v3.0

BIM Guidelines for Major Renovations

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1 Acknowledgements

Duke University gives credit to the organizations that have developed previous VDC Guidelines and Standards. Particular acknowledgement goes to:

1. Indiana University BIM Guidelines (October 2009; revised July 2012)
2. State of Ohio BIM Protocol (2010)
3. Western Michigan University BIM Guideline (2100)
4. Penn State BIM Guideline (2013); Ralph Kreider, John Messner
5. buildingSMART Alliance and CFTA (Campus FM Technology Association)
6. NBIMS National BIM Standard (March 2007)

2 Acronyms

Architectural Supplemental Instructions	ASI
Architect/Engineer	AE
BIM Execution Plan	BEP
Building Information Modeling	BIM
Computer-aided Drafting	CAD
Design Development	DD
Duke University	Duke
Facilities Management Department	FMD
Mechanical/Electrical/Plumbing/Fire Protection	MEPFP
Schematic Design	SD
Three Dimensional	3D
Two Dimensional	2D
Virtual Design and Construction	VDC

3 Virtual Design and Construction (VDC) Mission

Duke University is an academic university where the student comes first. James B. Duke's indenture mandated that Duke "exercise leadership and vision." The VDC Guidelines are intended to support the university-wide adoption of virtual design and construction technology and data-rich computer modeling practices.

The quality of Duke is enhanced through integration with education and research in an environment that encourages excellence of practice, critical inquiry and learning.

The Duke Facilities Management Department (FMD) is responsible and accountable for the leadership and management of all facilities and infrastructure on the campus. FMD has determined that the use of VDC technologies, Building Information Modeling (BIM) and the process changes that accompany the use of these tools are of vital strategic importance to the architecture/engineering/construction facilities management lifecycle.

Duke expects consultants' model(s) to support and enhance the following mission and goals:

- Incorporate VDC tools as integral, fundamental components of the Duke Project Management methodology.
- Incorporate VDC process requirements and best practices of integrated project deliver into the university's contracting, procurement and implementation processes.
- Facilitate digital preconstruction systems coordination using ARCHIBUS room naming conventions
- Provide more accurate and enhanced cost feedback share model interactions with estimators
- Support and drive the creation of prefabricated components providing for delivery clearances
- Accurate reflection of the as-built condition at closeout
- Support commissioning and achievement of LEED credits
- Enhance existing Duke facilities, operations, maintenance, Infor EAM configurations
- Support all Duke enterprise-wide systems, databases and protocols
- To be accurate based on proper control registration of scan data and modeling based on scans

4 Implementation

4.1 VDC Execution Plan

As required by the ConsensusDOCS™ 301, each project will execute a BIM Execution Plan (BEP) as soon as practicable, but no later than ninety (90) days after the execution of a contract between Duke and all project participants.

The Duke BEP template is available for download from the Duke FMD website: Forms & Instructions

All project participants will send appropriately authorized representatives to the project kick-off meeting, as well as all subsequent planning meetings. In addition to the Model Manager, personnel from FMD Facility Operations and representatives of involved vendors and service partners, will be present at all project kick-off meetings.

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Data Management Systems used for Documentation and Facility Maintenance

- ARCHIBUS – Room naming and space management
- Infor EAM – Asset management
- Meridian – Document management

In addition to the Model Manager, appropriate personnel from Duke's active project management software vendors and service partners will be present at all project kick-off meetings. Attendance at subsequence planning meetings is at the discretion of the Model Manager.

The Project Execution Plan will be reviewed and approved by the Model Manager within ten (10) days of submission.

The fully executed BEP will then be attached to each governing contract for the project.

Duke FMD expects their design, design consultants, engineering and construction partners to formally acknowledge, plan for and execute project-appropriate VDC strategies and workflows which best support a project's given contractual framework.

4.2 Duke Ownership of BIM Models After Deliverables Are Issued

Duke will retain ownership of all project models from all contributing sources, consistent with the governing contract and Section 6 of the ConsensusDOCS™ 301 VDC Addendum as executed by the project team. Duke's ownership of project models and documentation applies to both final deliverables and all intermediate materials generated during the design process.

4.3 Expected Workflow

Note: See exhibit G as scanning and processing must take place prior to design.

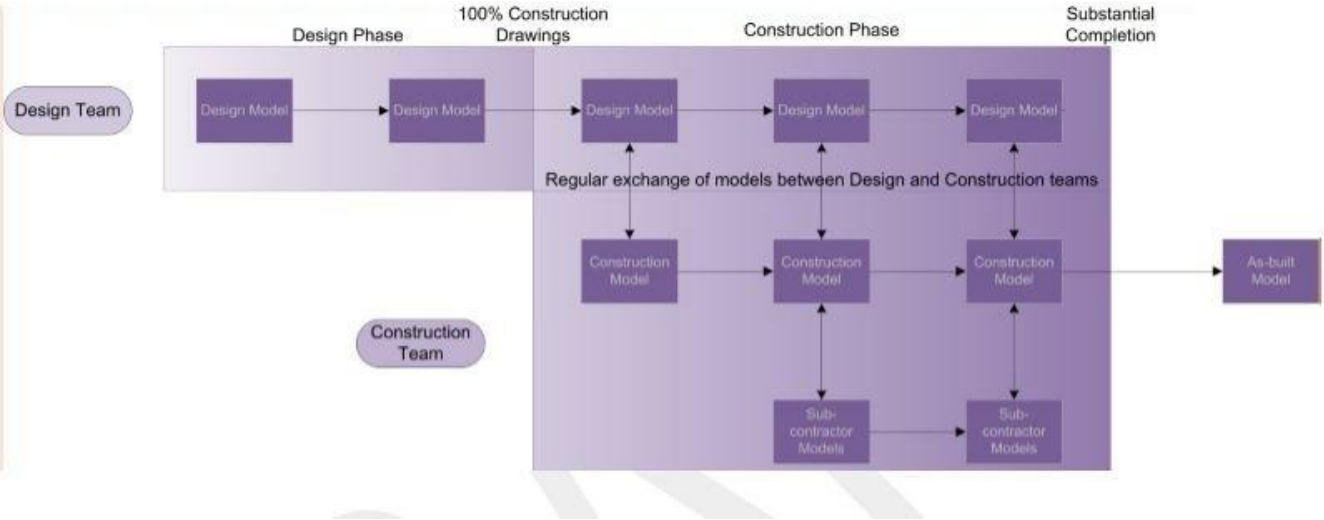


Figure 3.3.1 – Expected Workflow Diagram 1

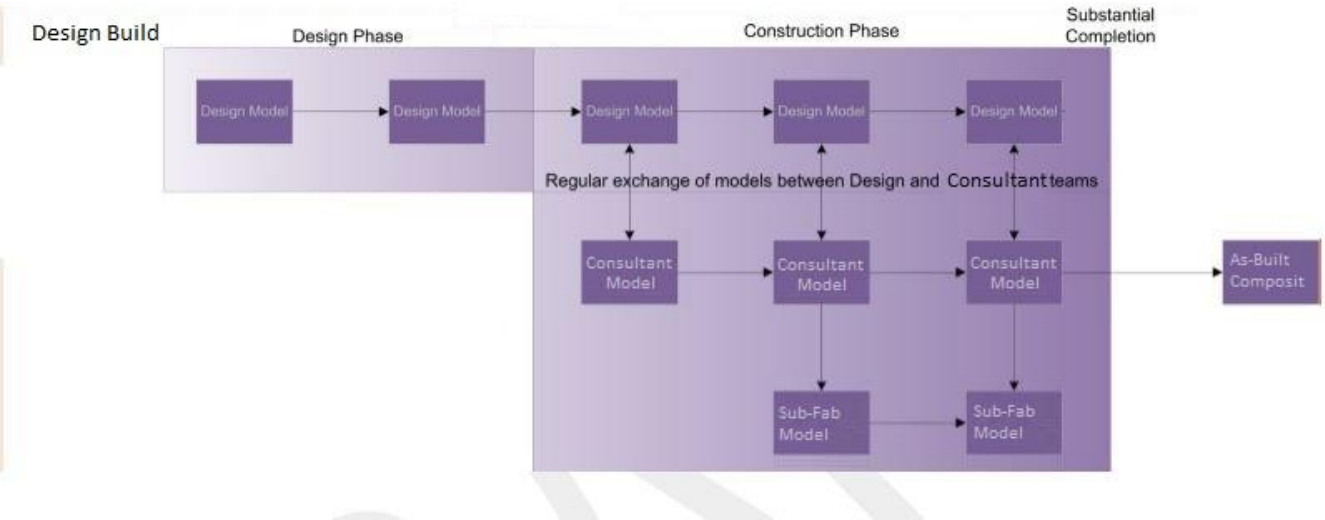


Figure 3.3.2 – Expected Workflow Diagram 2

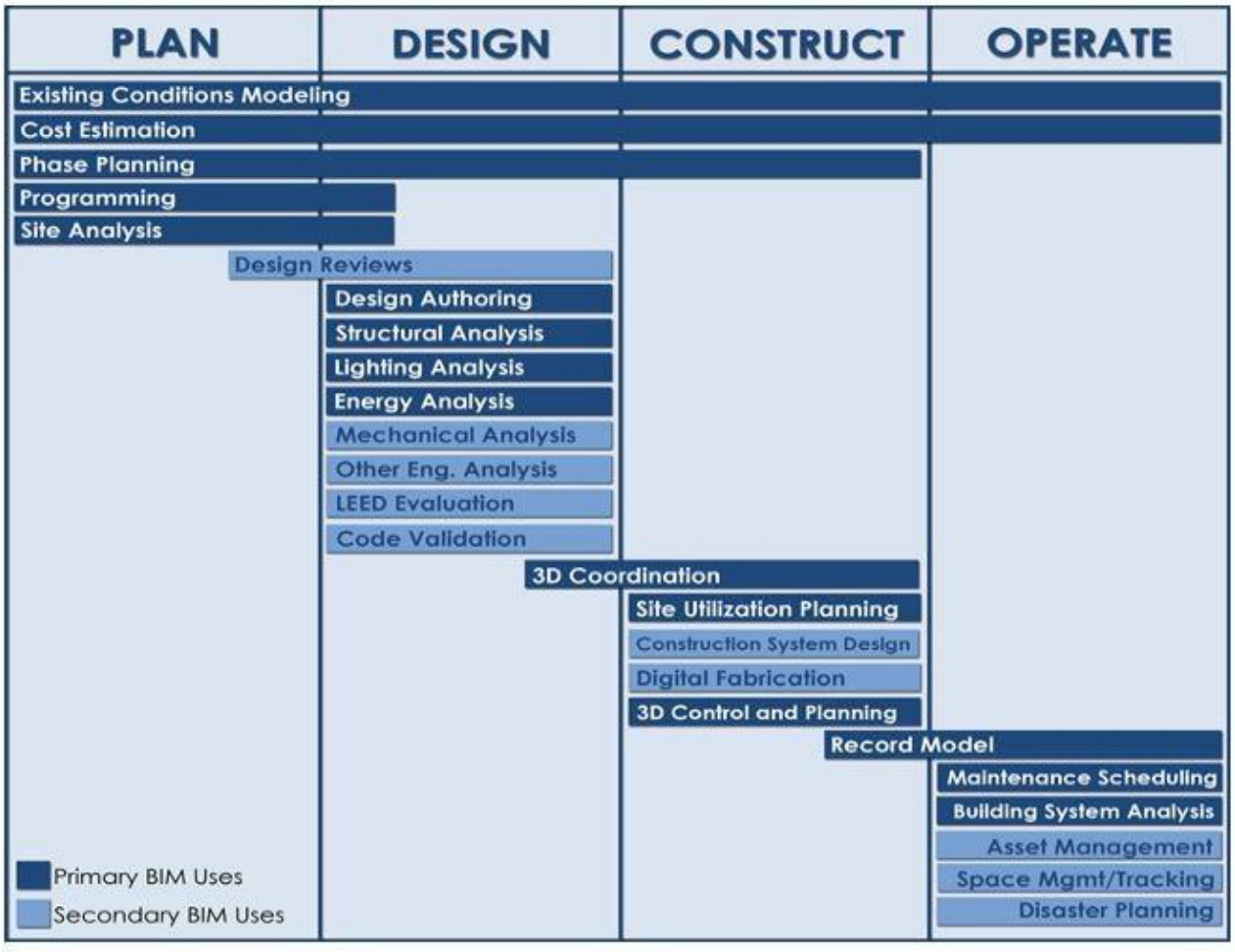


Figure 3.3.3 – Image Courtesy of John Messner, Penn State

5 Design Guidelines

5.1 Design Model Process

The required design VDC file format, for all Duke Projects, is the latest team-accepted versions of the platform (accepted software platforms are listed in Exhibit A) at the time of submission. All exceptions need approval from the Model Manager.

The design team will begin development of the models, based on existing scan data with the software listed in Exhibit A, at the onset of the pre-design (conceptualization) phase. The use of linked files, that are not fully parametric (i.e. files requiring manual, rather than automated referencing), must be approved by the Model Manager.

Irrespective of the project's contractual arrangement, the design team will, as soon as possible, but no later than the start of Design Development, submit evidence of collaborative sharing of information with a tracking log of issues on a bi-weekly basis. This may be submitted as a composite model review log, with markups of adjustments or clearance issues, thumbnail views of issues with dimensional requirements along with optimization schedules. The purpose of this type of information is to track resolutions keeping a log of issues so that the reason decisions are made can be tracked. If an issue needs to be revisited, one can then understand the history of the issue with respect to how the design evolved.

Parametric models will contain all geometry and elements with physical characteristics, tagged with a unique global ID in compliance with Duke's nomenclature policies, and linked to project data needed to fully and accurately describe the design and construction work. All major consultants on the design team including, but not limited to: architectural; structural engineering; mechanical, electrical and plumbing engineering; life safety; fire protection; civil site utilities; and telecommunications are required to deliver their respective project scopes using one or more of the modeling platforms listed in Exhibit A.

All Architecture/Engineer (AE) consultants are required to deliver the project files using authoring software capable of producing three-dimensional solids based models with appropriate access clearances modeled to be used for coordination with the correct insertion points as determined by the AE.

The design team will provide a fully coordinated and assembled model. In addition, the design team will provide postings that include the other disciplines for periodic quantity extractions and for planning construction early in the Design Development phase.

Each project will be required to develop an Object Element Level of Development (LOD) Matrix (refer to Exhibit F) as part of its Execution Plan. The matrix will assign responsibility, level of development by project phase and accurately describe the design and construction work.

5.1.1 Model Integrity

- All two dimensional (2D) construction documents delivered to Duke in the Autodesk® AutoCAD® .DWG file format will have been derived and extracted from the design team model and will not include supplemental line-work, sketches, or annotation from any additional 2D computer-aided drafting (CAD) program(s) applied post-export from the model. All duplicate elements will be removed from the design model.

- All 2D detailing, annotation and other graphic information will be created natively in the modeling platform. Linking of drawings, schedule and any other documents from major consultants that have been created in an outside CAD program (e.g. Autodesk® AutoCAD®) which are linked or imported into the parametric model will not be accepted unless authorized by the Model Manager.
- The design team is expected to continuously maintain and update the design models through end of construction such that the final design model reflects the final design intent accurately.
- At a minimum of once (1) per month during construction, the design model will be updated by the design team to incorporate design changes from official change orders, ASIs, etc. The intent is that the design model information will be continuously shared through the project team collaboration site. This can be accomplished with plugins from the accepted platform software if the team agrees at the kick-off meeting.

5.1.2 Consultants

Duke requires the design team to work collaboratively with each of the owner's consultants to ensure that all the modeling work is coordinated between the various design team consultants and the owner's consultants that are part of the project team. A two-way exchange of models will be expected on a regular basis.

5.1.3 Design and Construction Model Elements

At a minimum, the design models will include the following elements:

5.1.3.1 Architectural Elements

A project's model file(s) will contain all architectural features for a project. These features include, but are not limited to:

- Exterior wall systems, interior wall systems and fire rated walls
- Floor levels and architectural floors based on survey elevations (if know as existing)
- Equipment including owner-provided equipment (AE to model existing equipment if model in unavailable from manufacturer)
- Reflected ceiling plans utilizing curtain wall families (example available upon request)
- Vertical circulation including elevators, stairs, escalators and railings
- Doors and door frames including access doors to existing shut-off valves, panels, etc.
- Glazing including windows, interior glazing, curtainwall and storefront
- Millwork and casework furniture
- Finishes including all room paint codes, flooring codes and other finish items
- Toilet partitions and accessories
- Specialties

5.1.3.2 Structural Elements and Analytics

Structural features along with sharing analytical models are required. These features include, but are not limited to:

- Foundations with stress diagram analytics at foundation wall systems to facilitate sleeve placement
- Columns, beams and joists based on existing scan data.
- Column grid(s) labeled with control lines to be used for layout
- Brace frames and shear wall (analytics at shear walls and link beams)

- Structural slab with shear and deflection analytics to facilitate sleeve placement
- Stair supports and window and door opening lintels
- Miscellaneous structural components (e.g. kickers, bracing, toiled partition supports, moveable wall supports) to the extent possible existing members will be modeled from scan data, marked existing.

5.1.3.3 Mechanical, Electrical, Plumbing, and Fire Protection Elements (MEPFP)

Structural features along with existing scan based models are required. These features include, but are not limited to:

- Mechanical ductwork system including access to fire dampers and balancing dampers
- New and existing systems including hot and chilled water, steam, gas, exhaust systems and valves
- Mechanical equipment with disconnects including access for maintenance and fuse replacement
- New and existing Sanitary systems including access to cleanouts and basins
- Domestic hot and cold water systems with access to shutoff valves
- Fire protection pumps with access, controllers, system lines and branch piping, and drain valves.
- Standpipe risers, sprinkler lines, sprinkler heads, wall hydrants and fire department connections
- Fire alarm system devices, control panels and access in front of control panels
- All conduit 1” diameter or greater including concrete encasement for high voltage lines
- Plumbing fixtures and equipment such as boilers and pumps
- Electrical light fixtures, devices, equipment, transformers, duct banks, switchgear and engine generators. All existing equipment shall be labeled as such, modeled from scan data.
- Existing and new Electrical panels with access, cable tray systems with wire way access
- Equipment clearances for access, service space requirements, gauge reading, valve clearances and other operational clearances and access panels

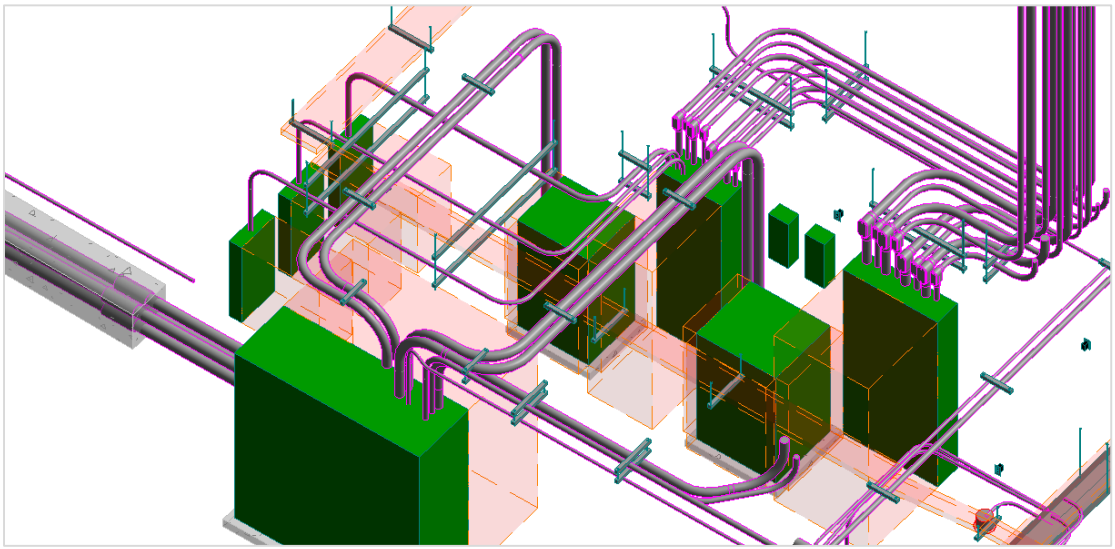


Figure 5.1.3 – Example of equipment with modeled clearances courtesy of Vada Kornegay

5.1.3.4 Life Safety and Communications Elements

The life safety and telecommunication system devices will be modeled for this project and be require to be listed with unique identifiers. Such items include:

- Input devices (flow and tamper switches from the fire protection systems
- Fume hood and specialty FM 200 exhaust systems annunciators
- Audible horn and strobe devices and emergency notification signage and systems
- Pull station and other notification devices
- Associated equipment and clearances
- Permanently-mounted fixtures building controls
- Clearance zones for access, valve service, gauge reading, etc.

5.1.3.5 Sensor Monitoring

Unique identifiers and required on all major serviceable equipment and on sensor devices to detect system flow. This enables interactive ties between graphical models and the building automation systems.

5.1.3.6 Civil Engineering Elements

The civil model files(s) will contain all modeled features and elements within the property line boundaries. These include, but are not limited to:

- Topography (3D terrain model of existing conditions within the construction boundary and all project-related site disturbances)
- Site utility systems (existing and new) relocated and rerouted systems and temporary lines. Radio frequency marker locations for existing and new site utilizes shall be modeled in APWA colors.
- Power poles and traffic signaling systems showing light poles that need to be removed and/or protected during crane setups, operation and removal
- Electric, storm, sewer and water structures, pump stations, vaults (existing and new) including existing structures and new items proposed within the property line and proposed offsite as required

6 Model-Based Extractions & Comparisons

6.1 Quality Checking Methodology

The design and consultant teams will, individually and collectively, take all necessary steps to prepare the model content in a manner that streamlines accurate quantity takeoffs to support the estimating process. This includes synchronizing cost codes and removing extraneous stat such as duplicate items or alternative design option. It also includes verifying modeled scan data is accurate and fencing off areas of the scan model that must be removed for demolition and access.

Duke requires that the construction team utilize the design VDC to back check and corroborate their traditional estimating and quantity takeoff methods with model extractions.

At a minimum and regardless of governing contract arrangements, the construction team is required to perform formal reviews of the project's design VDC at: 100% Schematic Design (SD), 50% Design Development (DD) and 100% DD to corporate their traditional quantity takeoff and systems estimating methods.

Summary reports of these estimate reviews will be prepared and delivered to the project manager.

6.2 Existing Building Geo-Referencing

The design model lead will confer with the GIS Manager and convey to the team the insertion point for the site plans and building models to appropriate coordinate system and plane datum(s).

All survey, scan data and property line information will be provided in a digital format that allows the design team to accurately set the project and site coordinate system(s) and property line elements within the appropriated design team models.

The design team will follow the **Duke Room Use Standard** for labeling rooms. If the design team anticipates that data exports will be necessary for energy modeling related to LEED certification, it is essential that energy modeling zones are modeled and defined in a manner consistent with all certification requirements and Section 4.6 of this document.

6.2.1 Program and Space Validation

The design team will use the model, along with other appropriated analysis tools, to compare and validate the project's stated program requirement with the design solution.

At a minimum, the following will be automatically extracted to MS Excel and scheduled from the design model:

- Gross building area
- Department net

6.3 Spatial Coordination Meetings

The design team is required to use a collaboration platform (Solibri Model Checker, Autodesk® Navisworks®, BIM 360™ Glue® or an approved equal) for performing tracking of conflict resolutions between the disciplines.

As soon as practicable, but in no event later than 25% SD, the design team will begin holding regularly-scheduled initial conflict resolution reporting meetings. These meetings should begin at Design Development kick off and must occur biweekly at a minimum. The design team, in conjunction with the Duke VDC Manager, will agree upon the conflict reporting protocol. The conflict reporting protocol will seek to benefit from current industry best practices such as the following tiered approach:

- Level One Conflicts (critical to design and construction)
  - Mechanical ductwork and piping vs. ceilings
  - Mechanical ductwork and piping vs. rated walls
  - Mechanical ductwork and piping vs. structure
  - All equipment and clearances vs. walls
  - All equipment and clearances vs. structure
  - Mechanical equipment and fixtures vs. electrical equipment and fixtures
  - Mechanical ductwork and piping vs. plumbing piping
- Level Two Conflicts (important to design and construction)
  - Casework vs. electrical fixtures and devices
  - Furnishing vs. electrical fixtures and devices
  - Structure vs. specialty equipment
  - Structure vs. electrical equipment, fixtures and devices
  - Ductwork and piping vs. electrical equipment, fixtures and devices
  - Ductwork vs. floors
- Level Three Conflicts (recognized as changing regularly)
  - Casework vs. walls
  - Plumbing piping vs. electrical equipment, fixtures and devices
  - Plumping piping vs. mechanical equipment, fixtures and devices
  - ADA clear space requirements vs. doors, fixtures, walls and structure

Summary reports from each conflict meeting will be submitted to the Duke VDC Manager or other Duke staff as requested. All design team system conflicts will be resolved prior to the submission of any 100% CD package associated with a project. Any unresolved conflicts that are a part of any 100% CD submittal package must be documented with a written narrative explaining, with each conflict numbered, the reasoning and/or circumstance for each unresolved conflict and be submitted with the corresponding 100% CD submittal. Please note, the Duke Model Manager will be invited to all project conflict meetings.

All appropriate Duke Facilities Management & Operations personnel and partners will be included in all project kick-off meetings, as well as all major milestone conflict meetings. Attendance at additional conflict meetings is at the discretion of the parties and the Model Manager.
The design team will provide a fully-coordinated and assemble model in a collaboration software format (Autodesk Navisworks®, BIM 360™ Glue® or an approved equal). If utilizing Autodesk® Navisworks®, the design team will provide .NWD, .NWF and .NWC file formats.

6.4 File Storage Systems

If acceptable by the team at the kick-off meeting, the Architect may use their internal collaborative site for the distribution of models to the team. Systems such as Autodesk® Buzzsaw®, Newforma®, Hi-wire, Base Camp,

Sharepoint, Boxx and customized FTP sites and extranets may be used as long as Duke FMD approves. Such sites will have sufficient file size storage to accommodate the project modeling needs. These sites may parallel the various team's systems if so agreed up front in the initial kick-off meeting, by the team. If securing protocols are required by Duke, such sites may have to pass third-party audits for acceptance. The administration costs of maintaining and administering such sites will be at the cost of the hosting organization and may not be charged as an additional cost to the owner. Such sites will allow all team members to have access to files as defined in the project BEP.

6.5 Utilizing Model Data for Energy and Optimization

If the design team is seeking LEED Energy Optimization credits, it is necessary that all rooms have defined volume characteristics with defined finished surfaces. This is necessary for the HVAC system designer to export the information from modeling applications such as Autodesk Revit to other applications for completing LEED credits such as:

- *Green Building Studio*® by Autodesk®
- *Carrier eDesign HAP 4.8* by Carrier®
- *Trace™ 700* by Trane®

Since each modeling platform has different requirements, the design team will validate and test these exports for projects seeking LEED ratings and/or wish to determine energy optimization credits. For those teams using Autodesk® Revit® as an example, various GBxml settings are required for these other analysis systems to work.

7 Model-Based Extractions & Comparisons

7.1 Construction Team VDC Processes

- The construction team will create construction gap models containing constructability items that are not represented in the design team VDC that are needed for constructability review and systems coordination with MEPFP trades (e.g. crane placement, scaffolding, safety).
- The required VDC file formats for construction gap models will be created in the most current version of the agreed upon modeling platform by the project team at the time of submissions. Any exceptions or migrations to newer versions require approval from the Duke VDC Manager.
- Duke requires that all major MEPFP subcontractors, system suppliers and equipment suppliers (subcontractors) utilize computer software capable of producing 3D .DWG, .SLDPRT, .NWD and/or .DGN files as part of their contractual deliverable, hereafter known as fabrication model(s).
- The construction model will contain all geometry, object enablers and physical characteristics and have links to produce data needed to fully and accurately describe the construction work.
- All drawings, schedules, simulations and services required for the assessment, review, bidding and construction of the project will be derived and extracted from the model(s).
- Each project will be required to develop an object element level of development matrix (refer to Exhibit G) as part of its VDC Execution Plan. The object element matrix will assign responsibility, level of development by project phase and authorized uses (e.g. analysis, cost estimation and schedule) for all elements needed to fully and accurately describe the design and construction work.
- Any 2D fabrication of shop drawings delivered to Duke in the Autodesk® AutoCAD® .DWG file format will have been derived and extracted from the construction team VDC only and not include supplemental line-work, sketches or annotation from any additional 2D CAD program(s) applied post-export from any project .RVT if Revit® was used.
- All 2D detailing, annotation and other graphic information will be creative natively in the Autodesk® Revit® platform. Drawings, schedules, or any other document plan set deliverables from major consultants that have not been created in an outside CAD program (e.g. Autodesk® AutoCAD®) which are linked or imported into the model, will not be accepted unless otherwise authorized by the Duke Model Manager.
- Irrespective of the project's contractual arrangement, the construction team will, as soon as possible, but no later than the start of DD, begin receiving, at a minimum, the design model from the design team on a bi-weekly basis.
- As the design model is updated through construction at least once a month, the construction team will incorporate all design updates into the construction model ensuring that the construction model reflects the to-be-constructed or constructed conditions accurately. The construction model will also be published for the design team's review at least once a month.
- The construction team will submit the as-built models for the project within 30 days of substantial completion. These models will be submitted to the design team for review.
- The design and construction teams will, individually and collectively, take all necessary steps to prepare model content in a manner that streamlines the quantity takeoff and systems estimation process.
- Duke requires that the construction team utilize the design model(s) to back-check and corroborate their traditional estimating and quantity takeoff methods.
- At a minimum, and regardless of the governing contract arrangements, the construction team is required to perform formal reviews of the project's design model(s) at 100% SD, 50% DD and 100% DD to corroborate their traditional estimating and quantity takeoff methods.

- Summary reports of the construction team's formal estimate reviews will be provided to the Duke Mode Manager four (4) weeks after the issuance of each package.

7.1.1 Minimum MEPFP Subcontractor Model Elements

General modeling assumptions to be included in all MEPFP models:

All construction team models will contain element properties for all items required to support the full functionality of Duke's facility maintenance, operations and monitoring software. The scope and specific element property requirements will be determined and coordinated on a per project basis.

Operations and maintenance, warranty and product data documentation − Duke requires that the construction team VDC deliverable contain links to .PDF files of O&M, warranty and product data information. Specific linking scope and requirements will be coordinated on a per project basis but Duke anticipates documentation links to the following:

- Mechanical, electrical, plumbing and telecommunication equipment
- Fire protection equipment
- Security equipment and fire alarm devices control panels
- Owner-supplied equipment

7.1.2 Penetrations

- All penetrations in cast-in-place concrete will be modeled including penetrations through slabs and wall requiring special reinforcing for support steel. All penetrations through structural members will be modeled.
- All miscellaneous support steel will be modeled by their respective trades.
- All codes, industry standards and/or manufacturer-required clearances and/or access zones for serviceable equipment and components, will be modeled. These clearance and access zones will be represented as solids and provided as a separate family or on a separate layer.
- Where applicable, simple solid blocks will be used in lieu of complex geometries to limit file sizes.
- All serviceable components (control valves, isolation/shut-off valves, medical gas zone valves, fire dampers, smoke dampers, combination fire smoke dampers, fire alarm panels, equipment, etc.) will be tagged/identified in the record document as-built models in accordance with the final labeling scheme agreed to with Duke and the design team for the project.
- Subcontractor will create and provide composite models of each complete system upon completion of the coordinated process. These models will assist the owner in the service and maintenance of their new facility.
- Discipline-specific minimum model elements.

7.1.3 HVAC

Subconsultants will model all system components required to accurately depict the complete HVAC plumbing system. The subconsultant's final model will accurately incorporate all as-built conditions as documented by the relevant subcontractor's shop drawings, fabrication models and redlines.

- Ductwork − Sheet metal and fabric ductwork will be modeled with the duct flanges and insulation, or to the outside face dimension of the flanges/insulation, whichever is greater. All hangers will be modeled to ensure conflicts are minimized. Lengths of prefabricated assemblies (vertical or horizontal) will be noted for planning.

- Equipment – All equipment will be modeled to represent actual overall height, width and depth of manufacturer. Sizes and locations of duct and piping hookups will be verified with manufacturer(s). Access and service clearances/zones will be modeled for all equipment. This may be a separate layer so that this may be toggled on/off as required. Equipment includes, but is not limited to:
    - Furnace
    - Boilers
    - Hot Water Converters
    - Incinerators
    - Solar Energy Systems
    - Chillers
    - Ducts
    - Sheet Metal Enclosed Plenum Areas
    - Sound Attenuation Equipment
    - Variable-Air Volume Boxes
    - Air Balance Control Devices
    - Air Terminals
    - Package Units
    - Exhaust Fans
    - Heat Exchangers
    - Furnaces
    - Fire Dampers
    - Smoke Dampers
    - Combination Fire/Smoke Dampers
    - Walk-In Coolers
    - Freezers
    - Compressor Systems
    - Pool Equipment
    - Ventilation
- Fire/Smoke Dampers – All fire dampers, smoke dampers and combination fire/smoke dampers will be modeled, including all associated access doors and clearance zones. All fire dampers, smoke dampers and combination fire/smoke dampers will be tagged within the model in accordance with the contract documents or as approved by Duke FMD.
- Piping – All piping (HVAC, medical gas, fuel oil, etc.) including underground and any piping associates with mechanical equipment will be modeled. Pipes will be modeled to the outside diameter of the pipe (including flanges) or pipe insulations, whoever is greater. Pipe slope will be modeled. Pipe sleeves and supports will be modeled. Valves, vents, traps, fittings, connections and other components will be modeled. Access zones for valves will be modeled to ensure proper access is available for operation and maintenance.
- Electrical – All electrical components (conduit, boxes, equipment, devices, etc.) associated with mechanical equipment will be modeled. Conduits 1" or greater will be modeled individually. Smaller conduits ganged in runs of three (3) or more will be modeled but may be represented by a single block that include all mounting support and clearance.

7.1.4 Plumbing

Subconsultants will model all system components required to accurately depict the complete plumbing system. The subconsultant's final model will accurately incorporate all as-built conditions, as documented by the relevant subcontractor's shop drawings, fabrication models and redlines. The model must include:

- Piping – All plumbing piping and gas piping will be modeled including water, sanitary, storm, catch basins rain leaders, scuppers, access zones and equipment. Pipes will be modeled to the outside diameter of the pipe or the pipe insulation, whichever is greater.
    - Pipe slopes will be modeled. Pipe supports and sleeves through foundation walls will be modeled.
    - Valves, vents, traps, fittings, connections and other components will be modeled.
    - Access zones for valves will be modeled to ensure proper access operation and maintenance. Access zones will be modeled as an individual object, family or layer.

- Equipment – All plumbing equipment will be modeled to its overall height, width and depth. Access/service clearances/zones will be modeled as an individual object family or layer.
- All valves and cleanouts, along with access to valves/cleanouts will be modeled. Chain-operated valves are to be modeled as an access zone.
- Any electrical components (conduit, boxes, equipment, devices, etc.) associated with plumbing equipment will be modeled. Conduits 1" or greater will be modeled individually. Smaller conduits ganged in runs of three (3) or more will be modeled, but may be represented by a single block that includes al mounting support and clearance.

7.1.5 Electrical

Subconsultants will model all system components required to accurately depict the complete electrical system. The subconsultant's final model will accurately incorporate all as-built conditions, as documented by the relevant subcontractor's shop drawings, fabrication models and redlines. The model must include:

- Conduit – Conduit 1" or greater will be modeled individually. All horizontal and vertical concrete encased conduits will be modeled to include concrete encasement. Conduit smaller than 1" in diameter ganged in runs of three (3) or more will be modeled, but may be represented by a single block that includes all mounting support and clearance space. These requirements apply to all electrical systems including low voltage.
- Cable Tray – Cable tray, floor duct, wall duct, rated wall sleeves, access zones and electrical equipment including power distribution, branch circuitry and low voltage systems will be modeled. Access/service clearances will be modeled for all equipment and cable trays. Cable trays can either be modeled as a double stacked box, one for the tray and one for the zone, or modeled with the actual component as one and access zone as another. All access zones will be modeled as an individual object, family or layer.
- Equipment – All switchgear, engine generators, bus duct and motor control centers will be modeled. Access/service clearances/zones will be modeled for all equipment as an individual, family or layer.
- Lighting – Light fixtures will be obtained from the manufacturer and modeled accurately in terms of height and spacing to reflect the specific fixtures of the completed work. The light fixtures should represent the geometric extents of the approved light fixtures and also include a clearance layer representing the space needed to install and service the lights.
- Power – All power feeds to equipment including electrical work associated with HVAC, plumbing and fire protection, that is identified as part of the electrical contractor's scope, will be modeled. Access/service clearances/zones will be modeled for all equipment as an individual object, family or layer.

7.1.6 Fire Protection

Subconsultants will model all system components required to accurately depict the complete fire protection system. The subconsultant's final model will accurately incorporate all as-built conditions, as documented by the relevant subcontractor's shop drawings, fabrication model and redlines. The model must include:

- Fire protection system – All components of the fire protection system including but not limited to piping, valves, system equipment, fire department connection fitting, 3D fire and jockey pumps, controllers, supports, hose cabinets, standpipe risers, test valves, drain valves, branch lines, head locations and elevations, and sprinkler heads will be modeled.
    - Access/service clearances will be modeled for all equipment as an individual object, family void form or layer. Light red or translucent red may be used.

- Access zones for valves and for fire dampers and clearance to equipment delivery hatches and product delivery paths will be modeled to ensure proper access for operations and maintenance and to prevent arm over extensions from interfering.

- Fire alarm system (pink color system) − Fire alarm color panel with access locations, major conduit feeds, fire suppression systems such as hood exhaust systems and fire extinguisher cabinets will be modeled.
- Electrical – All electrical components of the fire protection system, including but not limited to switchgear panels, transformers and temporary power.

NOTE: Temporary power with voltage of 480 VAC or greater requires location approval and will be placed in the construction model during site logistics planning. Concrete encased electrical feeds, conduit 1" in diameter or greater, generators, motors and motor control centers and devices will be modeled.

7.1.7 Pneumatic Tube (If Applicable)

Sub-consultants will model all systems components required to accurately depict the complete pneumatic tube system. The sub-consultant's final model will accurately incorporate all as-built conditions, as documented by the relevant subcontractor's shop drawings, fabrication models, and redlines. The model must include:

- Pneumatic Tube System
- All tube stations, tubing, transfer stations and equipment must be modeled. Access space(s) for transfer stations will be included as needed to maintain clearance for maintenance.

7.1.8 Gas, Air, and Vacuum Piping (Medical Gases)

Subconsultants will model all systems components required to accurately depict the complete gas, air and vacuum piping (medical gas). The subconsultant's final model will accurately incorporate all as-built conditions, as documented by the relevant subcontractor's shop drawings, fabrication models, and redlines. The model must include:

- Mechanical Piping Systems
- Models will contain rough in location through casework with fitting spacing, termination fittings, valves, supports and access areas.

7.1.9 Telecom

Subconsultants will model all systems components required to accurately depict the complete telecom. The subconsultant's final model will accurately incorporate all as-built conditions, as documented by the relevant subcontractor's shop drawings, fabrication models, and redlines. The model must include:

- Telecommunication system
- Models will contain panels, cable tray, major conduit runs and fire wall penetrations.

7.2 Fabrication Model(s)

- All subcontractors will continuously develop, and keep up-to-date, the fabrication model(s) associated with their scope of work throughout the entire construction and closeout process. This includes, but is not limited to, updating the fabrication model(s) to include/incorporate all bulletins, updates, redlines, sketches, change orders, etc.

- Duke requires that upon project closeout, all subcontractor fabrication models will serve as the as-built drawings for a subcontractor's specified scope of work.
- Duke will incorporate both 3D geometric and metadata from all subcontractor fabrication models into its existing facilities, maintenance, operations and capital enterprise systems as appropriate.

NOTE: Guidelines and procedures for simplifying the fabrication model(s) for improved usefulness for Duke Facilities, maintenance and enterprise systems (e.g. Info EAM, ARCHIBUS, etc.) are actively under development and will be added to this document as they are defined and applicable.

Duke requires that all subcontractor contractors include the following closeout document clause on all projects utilizing BIM:

> *Duke utilizes Infor EAM software for their facility management operations. Mechanical, plumbing, electrical and fire protection trades and their equipment suppliers are required to provide the necessary equipment information to Duke for coordination with facility management software. The lead AE will provide a worksheet, in Excel format, to all sub-consultants. Sub-consultants are responsible to complete all the fields indicated in the spread sheet and submit in digital form as part of the required. Likewise, the construction manager or general contractor and their sub-consultants will follow the same adding and validating additional information from the submittal process.*

7.3 Closeout Documentation

In addition, subconsultants and sub-contractors are required to assign a unique ID tag to the actual equipment contained in the subcontractors' as-build model(s). This ID scheme(s) will be established by Duke and will be provided to each subcontractor. The unique ID assigned to each element will serve as the basis for element tracking within Info EAM.

Duke will supply the above mentioned Excel worksheet of required equipment attributes and Duke unique ID scheme(s) to each project and appropriate Model Manger/personnel for the AE to administer with the sub-consultants, construction manager or general contractor.

As a general rule, the Duke ID scheme(s) that subconsultants and fabricators apply to their fabrication model(s) will be the same as the unique ID applied to design model elements by the design team in the first instance. Any deviations, clarifications or additional requirement to this general rule will be clearly articulated to the construction team by the Model Manager.

7.4 Link to Operations and Maintenance Documentation

Subconsultants are required to submit an Excel worksheet, compliant with Duke standards, documenting relevant O&M information for each serviceable piece of equipment. The parameter for each equipment family or component in the consultant's as-built BIM model will include a data field called "URL," which will link to the applicable Excel worksheet describing the equipment. This will allow Duke to have a database of 3D elements linked to the accompanying O&M information.

7.5 Operations and Maintenance

Subconsultants and equipment suppliers will model all owner-supplied equipment. The subconsultant's final model will accurately incorporate all as-built conditions, as documented by the relevant subcontractor's shop drawings, fabrication models, and redlines. The model must include structural lifting and support requirements (i.e. mounting points, isolation pads). All major electrical, piping and plumbing hookup center will be modeled. Indicate access and service areas to operate, replace components and maintain equipment.

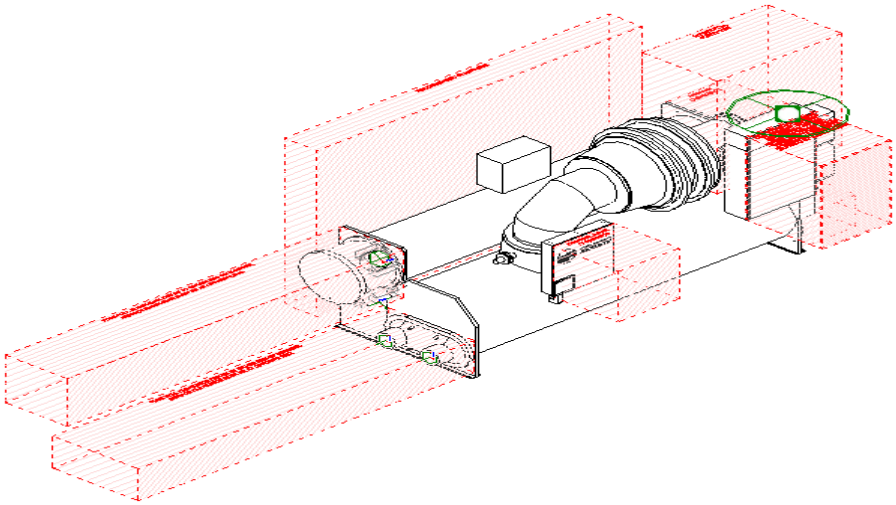


Figure 7.5 – Image Courtesy Silviu Petrea

8 Exhibits

Exhibit A. Software Platforms

- AE, Subcontractor, CM, GC and Subcontractors are required to use a collaborative platform (Autodesk® Buzzsaw® together with Navisworks®, BIM 360™ Glue®, Solibri's Model Checker, Bentley® Navigator or equal) for performing coordination and conflict reporting. Model content may be generated by Trimble® SketchUp and Tekla, Autodesk® Revit®, Inventor®, Autocad®, Dassault Catia™ and Solidworks, and Bentley® AECOsim Building Designer with Bentley® Microstation.
- Contractors will use the design model provided by the design team as the reference basis for their fabrication models.
- Subcontractors will fully coordinate the fabrication models associated with their scope of work with the fabrication models associated with the scope of work of other subcontractors on the project under the direction of the appropriate project authority (e.g. construction manager).
- Subcontractors will under the direction of the appropriate project authority (e.g. construction manager) actively participate in regularly scheduled clash detection/coordination meetings and be responsible for making water reasonable dimension, configuration, or location modification to their fabrication models as may be required to support the coordination process at no additional cost.
- All subcontractors and subconsultants bidding projects will be pre-qualified with demonstrable VDC resources, technical skills, and experience to be verified by Duke's planning department.

Exhibit B. Closeout Documentation

Development/Finalization
Example of milestone deliverables: (.pdf documentation and native MS Excel format)

Milestones (All Due 90 days after Substantial Completion)	Deliverables
Project Close-Out (Design Team)	As-Built Models (.rvt format)
	(1)Full Set of As-Constructed Record Drawings (.pdf format)
	(1)Full Set of As-Constructed Record Drawings (.dwg format)
Project Close-Out (Contractor)	(1)Full Set of Red-Line Drawings (scanned - .tif format)
	O&M Manuals (Paper, .pdf, excel format)
	As-Built COBIE Construction (worksheets 11, 14-28; excel format)
	Coordination Models in their Native File Format

Figure B – Example of Milestone Deliverables

Exhibit C. Glossary of Terms

As-Constructed Model	The final version of the design intent model, modified to reflect revisions and field modifications implemented during the construction phase of the project. These revisions and modifications are communicated by the contractor to the design team. The design team is responsible for consolidation of all red-line documents into an accurate as-constructed model.
As-Constructed Record Drawings	Drawings that are prepared by the Architect and reflect on-site changes the Contractor noted in the red-line drawings. They are often compiled as a set of on-site changes made for the Owner per the Owner-Architect contract.
As-Designed Record Drawings	The record of everything the Architect designed for the project, and include the original construction documents plus all construction change directives and minor changes in the work.
BIM Execution Plan (BEP)	A plan that is created from Duke Universities BIM Execution Plan template that is to be submitted thirty (30) days after contract award. The BEP helps to define roles and responsibilities within a project team.
BIM Proficiency Matrix (BPM)	A matrix that was designed to measure the expertise of a firm as it relates to using a VDC process on projects. It will be used as one of the many selection criteria during the selection process.
Construction Operations Building Information Exchange (C.O.B.I.E.)	A standard for the exchange of information that allows the capturing of specified fields during design and construction in a format that can be used during the operations of a building upon completion.
Critical Path Modeling	A method of demonstrating a plan within the design team that accounts for the activities of each discipline and how they interact. It builds upon a critical path method for those activities, and allows the project team to schedule a complete project.
Department of Energy Version 2 (DOE2)	A file type that is an open file format used by most energy modeling software. It is also an approved file type for LEED simulations.
Design Team	The design team is considered to be the architect and all of the consultants that provide design services for a project. These design services can be rendered at any time during the project.
.DWF	Drawing Web Format is a file type that was developed by Autodesk to be used as a file transfer for estimating data, markups, and other third party software. It can be a combination of 3D and 2D information within the same file.
.DWG	Native AutoCAD® drawing file format. It is a widely used file format for exchanging drawing information and 3D information to different programs. While not a database file type, it has lots of uses for exchanging information.
Facilities Inventory and Classifications Manual (FICM)	Standard that describes practices for initiating, conducting, reporting, and maintaining an institutional facilities inventory.
.GBxml	Green Building file type. It is used to run simulations through energy modeling software. It is a widely accepted file format for those types of software.

Leadership in Energy and Environmental Design (LEED)	Green Building Rating System is a suite of standards for environmentally sustainable construction. Based on a point system, a building can achieve different ratings based on the performance of the design, construction, and operation of the building.
Navisworks®	Autodesk® software that allows users to open and combine 3D models, navigate around them in real-time and review the model using a set of tools to simulate the interaction between model files. Interaction types include, but not limited to, conflict reporting, clash detection, time lining, and coordination.
Navisworks® Freedom	Autodesk® viewer version of Navisworks®. This software is the free viewer for NWD and DWF™ file formats.
Operational and Maintenance Manuals (O&M Manuals)	Include equipment specifications and schedules, drawings and overall information needed to maintain installed equipment.
Open Architecture	Concept of creating a framework that helps to describe a common set of rules for how a project is created. This includes what types of software, interoperability of the information. It differs from open standards in that it promotes progress.
Owner's Project Requirements	A dynamic document that provides the explanation of the ideas, concepts and criteria that are considered to be very important to the owner. It is initially the outcome of the programming and conceptual design phases.
Phases	The phases of a project can be described as follows: Programming Phase, Schematic Design/SD, Design Development/DD, Construction Documents/CD
Red-Line Drawings	Commonly known as as-builts, are drawings that are prepared by the contractor, in red ink, all changes from the as-designed record drawings. This set of drawings depicts the actual conditions of the completed construction "as it was built." Red-line drawings are delivered to the Architect by the Contractor upon completion of the work, and are integrated by the Architect into the as-constructed record drawings.
Shop Drawings	A drawing or set of drawings produced by the contractor, supplier, manufacturer, subcontractor, or fabricator typically required for pre-fabricated components.
Simple Building Information Model (SBIM)	Simple Building Information Modeling s a concept of producing a "light" model that can be used for simulating the building's performance very early within the design process. SBIM is the process of modeling only the exterior envelope, and the interior volumes to produce a lean model that energy modeling software can use easily.
Sketches	A simple, technical drawing created to isolate a particular engineering/architectural item and provide specific requirements related to that item.
Telecommunications Drawings	Telecommunication design for use in coordinating selection and procurement of telecommunications and data equipment. Drawings shall be derived from coordinated model based data.
Virtual Design and Construction (VDC)	A process that takes a more comprehensive approach of simulating the construction and design process and often utilizes reverse engineering principals.

Exhibit D. Collaboration

Please refer to instructions for creating team members on BOX.

Exhibit E. Global Unique Identifiers

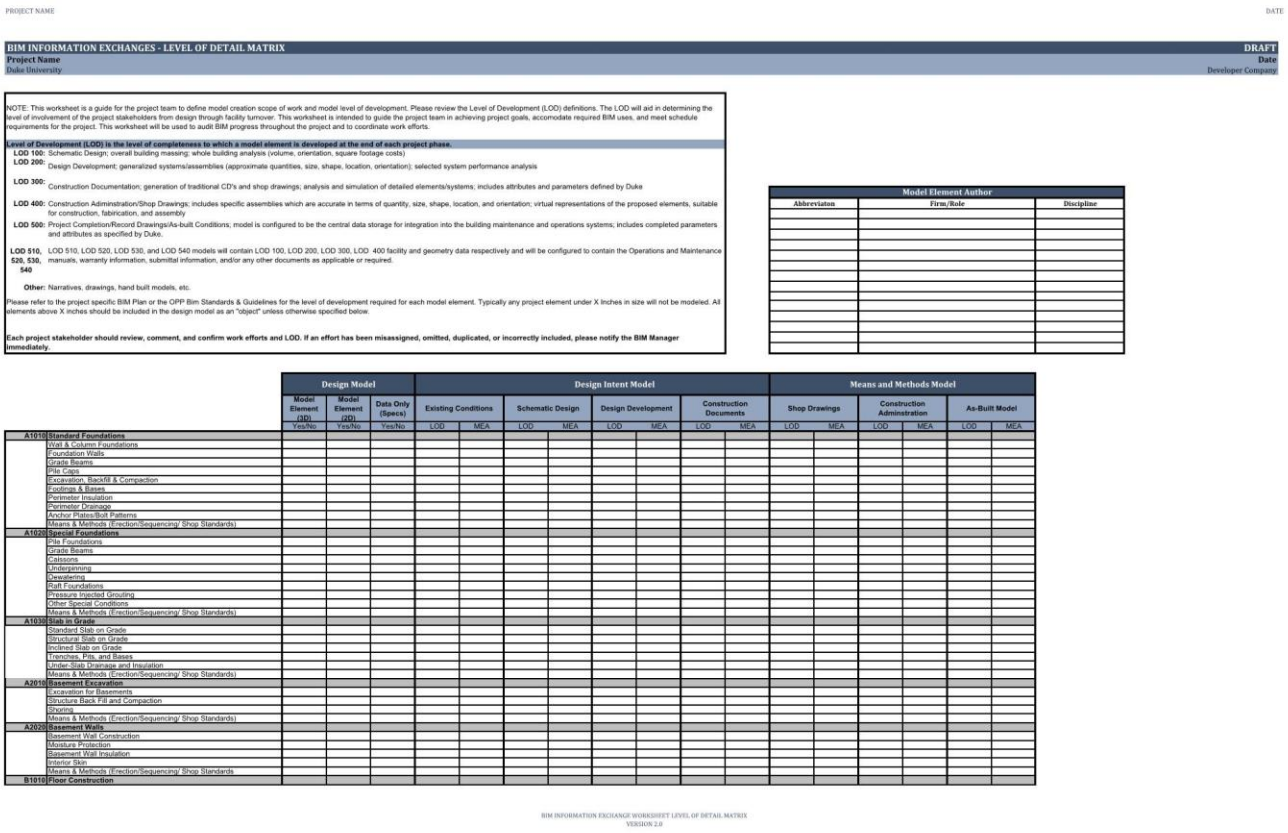
- Duke sample LOD Matrix
- Equipment information spreadsheet template approvals required; indicate which approvals have been received (✓) and which are being reviewed (**R**).
- Unique ID naming convention – The Duke VDC manager will provide all necessary details for the Duke unique ID scheme at the kick-off meeting.
    - All required elements within the subcontractor models must include a unique ID as a distinct parameter.
    - The general format for the unique ID is:

        Unique ID: RAL-FL1-AHU-01

        Convention: [Duke Building]_[Floor]_[Equipment Type]_[Serialized #]

Exhibit F. Level of Detail (LOD) Matrix

This is available for download from the Duke FMD website: Forms & Instructions



PROJECT NAME DATE

BIM INFORMATION EXCHANGES - LEVEL OF DETAIL MATRIX — DRAFT
Project Name — Date
Duke University — Developer Company

NOTE: This worksheet is a guide for the project team to define model creation scope of work and model level of development. Please review the Level of Development (LOD) definitions. The LOD will aid in determining the level of involvement of the project stakeholders from design through facility turnover. This worksheet is intended to guide the project team in achieving project goals, accomodate required BIM uses, and meet schedule requirements for the project. This worksheet will be used to audit BIM progress throughout the project and to coordinate work efforts.

Level of Development (LOD) is the level of completeness to which a model element is developed at the end of each project phase.

LOD 100: Schematic Design; overall building massing; whole building analysis (volume, orientation, square footage costs)

LOD 200: Design Development; generalized systems/assemblies (approximate quantities, size, shape, location, orientation); selected system performance analysis

LOD 300: Construction Documentation; generation of traditional CD's and shop drawings; analysis and simulation of detailed elements/systems; includes attributes and parameters defined by Duke

LOD 400: Construction Administration/Shop Drawings; includes specific assemblies which are accurate in terms of quantity, size, shape, location, and orientation; virtual representations of the proposed elements, suitable for construction, fabrication, and assembly

LOD 500: Project Completion/Record Drawings/As-built Conditions; model is configured to be the central data storage for integration into the building maintenance and operations systems; includes completed parameters and attributes as specified by Duke.

LOD 510, 520, 530, 540 LOD 510, LOD 520, LOD 530, and LOD 540 models will contain LOD 100, LOD 200, LOD 300, LOD 400 facility and geometry data respectively and will be configured to contain the Operations and Maintenance manuals, warranty information, submittal information, and/or any other documents as applicable or required.

Other: Narratives, drawings, hand built models, etc.

Please refer to the project specific BIM Plan or the OPP Bim Standards & Guidelines for the level of development required for each model element. Typically any project element under X Inches in size will not be modeled. All elements above X inches should be included in the design model as an "object" unless otherwise specified below.

Each project stakeholder should review, comment, and confirm work efforts and LOD. If an effort has been misassigned, omitted, duplicated, or incorrectly included, please notify the BIM Manager immediately.

Model Element Author		
Abbreviation	Firm/Role	Discipline

		Design Model			Design Intent Model								Means and Methods Model					
		Model Element (3D)	Model Element (2D)	Data Only (Specs)	Existing Conditions		Schematic Design		Design Development		Construction Documents		Shop Drawings		Construction Administration		As-Built Model	
		Yes/No	Yes/No	Yes/No	LOD	MEA	LOD	MEA	LOD	MEA	LOD	MEA	LOD	MEA	LOD	MEA	LOD	MEA
A1010	Standard Foundations																	
	Wall & Column Foundations																	
	Foundation Walls																	
	Grade Beams																	
	Pile Caps																	
	Excavation, Backfill & Compaction																	
	Footings & Bases																	
	Perimeter Insulation																	
	Perimeter Drainage																	
	Anchor Plates/Bolt Patterns																	
	Means & Methods (Erection/Sequencing/ Shop Standards)																	
A1020	Special Foundations																	
	Pile Foundations																	
	Grade Beams																	
	Caissons																	
	Underpinning																	
	Dewatering																	
	Raft Foundations																	
	Pressure Injected Grouting																	
	Other Special Conditions																	
	Means & Methods (Erection/Sequencing/ Shop Standards)																	
A1030	Slab in Grade																	
	Standard Slab on Grade																	
	Structural Slab on Grade																	
	Inclined Slab on Grade																	
	Trenches, Pits, and Bases																	
	Under-Slab Drainage and Insulation																	
	Means & Methods (Erection/Sequencing/ Shop Standards)																	
A2010	Basement Excavation																	
	Excavation for Basements																	
	Structure Back Fill and Compaction																	
	Shoring																	
	Means & Methods (Erection/Sequencing/ Shop Standards)																	
A2020	Basement Walls																	
	Basement Wall Construction																	
	Moisture Protection																	
	Basement Wall Insulation																	
	Interior Skin																	
	Means & Methods (Erection/Sequencing/ Shop Standards																	
B1010	Floor Construction																	

BIM INFORMATION EXCHANGE WORKSHEET LEVEL OF DETAIL MATRIX
VERSION 2.0

Figure F – Example LOD Matrix

Exhibit G. Scanning Procedures

1.0 *Scanning Objectives* (Define the critical objectives to capture as part of this scanning effort)

1.1 *Deliverables (Check which types are to be provided)*

☐ Type 1: 2D drawings (Plans, Sections, Elevations, Details)

Submit one (1) full set of Adobe® PDF's

Submit one (1) full set of AutoCAD® DWG's

☐ Type 2: 3D Model

☐ Surface Model

☐ Object Model

(Specify component, units, and attributes)

☐ Type 3: Scan Data

☐ Registered Point Cloud (Broken down per file size, or a single file)

☐ Panoramic Data (Virtual tour is created from the registered point cloud data)

(Specify if measurements are required for critical areas)

1.2 *Resolution of Scan*

The following settings shall be used to capture the scan data:

1/6 Resolution

3x Quality Settings

Class 1 Laser – 1 million pts/sec.

1.3 Tolerance

1.3 *Tolerance*

The accuracy of the scan data shall be developed to within a minimum dimensional tolerance of plus or minus 1/8"

1.4 *Coordinate System*

To be established prior to scanning and set with targets placed on an agreed survey control. This will allow minimal translation required when inserting the scanned data into other modeling software.

2.0 *Scope of Work*

For this renovation project the following scope guidelines shall be provided as it relates to scan date:

(Insert description of areas and floors to be scanned)

2.1 *3D Laser Scanning*

Provide an on-site team to perform all scanning operations within the requested areas.

- The on-site documentation process will be completed in several mobilizations (pre-demolition, post-demolition, and post construction) with a two-man team working 8-hour days.

- In addition to 3D laser scanning, the team will establish a control network around the areas to be scanned, tying all scan data to the control network and plant coordinate system. All scans will be aligned to survey points established and verified by the project surveyor and observed by the Duke Facility staff.
- Survey specifications:
    - It is required to have a survey of the facility and create a master coordinate system with permanent monuments for reference on this and all future projects. The surveyor will align this survey to the master plan grid provided by Duke Facilities.
    - Surveyor will utilize established coordinate system for acquisition of target coordinates (checker board targets) used for facility scanning.
    - The survey data will be the master reference for scan/cloud alignment.
- All scanning will be undertaken with full color overlay. Floor lighting to illuminate truss spaces will be required prior to scanning. The scanning contractor is responsible for the quality of colored images is affected by the lighting provided on site. Any questions with available lighting shall be reviewed with Duke and corrected prior to scanning.
- Scanning positions will be chosen to give the necessary overlap required for complete project area documentation.
- Review proposed scanning positions with Duke Facilities prior to performing the work.

2.2 Point-Cloud Registration

Once 3D laser scanning is complete, provide registration of all individual scans collected by the on-site team. Once registered, the point-cloud data will represent one three-dimensional environment.

- Scanning data shall be filtered so all measurements in the registered cloud will be from points less than 80 feet from the respective scan positions.

2.3 Panoramic Virtual Tour

Once registration is complete, we will provide a team to create the files for the panoramic virtual tour.

2.4 Rescanning

Rescan the areas of the project that are crucial for coordination that might have been missed after review of the registered scans. This ensures data is captured correctly and accurately along with providing a higher level of detail in the selected critical areas.

2.5 Modeling (Optional)

- Revit® 2015 Format
- Level of Development 300 as defined by the 2013 AIA / AGC BIM forum guidelines
- Structural Elements
- Mechanical, Electrical, Plumbing Piping/Duct
- Pipe valves, electrical boxes, switches and other services mounted devices will be modeled as symbols of size approximately as per the point cloud
- Small steel hangars and clips will not be represented
- (Insert Additional detailed modeling as needed)