**Structural Engineering Institute - Council of American Structural Engineers White Paper**

# Building Information Modeling for the Engineer of Record

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## Introduction

Over the last few years, the use of Building Information Modeling (BIM) technology in design practice has grown dramatically. Once considered applicable only to the largest and most sophisticated projects, design firms of all sizes now use BIM in their work in a variety of settings (see Structural Engineering Institute, 2010). The perceived benefits of the technology in the AEC industry are so great that clients often expect, or even require that designers use BIM in the performance of their services.

Unfortunately, the contractual and legal frameworks for implementing BIM on design projects have often failed to keep pace with the spread of the technology. The lack of a clear standard of care for designers using BIM, including acceptable model uses and content, can introduce significant business risk and uncertainty to a project. For example, a firm may produce a model as part of its design services, but other design professionals or contractors may rely on those models for other purposes, such as coordination, quantity takeoffs, or estimation, that were not intended by the engineer. Errors or omissions in the model can have downstream impact beyond its original intended purpose. With a poorly defined scope of responsibility for BIM, designers can face a struggle to manage client expectations, and even increase their professional liability exposure.

Partly for these reasons, the AIA introduced a series of “digital practice documents” as part of its suite of contractual agreements several years ago. The “digital practice documents” include licensing agreements and protocol exhibits intended to better define the responsibilities of designers using BIM on different types of projects. Among these documents is AIA Attachment E-202 "Building Information Modeling Protocol Exhibit", which establishes a framework for managing BIM requirements for different phases of a project using a "model element table" that is filled out by each designer.

This white paper explores the implications of the AIA "digital practice documents" for the structural engineer of record (SER). Commentary and sample model element tables are provided to assist SERs in developing a scope of services for BIM that is consistent with CASE Document 962 (National Practice Guideline for the Structural Engineer of Record) and 962-D (Guideline on the Coordination and Completeness of Structural Construction Documents). While this paper focuses on the AIA documents, SERs may use the basic concepts to establish more generalized standards suitable for other contracts and types of projects.

## Definitions

**Allowable End Uses**. Those specific uses that can be applied to a BIM by an authorized third party at any given stage of its development. The allowable end uses may include quantity takeoff, cost estimating, schedule development, bidding/procurement, structural analysis, component engineering, shop drawing development, fabrication, and facilities management.

**Building Information Model (BIM).** A digital relational database of parametric objects representing the various systems of a building. For structural engineers, the BIM typically includes a database of the building foundation and superstructure elements, with such parameters as member sizes, arrangements and weights. Like any database, the BIM can be viewed in multiple ways, both graphical (such as 2D and 3D drawings) and numerical (such as tables of quantities or weights), and can be used for multiple purposes (such as analysis, clash detection, or fabrication).

**BIM Execution Plan.** A document outlining the strategy, schedule, and goals for the modeling effort on a project. The plan can apply to an individual discipline, like the structural design, or to the modeling effort as a whole for a building project.

**COBie (Construction Operations Building Information Exchange)** A standard specification, originally developed by the United States Army Corps of Engineers, to capture space and equipment information that is needed to operate, maintain, and manage a facility and its various assets. The COBie approach is to enter this facilities management information (which includes things like equipment make, model, and serial numbers) into a database during the design and construction of a project. The database can then be handed over to the building owner at the end of construction. Many BIM applications now incorporate tools to link COBie information directly to model elements.

**Clash Detection.** The automated search for overlapping or interfering elements in a BIM. For example, clash detection may be used to automatically find areas where mechanical systems interfere with structural framing members.

**Construction Drawings.** The design documents that descriptively illustrate and graphically show the requirements and intent for construction of the building project. The structural drawings are only a part of the total documents for the project.

**Contract Documents.** The owner-contractor agreement, the conditions of the contract (general, supplementary, and other conditions), drawings, specifications, clarification drawings and all addenda issued prior to and all modifications issued after execution of the contract, and any other items that may be specially stipulated as being included. In some but not all BIM projects, the model itself may be considered a contract document.

**Integrated Project Delivery.** A form of agreement for a building project in which the owner, designers, and contractor enter into a single contract, sharing the risks and rewards. Also sometimes referred to as a "Tri Party Agreement".

**Level of Development.** A method of defining the maturity and completeness of a BIM at different stages of a project. Generally expressed as a progressive series of letters or numbers, with an increasing amount of information at each step (for example, a Level of Development 100 may represent a conceptual or schematic design model with member layout only and no member weights or sizes, while a Level of Development 400 may represent a complete model with sufficient information for fabrication of structural members). Also sometimes referred to as “Level of Detail” or “LOD”.

**Model Element Author.** The responsible party for creation of a specific object in a BIM. For example, the structural engineer of record is typically the model element author for the foundation and superstructure elements of a BIM, but may or may not be the model element author for member connections and detailing elements like reinforcing steel.

**Model Progression Specification.** A written table used to define the content, authors, and allowable end uses of a BIM at each stage of a project. A model progression specification is a useful way to clearly define modeling requirements for the engineer of record, as well as the limitations on use of the model. AIA attachment E-202 is a form of model progression specification that can be attached to a design contract, and contains a definition of the Level of Development, model element authors, and allowable end uses at each project phase.

**Polygonal Modeling.** A method of visualizing structures in 3D by representing or approximating their surfaces using geometric objects. Unlike a BIM, polygonal modeling contains little or no parametric information about the objects (such as member size or weight), can generally be viewed only graphically, and has limited use beyond generation of individual drawings. (see Ashcraft, 2006)

**Structural Engineer of Record (SER).** The Structural Engineer who is legally eligible to seal the structural documents for a building project. This seal acknowledges that he has performed or supervised the analysis, design, and document preparation for the building structure and has knowledge of the requirements for the load carrying structural system. The SER is responsible for design of the primary structural system.

**Specialty Structural Engineer (SSE).** A licensed professional engineer, not the structural engineer of record, who performs Structural Engineering functions necessary for the structure to be completed and who has shown experience and/or training in the specific specialty. The specialty structural engineer is usually retained by a supplier or subcontractor who is responsible for the design, fabrication and (sometimes) installation of engineered elements or by the General Contractor of subcontractors responsible for construction related services.

**NOTE**: Some definitions are from CASE 962 "National Practice Guidelines for the Structural Engineer of Record". The reader is referred to this document (see References below) for definition of additional terms included but not repeated in this white paper.

## Overview of BIM and Contracts for the Engineer of Record

It is essential that the Structural Engineer of Record (SER) enter a signed agreement with its client. The agreement should define the scope of services the SER will provide and necessary information that is to be provided to the SER by the client towards the completion of a successful project.

Many engineers acting as consultants to architects on teams using BIM will be asked to use the AIA Contract Documents. These documents include contracts for two different forms of agreement:

- Traditional Contract Documents. These are the standard agreements between owner and architect, and between architect and consultant. Under AIA subconsultant agreements, the scope of work of the SER is to produce design documents, including the construction documents, and perform construction administration services. In this context the structural BIM may be used to prepare the construction documents, to perform clash detection and coordination with other design disciplines, and possibly to share with contractors to assist them in developing their own fabrication models and shop drawings.
- Integrated Project Delivery (IPD). IPD is a type of project relationship in which the owner, design team, and contractor all sign a common agreement to share in the project risks and rewards. While BIM is not technically required to sign an IPD agreement, it is typically an important part of the project scope of work because of the highly collaborative nature of these projects. For an IPD project, the SER may be asked to have integral involvement in development of a structural model throughout the design and construction process, and share work with other team members. Since the SER and contractors are on the same team contractually, the SER's model is normally combined with other models for clash detection and coordination, as well as the development of fabrication models. Some IPD projects do not even have traditional contract documents like drawings, and simply rely on the model to define the contractor's scope of work.

We note that some engineers are performing “IPD-like” services under the traditional contract documents. For example, in “Design Build” projects, the engineer may be part of a highly collaborative model development effort with other designers and subcontractors, similar to the IPD method.

Detailed discussion of these two types of agreements is outside of the scope of this white paper, but the reader is encouraged to visit www.AIA.org/contractdocs for more information.

Clearly, the modeling responsibility of the SER will vary for different projects and different types of contracts. AIA attachment E-202 BIM Protocol Exhibit is included in the digital practice documents, and is intended to complement either form of agreement (traditional or IPD) and serves to define the BIM scope of work and deliverables for the project. This attachment is the primary focus of this white paper.

If not using an AIA agreement, the consulting engineer should consider using published CASE Documents which are available on line at www.acec.org/case. Particularly relevant forms of agreement include CASE Document 2-2008 Agreement Between Client and Structural Engineer of Record for Professional Services and Case Document 11-2011 Agreement Between Structural Engineer of Record and Contractor for Transfer of CAD or BIM E-Files. Current CASE agreements do not specifically address a BIM protocol, however the AIA attachment E-202 form may be used as an addendum to this type of contract to better define the BIM scope of work.

Other industry organizations, including the Engineers Joint Contract Document Committee (EJCDC), the Design-Build Institute of America (DBIA), and ConsensusDocs have published their own forms of agreement that may be of interest to the reader. References are provided at the end of this white paper with links to these resources.

AIA is presently drafting new digital protocol forms which are to be attached to the base "Agreement" regarding the managing, transmission and storage of E-files. Further information is available on line www.aia.org.

## Discussion of Levels of Development and Allowable End Uses

Depending on the agreed upon Level of Development provided in the BIM, there are several different possible end uses of the Model. These end uses can include quantity takeoff, cost estimating, schedule development, bidding/procurement, structural analysis, component engineering, shop drawing development, fabrication, and facilities management. For the purposes of this discussion we will refer to Levels of Development as defined by the AIA Attachment E-202.

Level of Development 100 – This basic model may be considered as a Schematic Design level which provides primarily massing and volumetric information. With only the most basic information available the practical uses of this type of model are limited to review of basic space layouts, volume and area calculations and orientation of the spaces. A basic volume or square footage based cost estimate is also possible with this level of development. There may also be enough information to provide an estimate of overall project schedule or duration. Some structural engineers prepare LOD 100 models using basic masses only, such as floor "slabs" of uniform depth representing the total depth of the structural framing supported by generic walls and columns.

Level of Development 200 – This model is a little more developed and is akin to a Design Development, or 35% level of design. There is generally sufficient information to allow basic analysis of the structural and other systems. Some of the model elements may include non-geometric information that can be used to assist with cost estimating. The model may include a time scaled appearance of major elements to assist with phasing or schedule planning.

Level of Development 300 – At this level, there is sufficient information to allow for the preparation of traditional construction documents. However, by the very nature of BIM, the elements include additional non-geometric information that may be used by the design/construction team. This model can be used to create analytical models for structural design. It may also be used as a basis for the preparation of shop drawings and for preparing detailed construction cost estimates. The Level 300 BIM may also be used to show time scaled appearance of detailed model elements and systems for scheduling and phasing purposes.

Level of Development 400 – In this level, the BIM includes additional detail and all primary and secondary framing elements. It includes complete fabrication, assembly and detailing information and as such can be used for shop fabrication. It is a virtual representation of the structure that can be used for construction. Detailed cost estimates based on the specific elements in the Model are possible. Detailed scheduling can be achieved by showing time scaled appearance of detailed specific elements.

Level of Development 500 – All elements and systems are modeled as specific constructed assemblies and are accurate in every detail. This Model can be used for much the same purposes as the LOD 400, but when authorized, this Model may be used for maintaining, altering or adding to the project, or building. While the AIA refers to "as constructed" models in attachment E202, the authors recommend the use of the term "record model" for the engineer of record unless he has specifically been contracted to document the constructed assemblies. Some owners may expect COBIE modeling with an LOD 500 model for facilities management, although this is not normally a requirement for structural systems.

Levels of Development should be agreed upon with the project team early in the project schedule (preferably before design begins), and should be based on the overall project goals. The AIA E-202 Levels of Development generally follow a model that was developed for Integrated Project Delivery (IPD) methods. In this approach, more modeling is often done in early project phases (such as conceptualization) than in a traditional project. This approach recognizes the potential leverage of early design involvement by subcontractors, who can collaborate in the BIM development to potentially arrive at more cost effective and constructible solutions without requiring costly redesign in later phases of the project. Furthermore, the IPD method blurs the lines of traditional structural engineering design services, given the more direct collaboration with contractors throughout design and construction.

When applying the AIA E-202 Levels of Development to more traditional (non-IPD) design projects, the engineer must take care to identify the scope of work clearly in each design phase of involvement. The AIA E-202 Levels of Development do not clearly map to the traditional project phases defined in the AIA Contract Documents (Conceptual Design, Schematic Design, Design Development, Construction Documents). For example, in a more traditional project, the engineer of record may not produce any model at all for Level of Development 100 (just a narrative), or he may simply produce a volumetric model showing the space occupied by the structural framing with no specific member sizes or even framing systems identified.

On the other hand, some engineers may create intermediate Levels of Development in order to create more specific deliverables for their clients. For example, the engineer may create a level "350" model that includes more of the miscellaneous steel framing and connection details than a level “300” model (which may represent the construction documents) in order to improve coordination and clash detection for the contractor. These additional Levels of Development may fall outside the scope of basic services (see discussion below on additional services).

Although not specifically included in AIA E-202, some engineers also identify a Level of Development 000 which defines elements that will NOT be included in the model (for example, metal deck closures or steel kicker braces) at any given project phase. Explicit definition of important model exclusions can help to clarify the scope and limitations of the work performed by the engineer of record.

Another issue for consideration in defining the Levels of Development is the modeling of existing structures to be modified or renovated. In such a case, what is an appropriate level of development for the BIM? Normally, the engineer of record would not prepare true “as-built” models for design, but instead prepare a sufficient level of detail to design the structural work. For example, some engineers will build a very schematic model of the entire existing building (LOD 100 or 200) and then only model to a higher level of detail in the areas to be structurally modified. This may not match the client’s expectations, so it is particularly important to define the modeling scope of work in proposals and contracts for such existing building projects.

It is of great importance for the structural engineer to communicate the expected scope of modeling to client. This is best done through a BIM Execution Plan, which is used to define, among other things, the model content and structure, model uses, the expected schedule, modeling tolerances, and how the model will be managed and shared. For examples of BIM Execution Plans, the reader is referred to “BIM Project Execution Planning Guide – Version 2.0.” by Pennsylvania State University Computer Integrated Construction Research Program (2010) (see References below)

## Suggested Level of Development Tables for the Engineer of Record

Each project is different and will require a specific treatment of the appropriate Level of Development. The following tables are intended as a starting point for the reader to use in development of a project-specific model progression specification. The format of AIA Attachment E-202 is used in these tables, but may be modified based on the form of agreement used for the project.

The following tables should be developed to be in compliance with the contract, and should be sufficient to accurately describe the scope of work of the engineer of record in the construction of a building information model for the referenced project. Modeling specifications required by the client or owner should also be included where applicable.

**Table 1** includes a general description of the Level of Development with phase names (AIA name for IPD phase given in parentheses); general model content; general allowable uses of the model for scheduling, estimating, and coordination (engineer should fill in "other uses" as appropriate for their project); typical model authors responsible for development; potential "model reviewers" (representing those users who will check the model, such as agency and permitting authorities); and "other users" (representing other authorized parties that may be authorized to re-use the model and extract or add to its content for their own purposes)

Model reviewers and users may be the same – for example an architect may need to review the engineer's model for coordination, and may also use the model to create a fully integrated and interdependent "federated model" during the design process.

Some engineers have "sealed" models with an electronic stamp, and submitted the model to permitting authorities directly for review. This procedure is relatively new and still uncommon, but as the technology matures some authorities having jurisdiction over building projects are beginning to recognize models as construction documents.

**Table 2** contains more detailed descriptions of the specific types of model elements that may be included in each category of construction (using Construction Specification Institute Standard Divisions). Engineers may wish to develop more detailed and specific content specifications for their own projects, and this table should be used as a general guide only.

(NOTE: Tables are adapted from "AIA Document E202™ – BIM Protocol Exhibit", American Institute of Architects, 2008")

**Table 1: Structural Levels of Development, Users, and Authorized Uses**

| **Level** | **100** | **200** | **300** | **400** | **500** |
|---|---|---|---|---|---|
| **Name of Phase** | **Concept Design** (Conceptualization) | **Design Development** (Criteria Design) | **Construction Documents** (Detailed Design) | **Fabrication** | **As-Built model** |
| **Structural Model Content** | Non-geometric data or line work, areas, volumes zones, etc. | Generic elements shown in three dimensions<br>- maximum size<br>- purpose | Specific element design intent sufficient for fabrication model development.<br>Some elements covered by typical details/notes | Detailed element connections, all typical detail content | Record model of actual conditions |
| **Scheduling** | Total project construction duration phasing of major elements | Time-scaled, ordered appearance of major activities | Time-scaled, ordered appearance of detailed activities | Detailed scheduling, including hoists, cranes, etc… | |
| **Estimating** | Square foot/area estimates only | Estimates based on overall geometries of major elements only | Estimates based on specific measurements, also must include typical details and annotations | Committed purchase price for structural elements | |
| **Coordination** | General systems only | Clash detection of major systems | Clash detection of design systems. Information may be insufficient for detailed clash detection | Clash detection of all system components, detailed coordination | |
| **Other uses…** | | | | | |
| **Model Author Responsible for Development** | Engineer of Record | Engineer of Record | Engineer of Record | Specialty Structural Engineers, Fabricators | Contractor, Fabricator |
| **Potential Model Reviewers** | Architect | Architect | Architect, Authorities having Jurisdiction | Engineer of Record, Architect | |
| **Other Users** | Estimator, Scheduler | Estimator, Scheduler | Specialty Structural Engineers, Fabricators, Contractor | Contractor | Owner |

**Table 2: Structural Model Elements at Each Level of Development to be included by the Engineer of Record**
The following table describes the model elements that will be included by the engineer of record at each level of detail. Intermediate levels can and should be defined as required by the project schedule and coordination protocol. INFORMATION IS SUGGESTED ONLY – ENGINEER MUST FILL IN EACH CATEGORY AS REQUIRED FOR THE SPECIFIC PROJECT

| | Level | 100 | 200 | 300 | 400 | 500 |
|---|---|---|---|---|---|---|
| **Div 2** | **Earthwork** | Narrative | Notes/refer to Geotech report | Subdrain systems shown as annotation | Actual subdrain locations modeled | Record model |
| **Div 3** | **Concrete Foundation** | Outline only, typical details for footings | Footings, walls, piers, typical details show brick shelf locations only | All walls, footings, piers shown with shelves in model, Reinforcement included in tables | Rebar modeled with detailing | Record model |
| | **Structural Concrete** | Basic layout of system with approximate depths and volumes | Slab depths only, typical details of reinforcement, tables indicating typical reinforcement | Slab layouts shown, reinforcement indicated as annotation on plans | Rebar modeled with detailing | Record model |
| | **Precast Concrete** | Basic layout and typical details | Element depths and layout only | Elements indicated as performance based design | Actual precast elements modeled with rebar | Record model |
| **Div 4** | **Structural Masonry** | Outline of walls only | Wall size and type only, reinforcement in typical details | Walls indicated with reinforcement and strength | Rebar modeled with detailing | Record model |

| | Level | 100 | 200 | 300 | 400 | 500 |
|---|---|---|---|---|---|---|
| **Div 5** | **Steel Framing** | None – table of estimated quantities | Framing layout with member depths and widths only | Framing sizes and weights shown, connections shown by typical detail or special annotation as required, Include column splices, brace gusset plate connections (estimated size). | Model sufficient for fabrication, all connections and related plates are modeled. | Record model |
| | **Metal Deck** | Narrative only | Deck size and span | Deck size and span, all edge conditions detailed in annotation, bent plates indicated on drawings on typical detail | Individual sheets modeled with splice locations | Record model |
| | **Open Web Steel Joists** | Narrative only | Layout with depths of members only | Typical visual model indicating member depths, seat depth, and generic configuration, weight designation | Manufacturer's model with accurate web geometry and bridging locations and geometry | Record model |
| | **Cold Formed Framing** | Narrative only | Typical annotation by wall type | Wall types shown with typical annotation and details | All studs indicated, all tracks. Fasteners shown by typical detail | Record model |

| | Level | 100 | 200 | 300 | 400 | 500 |
|---|---|---|---|---|---|---|
| **Div 6** | **Wood Framing** | Narrative only | Typical annotation by wall type | Wall types shown with typical annotation and details | All studs indicated, all tracks. Fasteners shown by typical detail | Record model |
| | **Pre-Fabricated Wood Trusses** | Narrative performance information only | Typical truss depth and layouts; typical connection details | Trusses indicated with specified depth using generic web geometry only; truss loading and other performance specifications; typical connection details and all special connection details. | Manufacturer's model with accurate web geometry and connection details modeled at each location. | Record model |
| **Other** | **Other structural categories** | As required based on the project scope and structural systems | | | | |
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(NOTE: Table is adapted from "AIA Document E202™ – BIM Protocol Exhibit", American Institute of Architects, 2008")

## BIM and Additional Services

If used in its most basic form, to produce two-dimensional construction documents only, the use of BIM related software would generally not be considered an additional service. CASE Document 962 *National Practice Guidelines for the Structural Engineer of Record* delineates basic and additional services for customary structural engineering projects. In that document, as in the minds of most practicing structural engineers, the preparation of drawings for construction is considered a basic service. Just as its predecessor, CAD, was only a tool to produce the same documents that were produced by hand and eventually became an expected part of the process, the use of BIM related software will have similar expectations if it does not add value to the project. Using the definitions of Levels of Development outlined in this white paper, basic services for the engineer of record would be consistent with the development of a model through LOD 300.

As the use of the model adds greater value to the project, the case for additional services or additional compensation increases. For example, it would generally be considered basic services for the engineer to perform model coordination and clash detection on a level 300 model during design. However, if the model is to be used for more detailed coordination and clash detection during construction, the SER may need to model items that would not normally be modeled if it is only used for drawing preparation. For example, rather than a single detail showing the angle “kickers” at the building perimeter, the “kickers” themselves will need to be modeled to determine if there is a conflict. Similarly, the gusset plates for braced frame connections may also need to be modeled. Adding these elements to the model provides additional value to the owner beyond the normal standard of care for design work. Also, the engineer’s time for the detailed clash detection process brings value to the project and deserves compensation.

As the model is used by project team members beyond the design team such as for fabrication drawings or processes, cost estimating or scheduling, and facilities management, the engineer should be compensated both for the additional effort needed to prepare the model for fabrication use and for the additional value the model brings to the project. For example, some engineers will produce a more detailed model, such as LOD "350" in order to facilitate these additional model uses. Clearly, such modeling would be a candidate for additional compensation to the engineer.

## Conclusion

Best practices for the development of structural engineering contracts and scopes of work for BIM and IPD projects are continuing to evolve. Each project is unique and will require its own agreement based on the project's modeling goals. In all cases, however, it is essential to communicate early with your client to understand their expectations for the development and management of the model throughout the project phases. Before any modeling begins, all team members should reach an agreement regarding the scope and Level of Development of the model and document it using some of the tools outlined in this paper. With the necessary planning and communication, the design team is able to leverage the power of BIM to provide an unprecedented value to our clients while ensuring a successful project for all those involved.

## DISCLAIMER

This white paper is intended to provide general guidance only for engineers to better understand Building Information Models and to assist in the development of their own BIM contracts.

As with all documents that are intended to formalize contractual relationships, the guidance and advice of an attorney is necessary to assure proper usage for specific applications and jurisdictions. We strongly recommend that you have your legal advisor, professional liability carrier, and your accountant review this document or any documents derived through the use of this white paper.

No warranty of any kind is made with respect to this document or other contractual or consequential damages in connection with, or arising out of, the furnishing, performance, or use of this document.

## References and Additional Resources

American Institute of Architects Digital Practice Documents (http://www.aia.org/contractdocs)

"AIA Document E202™ – Building Information Modeling Protocol Exhibit", American Institute of Architects, 2008.

"AIA Document C106™ – 2007 Digital Data Licensing Agreement", American Institute of Architects, 2007.

"AIA Document E201™ – 2007 Digital Data Protocol", American Institute of Architects, 2007 (includes Model Progression Specification).

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