Lecture 1
Virtual Design and Construction

David Odeh, S.E.
Principal, Odeh Engineers

BSCES Boston Society of Civil Engineers Section
American Society of Civil Engineers

SEI Structural Engineering Institute Boston Chapter

VDC – What is it?

VIRTUAL

- Parametric computer models of everything

DESIGN

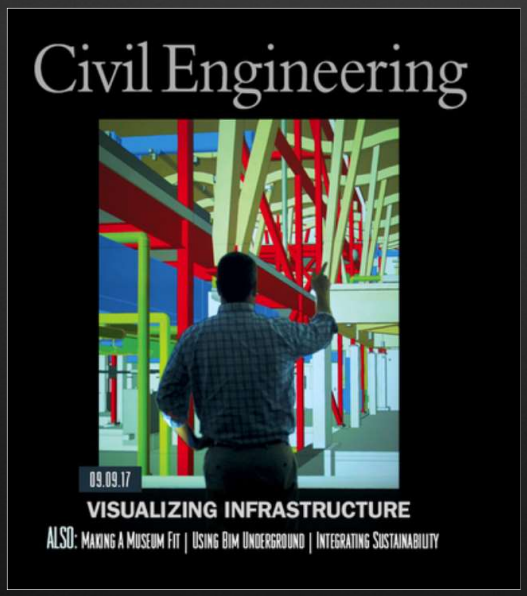
- Multi-disciplinary
- Integrated

CONSTRUCTION

- Logistics
- Cost
- Schedule

VDC in the News

Nearly every day, the industry media features VDC



Today's Talk

1	2	3	4	5	6
HISTORY of VDC	**SCOPE** of VDC for Structural Engineers	**MODEL** Development and Clash Management	**IPD** Integrated Project Delivery and VDC	**REALITY** Capture Technology	**VISION** for the Future

1	2	3	4	5	6
HISTORY of VDC	**SCOPE** of VDC for Structural Engineers	**MODEL** Development and Clash Management	**IPD** Integrated Project Delivery and VDC	**REALITY** Capture Technology	**VISION** for the Future

A Brief History Of Engineering Models

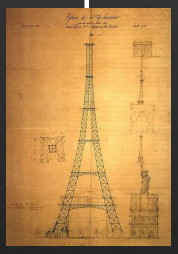
1600s | 1700s | 1800s | 1900s | 2000s

ANALYSIS

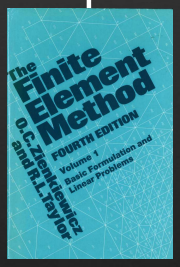
Newton: Statics

Galileo: Strength of Materials

Bernoulli, Euler
Basic ideas of solid mechanics



Great structures arise from principles of classical mechanics

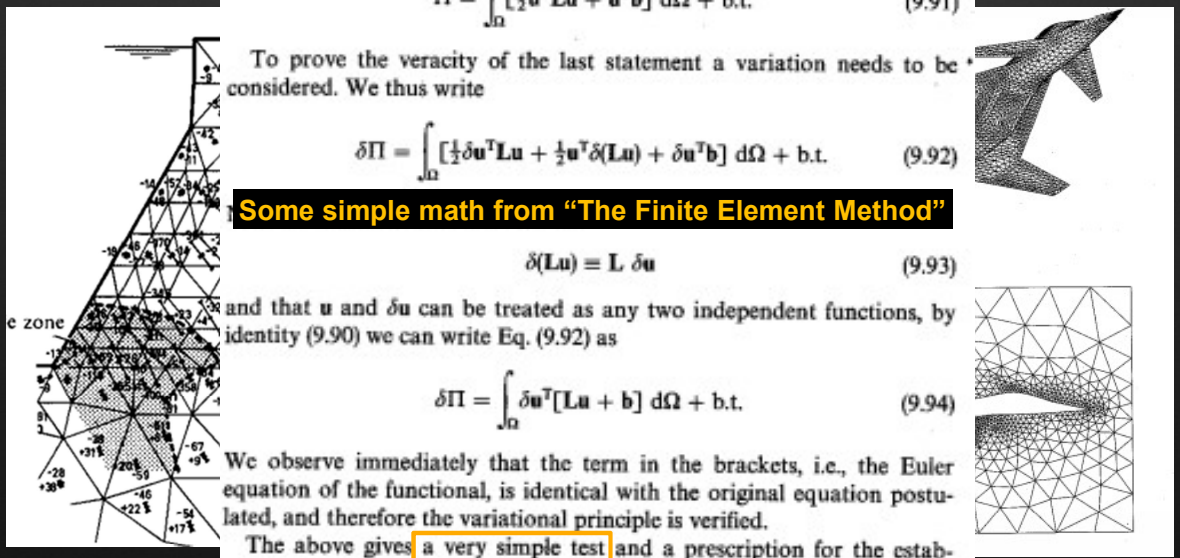


Post WW2: Numerical methods using mainframes

Personal computer brings FEM to desktop

CAD and BIM

Finite El…1980s



If the operator $\mathbf{L}$ is self-adjoint, the variational principle can be written immediately as

$$\Pi = \int_\Omega [\tfrac{1}{2}\mathbf{u}^T\mathbf{L}\mathbf{u} + \mathbf{u}^T\mathbf{b}]\, d\Omega + \text{b.t.} \qquad (9.91)$$

To prove the veracity of the last statement a variation needs to be considered. We thus write

$$\delta\Pi = \int_\Omega [\tfrac{1}{2}\delta\mathbf{u}^T\mathbf{L}\mathbf{u} + \tfrac{1}{2}\mathbf{u}^T\delta(\mathbf{L}\mathbf{u}) + \delta\mathbf{u}^T\mathbf{b}]\, d\Omega + \text{b.t.} \qquad (9.92)$$

Some simple math from "The Finite Element Method"

$$\delta(\mathbf{L}\mathbf{u}) = \mathbf{L}\,\delta\mathbf{u} \qquad (9.93)$$

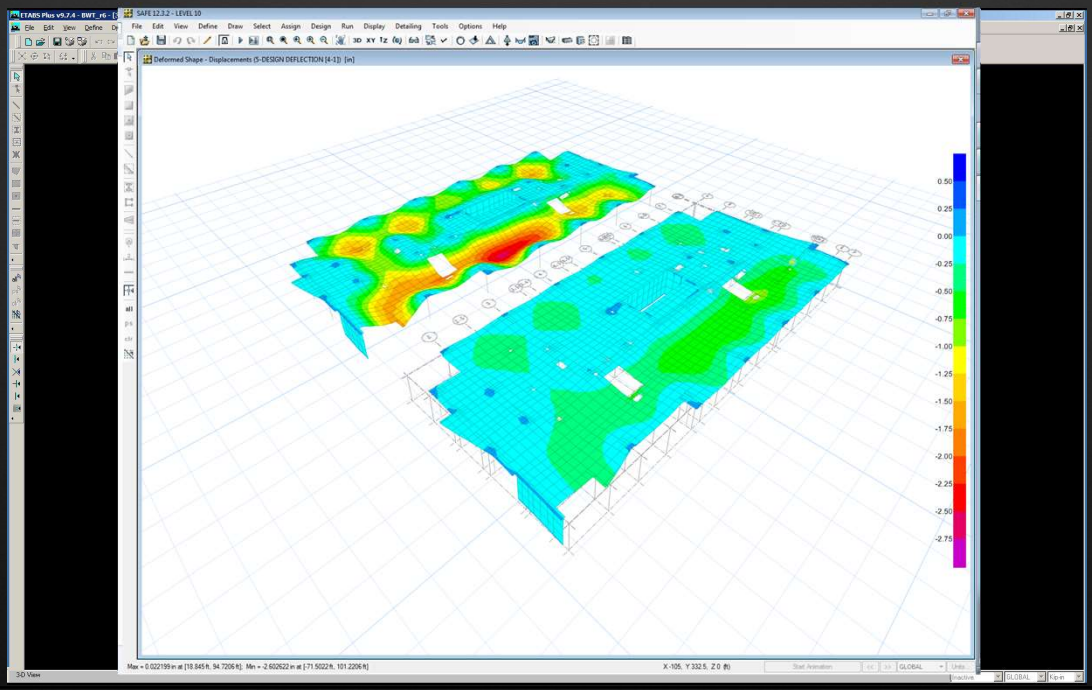
and that $\mathbf{u}$ and $\delta\mathbf{u}$ can be treated as any two independent functions, by identity (9.90) we can write Eq. (9.92) as

$$\delta\Pi = \int_\Omega \delta\mathbf{u}^T[\mathbf{L}\mathbf{u} + \mathbf{b}]\, d\Omega + \text{b.t.} \qquad (9.94)$$

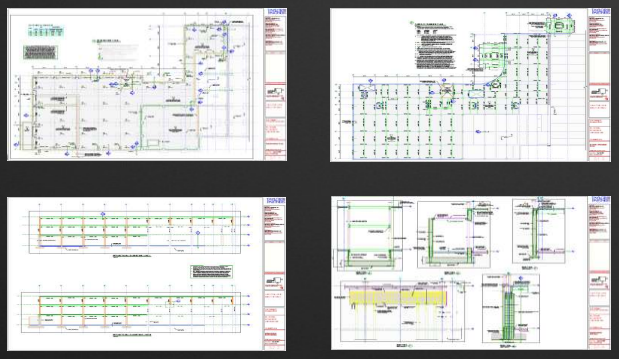
We observe immediately that the term in the brackets, i.e., the Euler equation of the functional, is identical with the original equation postulated, and therefore the variational principle is verified.

The above gives a very simple test and a prescription for the establishment of natural variational principles for differential equations of the problem.

Modern Finite Element Analysis using Visualization Tools

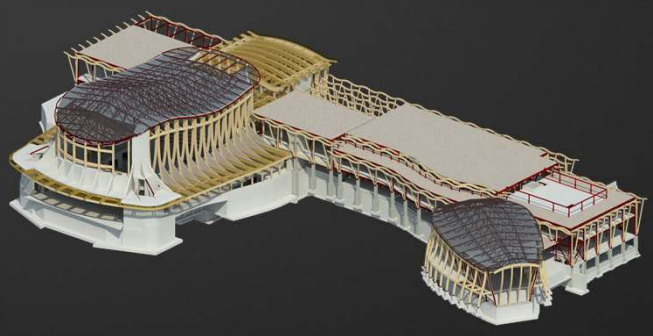


2D/3D POLYGON MODEL



- Information rich database
- Multiple model views
- Coordination through linked interoperable models
- Automated clash detection
- Reusable by other parties

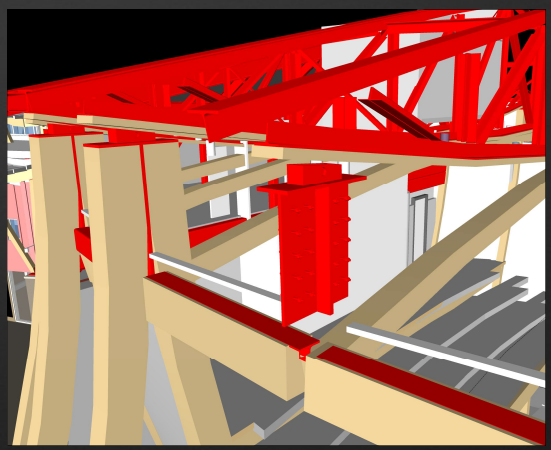
BUILDING INFORMATION MODEL

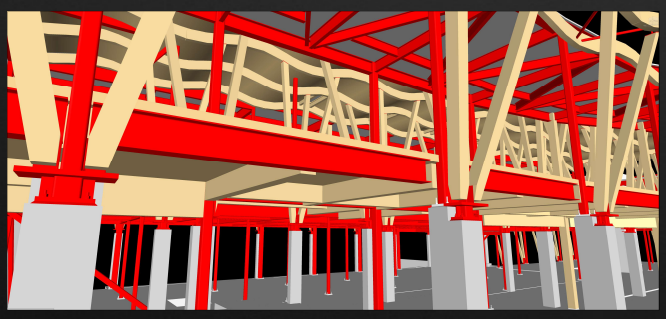


- Geometric representation only
- Coordination through overlay of backgrounds
- Limited reuse by other parties

Advanced Model Views

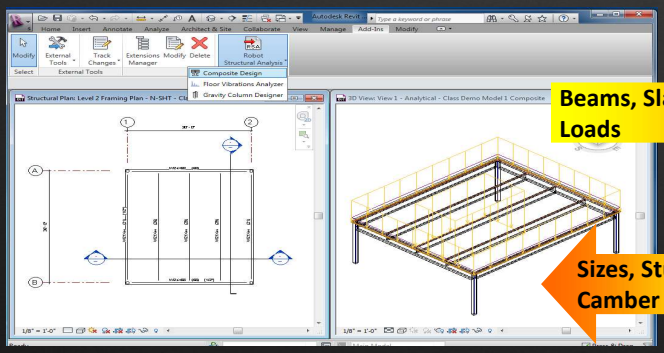
Detailed Structural Modeling





Structural Analysis and BIM

DESIGN WORKFLOW



BIM with analytical information present

Analysis Engine

Benefits of BIM

- **Costs of Inadequate Interoperability in AEC industry** (1)
  - Total annual cost in US alone: $15.6 billion
  - Estimated manual data re-entry costs for designers alone: $462 million
  - Estimated RFI management costs (combined, contractors and architect/engineers): $500 million

- **Integrated BIM is key to improving design and construction productivity, and ultimately facilities management cost efficiency**

(1) Gallaher, M. P.; O'Connor, A. C.; Dettbarn, J. L., Jr.; Gilday, L. T. , "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry", National Institute of Standards and Technology, August 2004

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BPEP: BIM Project Execution Plan

- Goals for BIM use
- BIM execution process
- BIM deliverables
- LOD for key phases, responsibility matrix

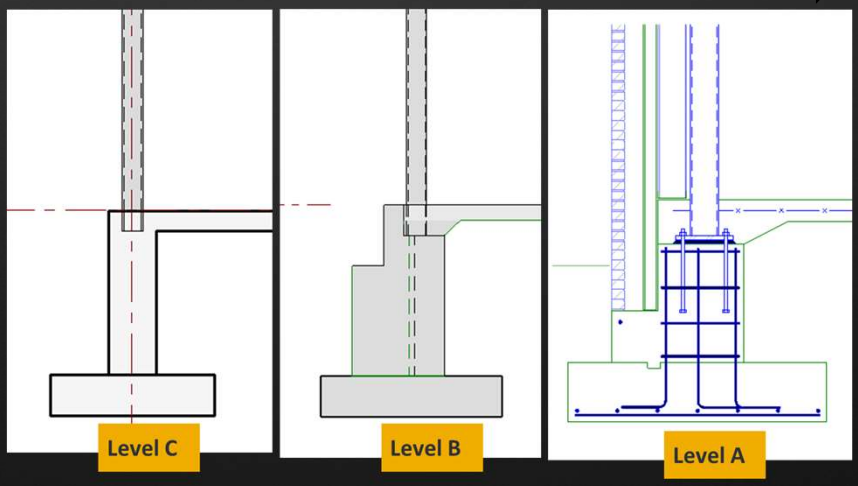
Reference: Penn State Computer Integrated Construction Research Program: http://bim.psu.edu/

Level of Development (LOD)

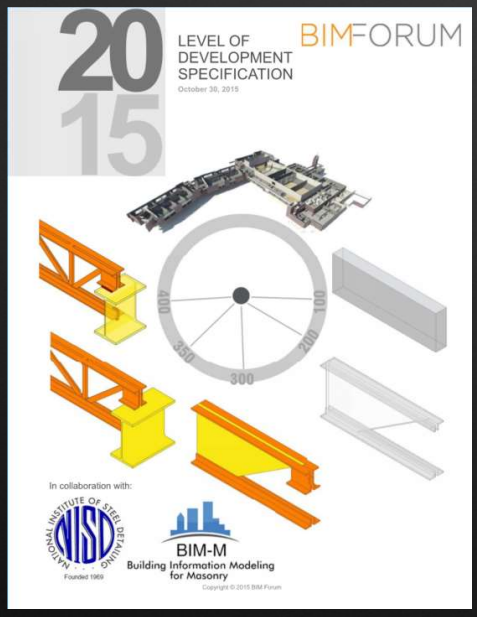
- What will be extracted from model?
- What are key graphical elements to be visualized?
- How will level of detail be documented?

EXAMPLE OF LOD FOR FOUNDATION

Concept Design → Design Development → Construction Documents



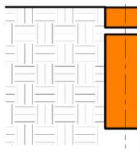
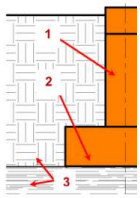
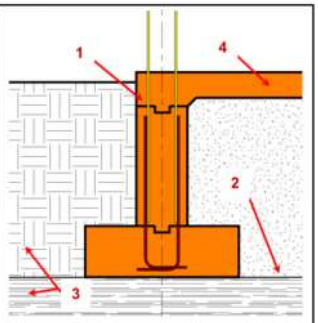
Level of Development (LOD)



- AIA defines Level of Development in its 2013 Digital Practice Documents
- BIMForum licensed the AIA specifications and created its own LOD specification with detailed examples
- Structural elements are particularly well developed in this specification
- Introduces new LOD "350" – that level of development required for detailed coordination between disciplines

BIMForum LOD Specification Example: Foundation Wall

A1010.10 – Wall Foundations (Shallow Foundations)

100	See A10	
200	See A10 *Image Notes:* *1) Generic wall foundation is modeled.* *2) Site is generically modeled from geotechnical information in geotechnical report.*	 *5 A1010.10-LOD-200 Wall Four*
300	See A1010 Element modeling to include: 1) Overall size and geometry of the foundation element 2) Sloping surfaces. 3) External dimensions of the members Required non-graphic information associated with model elements includes: 4) Concrete strength 5) Reinforcing strength 6) Geotechnical bearing strata elevation is modeled from geotechnical report. *Image Notes:* *1) Wall foundation sizes are accurately modeled with footings where applicable.* *2) Bearing elevation is modeled from the geotechnical report.* *3) Geotechnical regions are shown for context and not required to be modeled as part of this element at this LOD.* *4) See slab on grade for related conditions at this LOD.*	 *6 A1010.10-LOD-300 Wall Foun*
350	Element modeling to include: • Location of sleeve penetrations • Pour joints • Moisture retarder • Dowels • All exposed embeds or reinforcement such as lintels • Expansion joints • Geotechnical Bearing Strata is modeled from geotechnical report estimates. *Image Notes:* *1) Grade beam sizes are modeled with interfaces to other systems such as but not limited to slab turn downs, key-ways between concrete pours, construction joints and reinforcing dowels into adjacent pours.* *2) Bearing elevation is modeled from the geotechnical report with the addition on interface elements such as void boxes where applicable.* *3) Geotechnical regions are shown for context and not required to be modeled as part of this element at this LOD.* *4) See slab on grade for related conditions at this LOD.*	 *7 A1010.10-LOD-350 Wall Foundations (Shallow Foundations)*
400	Element modeling to include: • Rebar including hooks and lap splices • Dowels • Chamfer • Finish • Coursing for unit masonry defined • Waterproofing	

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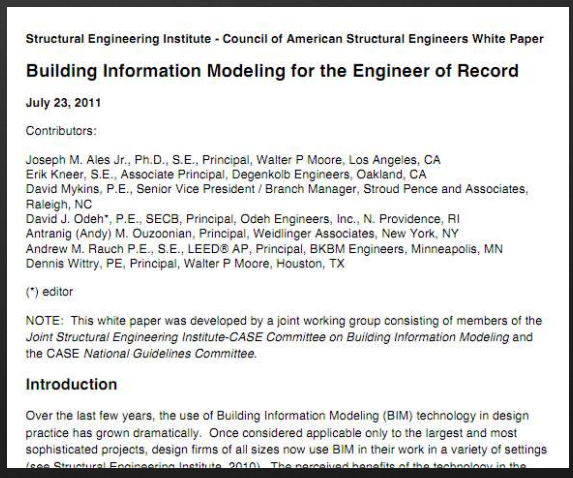
BIM for the Engineer of Record

- Definitions
- Overview of BIM and Contracts
- Discussion of LOD and Allowable End Use
- Suggested LOD Tables for the EOR
- BIM and Additional Services



Structural Engineering Institute - Council of American Structural Engineers White Paper

Building Information Modeling for the Engineer of Record

July 23, 2011

Contributors:

Joseph M. Ales Jr., Ph.D., S.E., Principal, Walter P Moore, Los Angeles, CA
Erik Kneer, S.E., Associate Principal, Degenkolb Engineers, Oakland, CA
David Mykins, P.E., Senior Vice President / Branch Manager, Stroud Pence and Associates, Raleigh, NC
David J. Odeh*, P.E., SECB, Principal, Odeh Engineers, Inc., N. Providence, RI
Antranig (Andy) M. Ouzoonian, Principal, Weidlinger Associates, New York, NY
Andrew M. Rauch P.E., S.E., LEED® AP, Principal, BKBM Engineers, Minneapolis, MN
Dennis Wittry, PE, Principal, Walter P Moore, Houston, TX

(*) editor

NOTE: This white paper was developed by a joint working group consisting of members of the *Joint Structural Engineering Institute-CASE Committee on Building Information Modeling* and the CASE *National Guidelines Committee.*

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

The CASE BIM White Paper

Sample Model Specification

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 - maximum size - purpose	Specific element design intent sufficient for fabrication model development. 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	

Source: "Building Information Modeling for the Engineer of Record", CASE White Paper, July 2011

The CASE BIM White Paper

Sample Model Specification

Level	100	200	300	400	500
Earthwork	Narrative	Notes/refer to Geotech report	Subdrain systems shown as annotation	Actual subdrain locations modeled	Record model
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

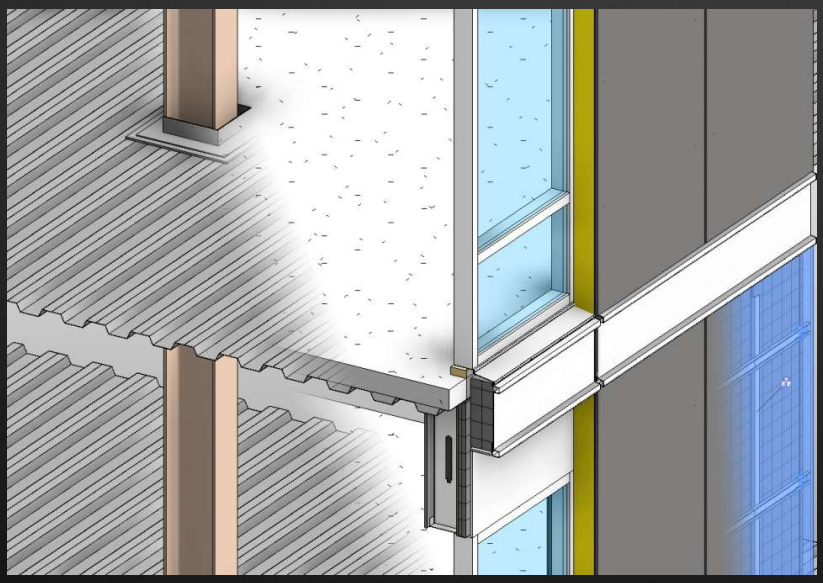
Source: "Building Information Modeling for the Engineer of Record", CASE White Paper, July 2011

The CASE BIM White Paper

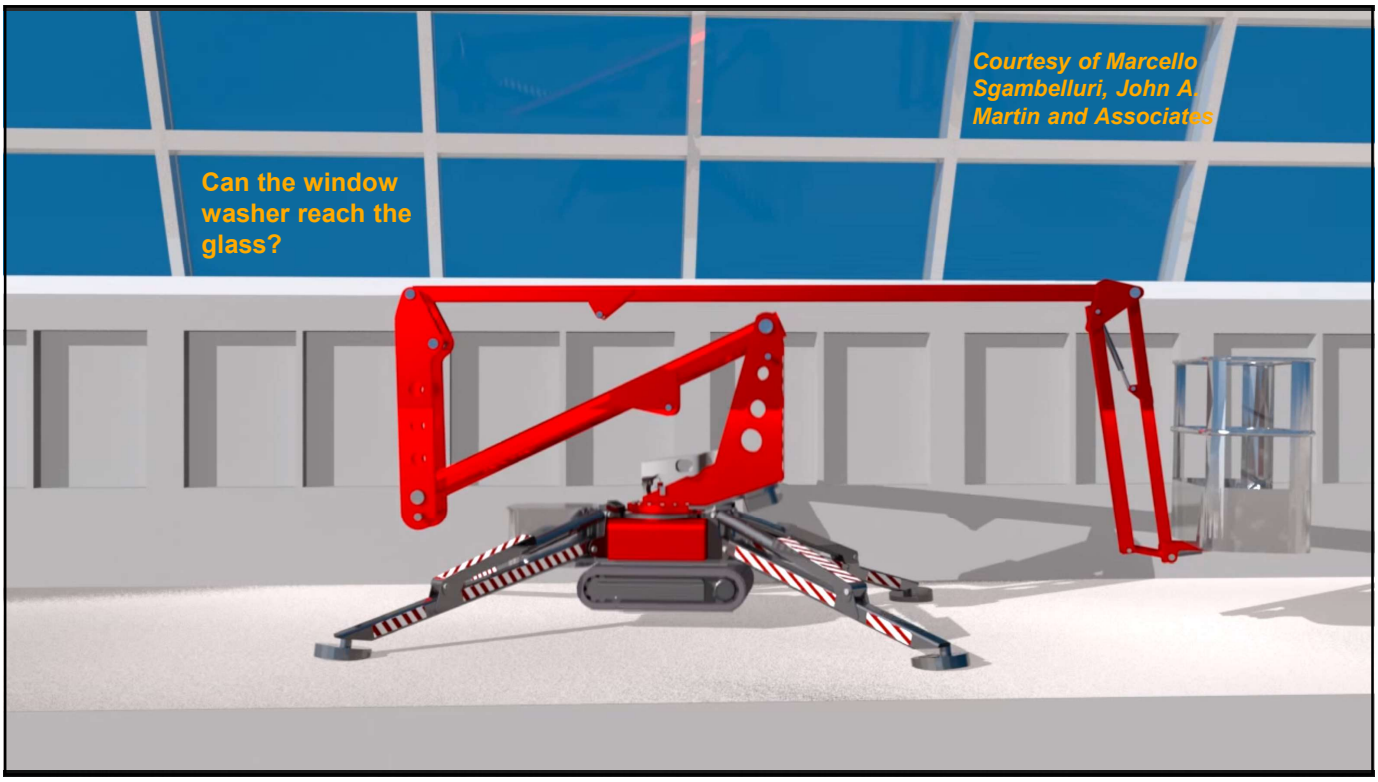
Typical Scope of Services

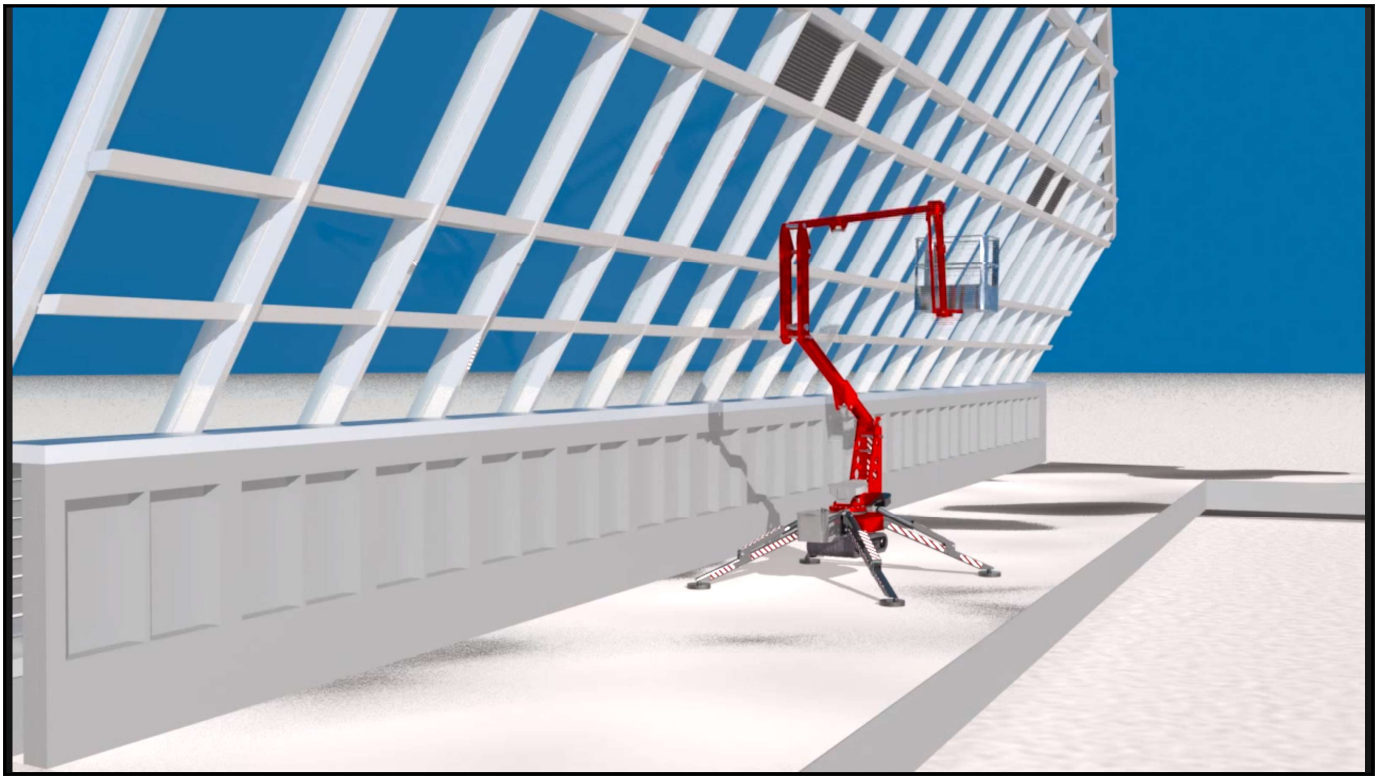
- **Basic Services**
  - Define clearly in BPEP
  - Create responsibility matrix
  - LOD 300 is often considered EOR's responsibility
- **Additional Services**
  - Multiple design options
  - Higher LOD – examples: connection design, curtain wall model, misc. metals

Examples of Level 350 services



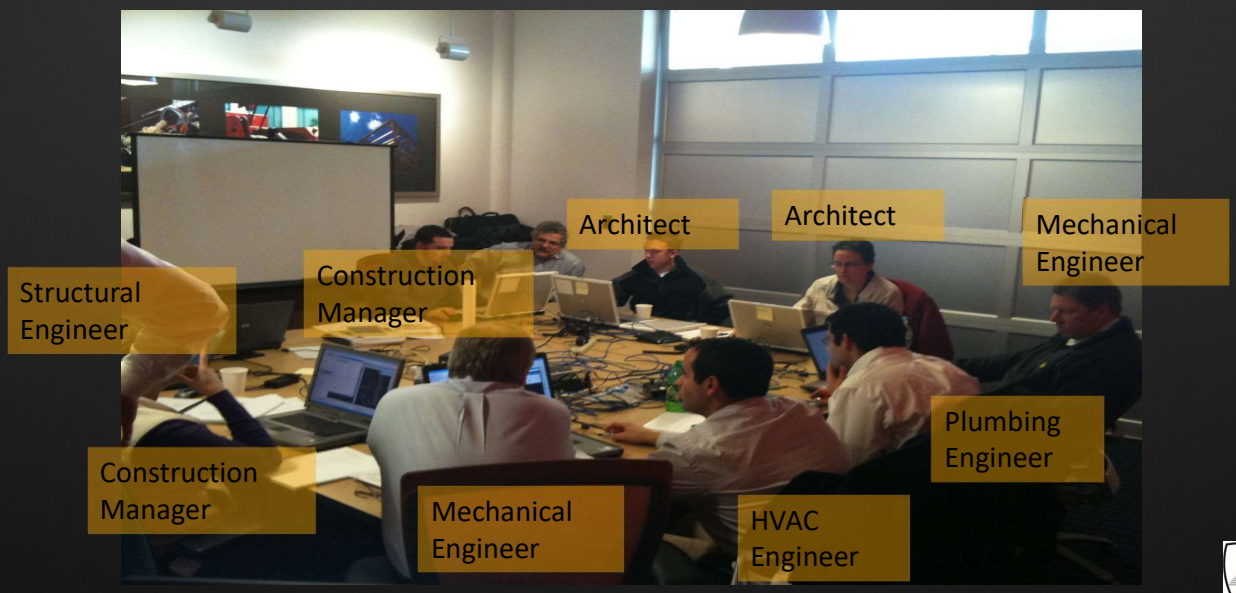
Higher levels of detail for curtain wall coordination


Courtesy of Marcello Sgambelluri, John A. Martin and Associates
Can the window washer reach the glass?



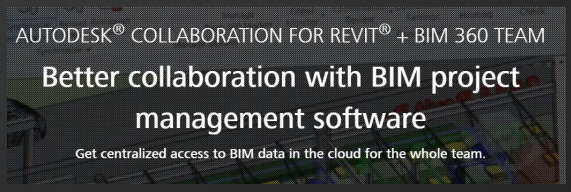
1	2	3	4	5	6
HISTORY of VDC	**SCOPE** of VDC for Structural Engineers	**MODEL** Development and Clash Management	**IPD** Integrated Project Delivery and VDC	**REALITY** Capture Technology	**VISION** for the Future

Co-Location and Interdisciplinary Modeling



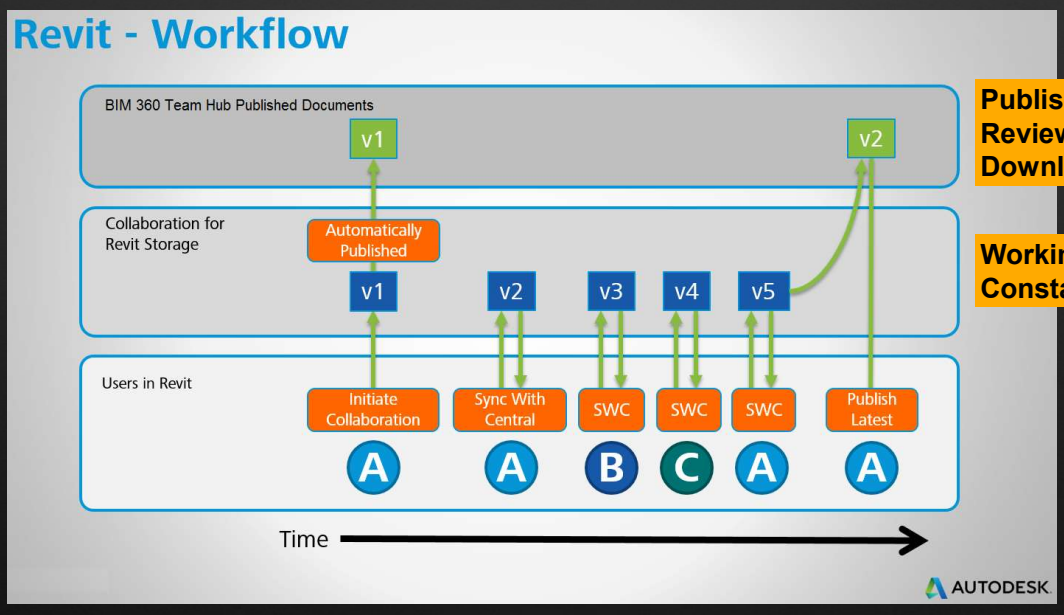
Cloud based models

https://www.bentley.com/en/products/product-line/project-delivery-software/projectwise-design-integration



http://au.autodesk.com/au-online/classes-on-demand/class-catalog/classes/year-2016/collaboration-for-revit/ar17677#chapter=0

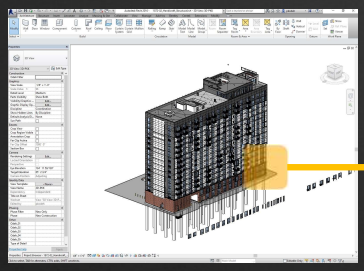
Cloud based models

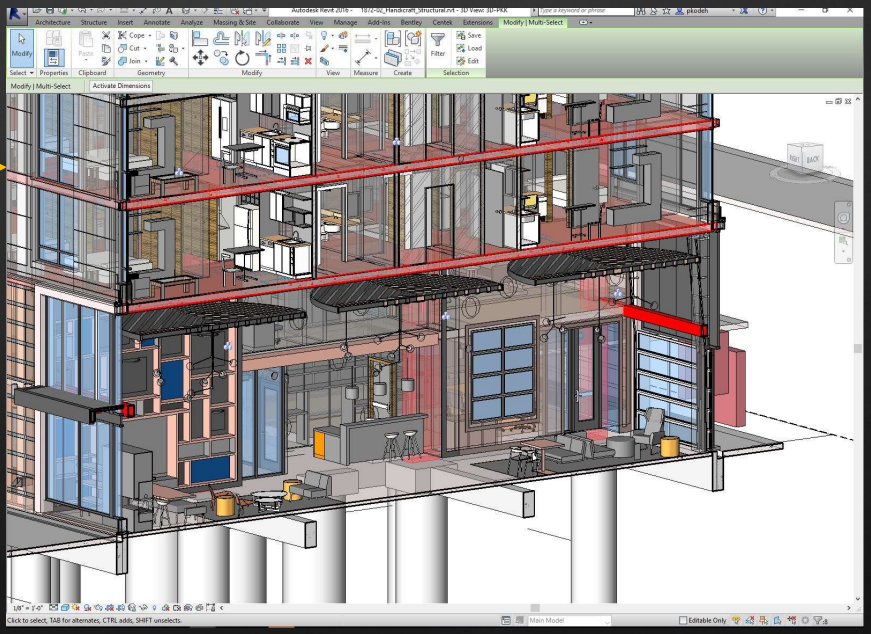


Published Models for Review, Markup, Download

Working Models Constantly Updated

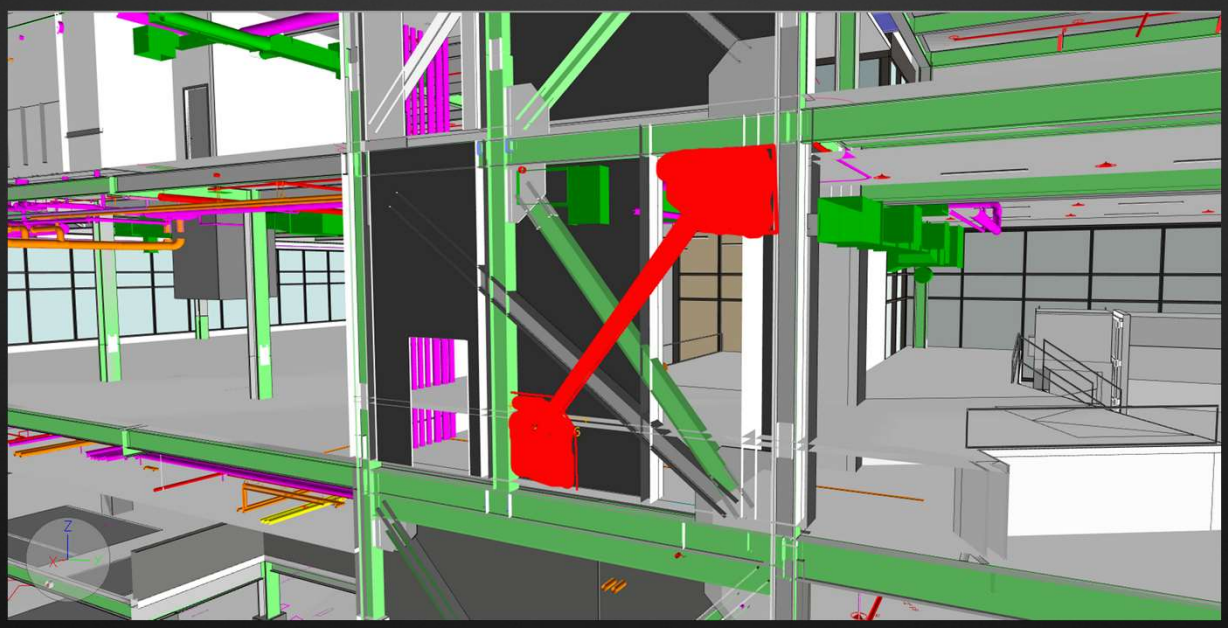
Cloud based models





Example of integrated cloud based model (structure, architecture, interiors, MEP)

Clash Detection



Case Study

Mercedes Benz Stadium

Atlanta, GA

BUROHAPPOLD ENGINEERING

Courtesy of Erleen Hatfield, Buro Happold Engineering

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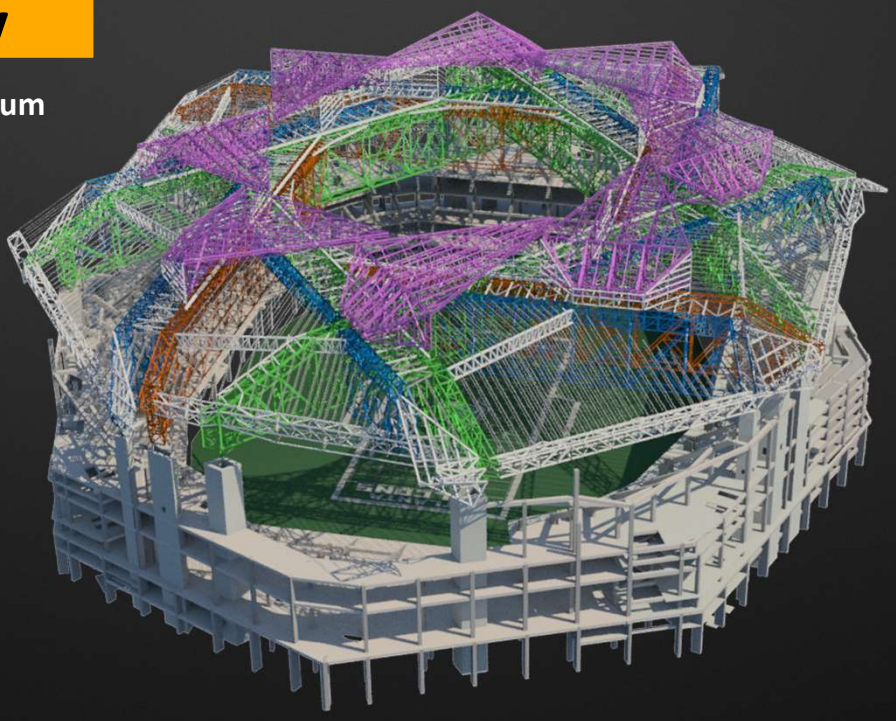
Case Study

Mercedes Benz Stadium

Atlanta, GA

Integrated modeling by engineer and fabricators



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Mercedes Benz Stadium

Atlanta, GA

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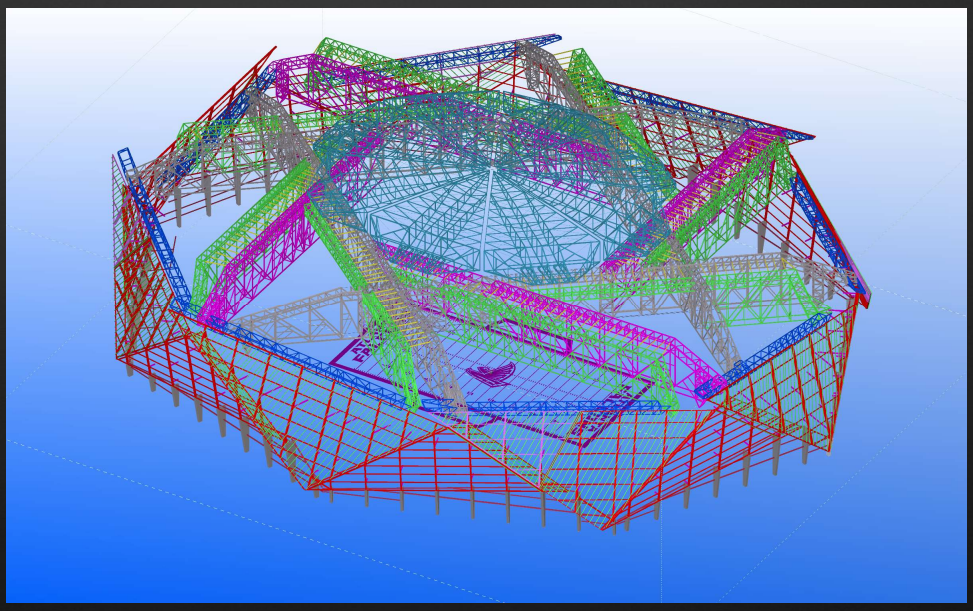

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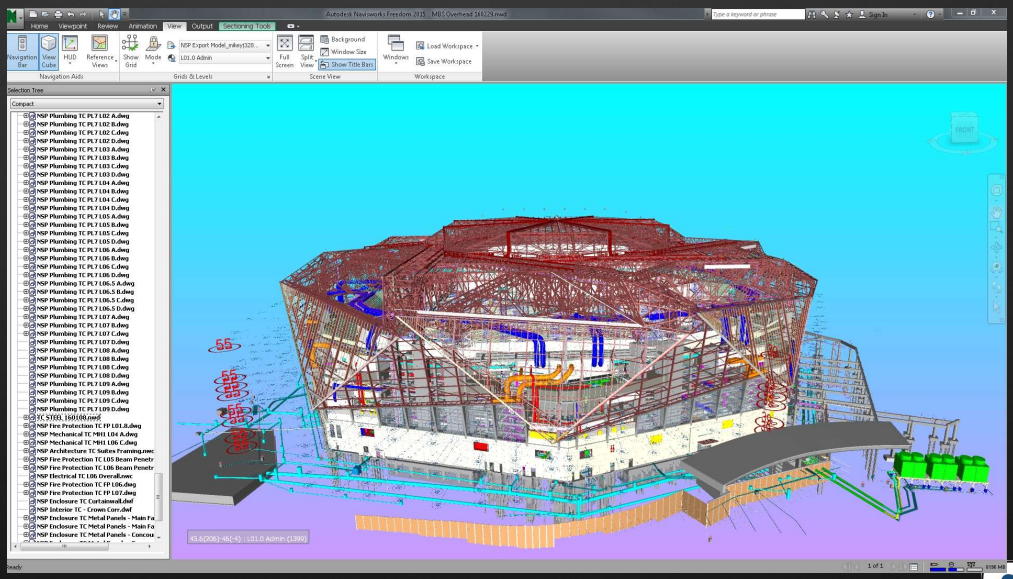

BUROHAPPOLD ENGINEERING

Courtesy of Erleen Hatfield, Buro Happold Engineering

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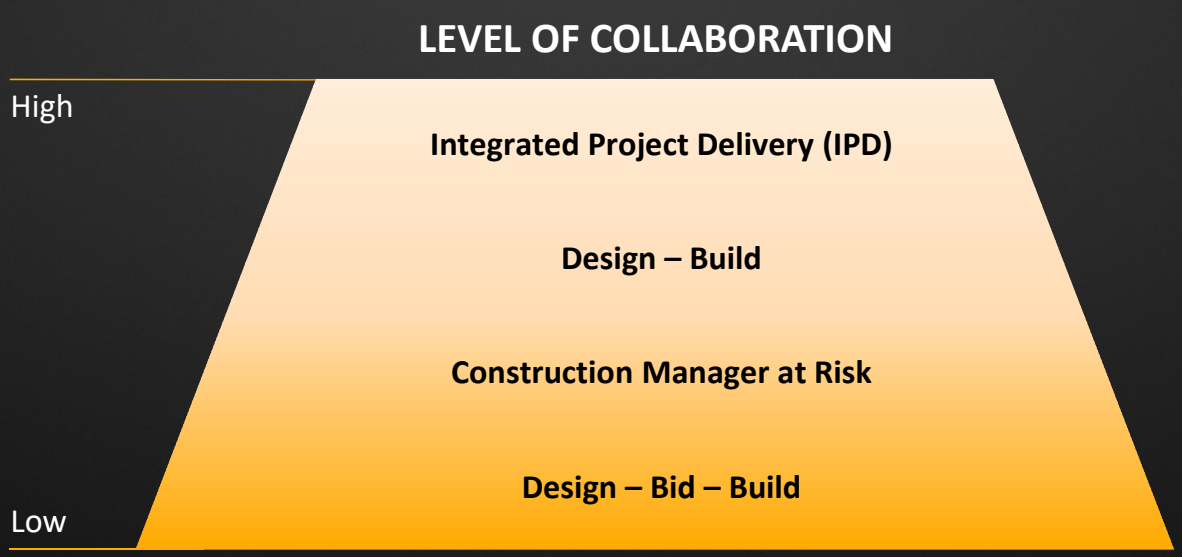
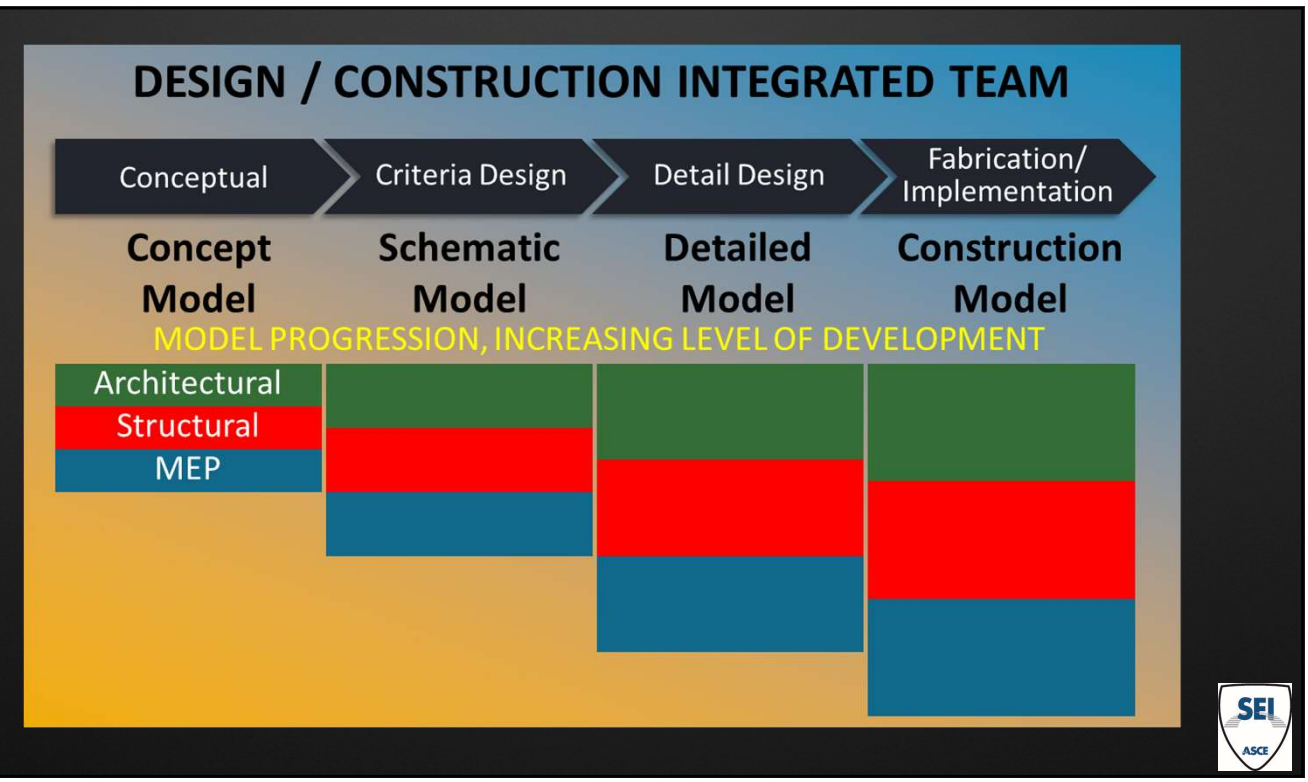
Design vs. Construction: The Standard Approach

The Answer: Collaborative Project Delivery





The Five Pillars of IPD

1. Early Involvement of Key Participants
2. Joint Project Control and Decision Making
3. Shared Risk/Reward Based on Project Outcomes
4. Jointly Developed Validated Targets/Goals
5. Reduced Liability

Source: After Howard Ashcraft – Contract Reference Materials for BMC IPD project

Case Study

Boston Medical Center
Master Plan

Boston, MA

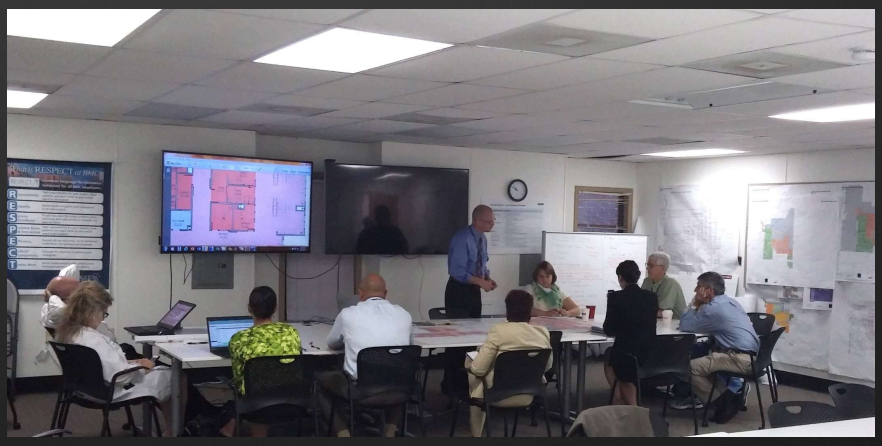
Integrated Project Delivery

Case Study

Boston Medical Center
Master Plan

Boston, MA

Co-location for coordination



odeh engineers

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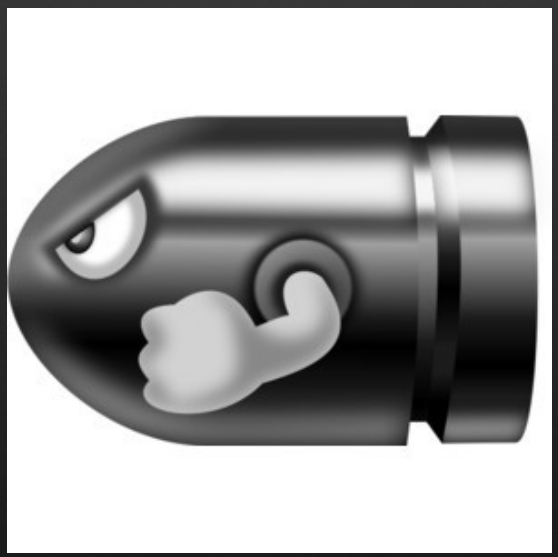
Is IPD the Answer?



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Point Clouds

What is a Point Cloud?

- A dense set of points each with a unique x, y, and z coordinate
- Points created by taking a series of laser measurements to the object of interest
- Three-dimensional representation of surroundings

Point Clouds

Benefits

- High density, accurate set of data
- More complete and accurate information available than from conventional measuring methods
- Reduced time for more information

Laser Scanning

Use Cases

- Rapidly generate as-built documentation and models when existing drawings are not available
- Check for discrepancies between drawings and existing conditions
- Easily and accurately understand complex existing geometries
- Obtain measurements that would otherwise be impractical to take
- Observe major structural deficiencies and excessive deflections
- Integrate with other 3D modeling tools and BIM

Structural Investigation of Deficient Structure

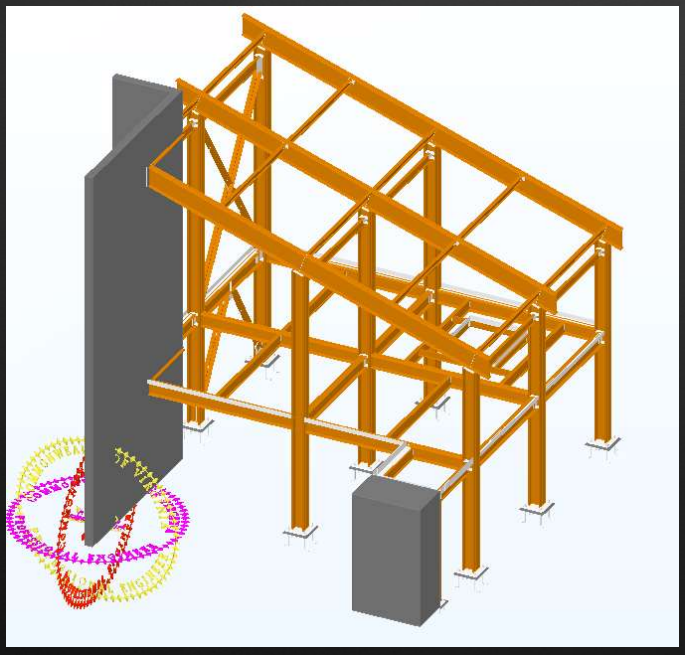
- Scan of a long-span post-tensioned roof structure with deflection issues
- Verification of structural analysis model used to predict existing deflected shape
- Relative elevations determined along the entire length of the structure

Coordination with Complex Geometries

Coordination with Complex Geometries

1	2	3	4	5	6
HISTORY of VDC	**SCOPE** of VDC for Structural Engineers	**MODEL** Development and Clash Management	**IPD** Integrated Project Delivery and VDC	**REALITY** Capture Technology	**VISION** for the Future

Model Based Delivery



3D PE SEAL ©

PROPRIETARY
COURTESY OF PETER CARRATO, PE, SE, CEng

How to Stamp a BIM?

Each "block" could represent a revision of a "BIM" with a given timestamp

Copies of "blocks" are stored on many computers in a network

Block n
- Hash (n)
- Hash (n-1)
- Timestamp
- Nonce

Block n+1
- Hash (n+1)
- Hash (n)
- Timestamp
- Nonce

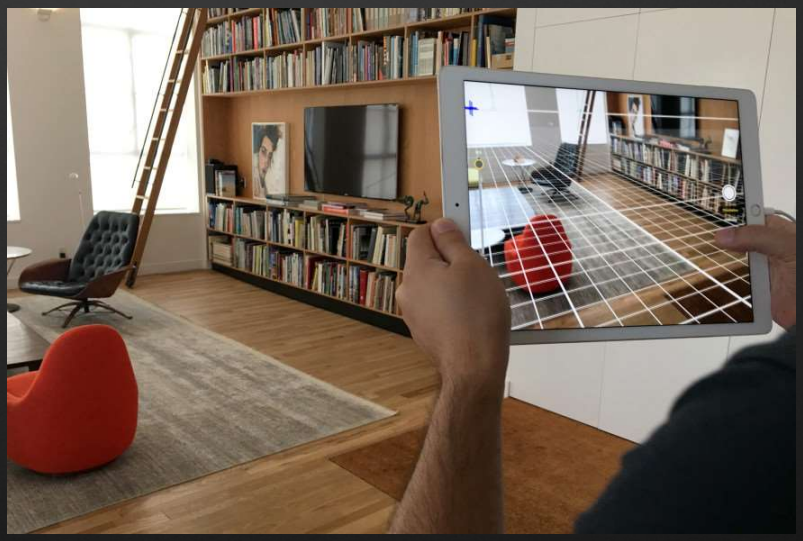
Block n+2
- Hash (n+2)
- Hash (n+1)
- Timestamp
- Nonce

Blockchain Technology

- Developed originally for cryptocurrency
- Method of storing and certifying a database
- Immutable record of transactions
- Transparent ledger

Virtual Reality

Augmented Reality



Morpholio Trace
(www.morpholioapps.com)

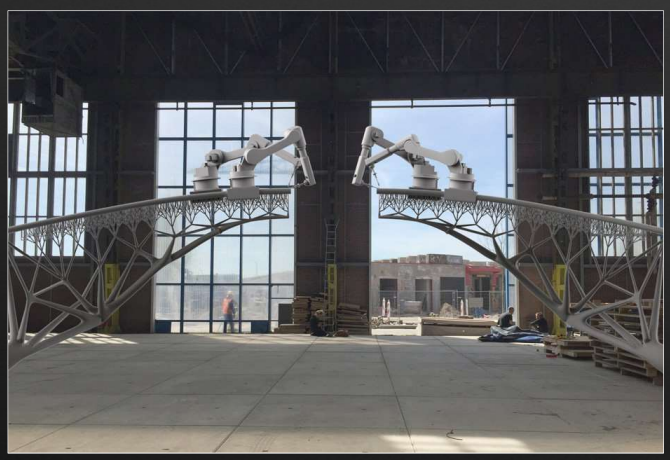
3D Printed Buildings

MX3D bridge (Amsterdam)

Courtesy of Tim Guertjens, MX3D
www.mx3d.com

3D Printed Buildings

MX3D bridge (Amsterdam)

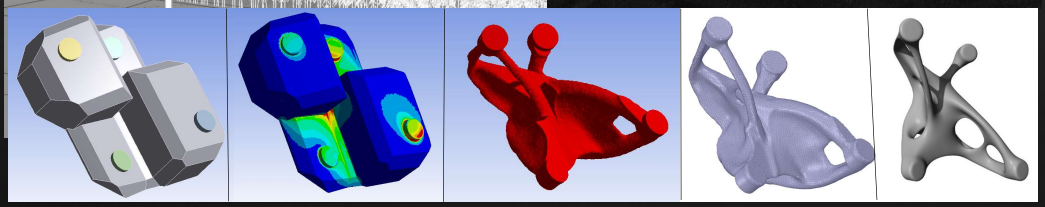


Courtesy of Tim Guertjens, MX3D
www.mx3d.com

3D Printing of Spider for Point-Supported Glass

Courtesy of Glenn Bell and Paul Kassabian, Simpson, Gumpertz and Heger

SIMPSON GUMPERTZ & HEGER



A strategy to promote leadership and innovation in Structural Engineering

http://www.asce.org/structural-engineering/sei-futures-fund/

Structural Engineering Institute - Council of American Structural Engineers White Paper

Building Information Modeling for the Engineer of Record

July 23, 2011

Contributors:

Joseph M. Ales Jr., Ph.D., S.E., Principal, Walter P Moore, Los Angeles, CA
Erik Kneer, S.E., Associate Principal, Degenkolb Engineers, Oakland, CA
David Mykins, P.E., Senior Vice President / Branch Manager, Stroud Pence and Associates, Raleigh, NC
David J. Odeh*, P.E., SECB, Principal, Odeh Engineers, Inc., N. Providence, RI
Antranig (Andy) M. Ouzoonian, Principal, Weidlinger Associates, New York, NY
Andrew M. Rauch P.E., S.E., LEED® AP, Principal, BKBM Engineers, Minneapolis, MN
Dennis Wittry, PE, Principal, Walter P Moore, Houston, TX

(*) editor

NOTE: This white paper was developed by a joint working group consisting of members of the *Joint Structural Engineering Institute-CASE Committee on Building Information Modeling* and the CASE *National Guidelines Committee*.

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 - maximum size - purpose	Specific element design intent sufficient for fabrication model development. 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				

(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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SEI Vision for the Future

STRUCTURAL ENGINEERING INSTITUTE

Executive Summary
September 2015

The "Vision for the Future" is SEI's long term strategy to ensure a vibrant and dynamic future for the structural engineering profession.

We are at a turning point. Increasing complexity of structures, computer automation, and global interconnectivity are among many trends that are fundamentally changing the profession. Our challenge is to harness these trends to reinforce and expand the role of structural engineers as innovators and leaders.

SEI envisions a future where, as stewards of the built environment, structural engineers will make key contributions to the advancement of society on a global scale. They will create and use innovative technologies to design inspiring, resilient structures while ensuring the economic and sustainable use of natural resources. The best and brightest individuals will choose to enter the profession, which will provide them with rewarding and dynamic opportunities for advancement and recognition at every stage of their careers. Structural engineers will be leaders and innovators that play a critical role in improving the safety and well being of the global population.

To achieve these long term goals, SEI recognizes that the profession must fundamentally evolve. Therefore, we are leading and investing in the following key initiatives:

- Reform structural engineering education. Adopt new educational models to equip students with the broad technical, communications, and critical thinking skills they will need to compete in the global economy.

• Improve mentoring and continuing education. Develop a national, standardized framework to launch the careers of young professionals, and create a meaningful platform for lifelong learning and constant professional growth.

• Create a new SEI global activities division. Expand the influence of SEI and our standards overseas, address the needs of a worldwide membership, and position our members as global leaders in structural engineering research and practice.

• Promote performance based codes and standards. Give structural engineers new tools to liberate them from the limitations of prescriptive code-checking, encourage innovation in their designs, and increase the value of their services.

• Lead multi-disciplinary summits on technical matters of broad interest. Think outside of the traditional boundaries of structural engineering to identify and apply the most advanced new technologies and science to the practice.

• Promote the structural engineer as a leader and innovator. Support and encourage the expansion of members' roles to recognized positions of leadership in society by equipping them with the tools they need to succeed and be recognized by the public.

• Advocate for structural engineering licensure. In partnership with our peer associations, advance the implementation of the SE license as a post-PE credential to ensure public safety and recognize the unique qualifications of structural engineers.

SEI will continuously measure the progress of these initiatives and adapt our strategy when needed to respond to the dynamic trends that will shape the future.

The "Vision for the Future" firmly establishes SEI as an agent for positive change in the structural engineering profession. By harnessing the energy and talent of our members, along with engaging our partners in allied disciplines, we can ensure the long term viability and success of structural engineers as leaders and innovators in the global economy.

To learn more about SEI's vision, visit: www.asce.org/SEI

American Society of Civil Engineers
1801 Alexander Bell Dr. Reston, VA 20191
(800) 548-2723 | (703) 295-6300
www.asce.org/SEI | sei@asce.org