Flange: | Metal - Steel | [illegible] | $3000 | 25% | 20% | $1050 | 35.0% |
| Grand total: 15 | | | | | | $13350 | |

| Material Name | Manufacturer | Material Cost* ($) | Post-Consumer Recycled Content (%) | Pre-Consumer Recycled Content (%) | Recycled Content Information Source | |
|---|---|---|---|---|---|---|
| | | | | | | CLEAR |
| | | | | | | CLEAR |
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| | | | | | | CLEAR |

## Example that uses specialized graphic components

Some credits can be evaluated directly; no calculations or computer simulations are required. About 14 points in LEED can be evaluated by this method of creating customized components. LEED NC Sustainable Site Credit 2 and Credit 4.1 are two examples. The first credit is about development density; it requires that a project be located within ½ mile walking distance of 10 basic services that are specified by LEED. The second credit is about the number of required bicycle racks and maximum distance to changing rooms. In order to comply with this credit, the design must provide secure bicycle racks and/or storage within 200 yards of a building entrance for 5% or more of all building users (measured at peak periods). To achieve these 2 credits, site development plans are submitted as supporting documents online; aside from the calculation of full time equivalents (FTE), no additional documentation or calculations are required. For these credits, the project can be evaluated graphically after specialized families are created. A ½ mile radius circle line can be added in the entry door family, and a circle with a 200 yard radius added in the bicycle family. These are then imported into project. The circle can be shown in project site plans. With the guidance of these circles and GIS (geographic information systems) maps and eventually automatic linkages, designers learn if their project might be eligible for these credits.

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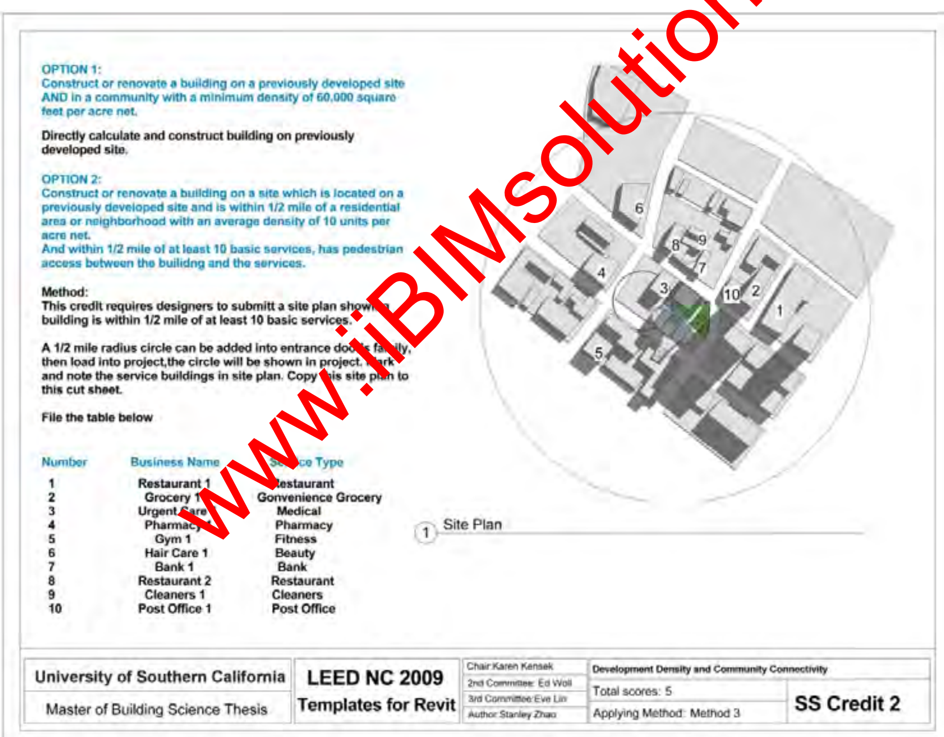

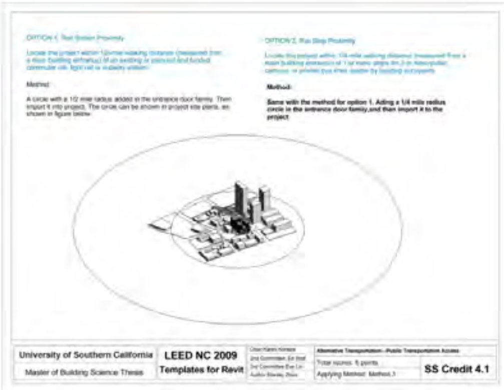


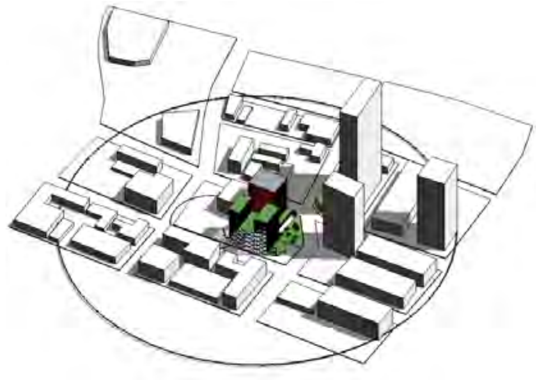

## Problems and summary

BIM could allow for an exchange of consistent information so that design team can make the best decisions related to LEED rating potential and the cost of design alternatives earlier in the design process. Mike Opitz, vice president of LEED technical development (2010) stated an appropriate vision: "Our goal is to have future versions of LEED online that will allow project teams to have their BIM software automatically send in their data, rather than laboriously upload it into the system." With advances in the building information model and better interoperability between software, the design team could go beyond just LEED compliance calculations and documentation towards creating truly sustainable buildings.

## Summary

Sustainable design is increasingly a moral imperative for our energy and water starved world. When used in conjunction with simulation tools, BIM can help designers achieve specific goals for code compliance, use real data for decision making earlier in the design process, streamline processes of creating and submitting documentation for green rating systems, and overall improve the performance of buildings.

"Parametric modeling will go well beyond mapping relationships between objects and assemblies. Both model and designer will have knowledge of climate and region. The model will know its building type, insulation values, solar heat gain coefficients, and impact on the socioeconomic environment it resides within. It will inform the design team with regard to upstream impacts and downstream consequences of the choices."
(Green BIM: Successful Sustainable Design with Building Information Modeling, Krygiel, Eddy and Nies, Bradley, copyright 2008, page 225).

## Acknowledgements

A big thanks to Stan Zhao for his work on this project! A portion of this work has been published as Kensek, Karen and Xin Stan Zhao, "Using Building Information Modeling as a Tool for LEED Score Calculations," BESS 2011 (Building Enclosure Sustainability Symposium – Integrating Design & Building Practices), Pomona, CA, April 2011. For further information, please also refer to Zhao, Xin Stan. "An Investigation on using BIM for Sustainability Analysis Analysis Using the LEED Rating System," 2011 MBS thesis, USC, School of Architecture.

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