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Ontology for Life-Cycle Modeling of Water Distribution Systems: Model View Definition

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June 2013

Prepared under CRADA-07-CERL-02 under the supervision of

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Abstract

Previous efforts by the US Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) to develop a life-cycle building model have resulted in the definition of a “core” building information model that contains general information describing facility assets such as spaces and equipment. To describe how facility assets (i.e., components) function together, information about assemblies of assets and their connections must also be defined. The definitions of assets, assemblies, and connections for the various building-information domains are discipline-specific.

The work documented here addresses the process flow and data exchange requirements for the design of water distribution systems in typical Army facilities. This ontology advances the state of the art by defining an Industry Foundation Class (IFC) Model View for water system design, supporting end users in developing compliant BIM models, and suggesting potential areas of automation in water system design.

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Preface

This study was conducted for the US Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) and the National Institute of Building Sciences (NIBS) by Kristine Fallon Associates Inc., and Constructivity.com, LLC, under CRADA-07-CERL-02, “Cooperative Research and Development Agreement Between US Army Engineer Research and Development Center–Construction Engineering Laboratory and National Institute Of Building Sciences.” The CRADA supports Research, Development, Test, and Evaluation (RDT&E) Program Element 622784 T41, “Military Facilities Engineering Technology”; Project 157249, “Life-Cycle Model For Mission Ready Sustainable Facilities (LCM).” The ERDC-CERL project manager was Dr. E. William East (CEERD-CF-N), and the NIBS project manager was Dominique Fernandez.

The work was supervised and monitored by the Engineering Processes Branch (CF-N) of the Facilities Division (CF), ERDC-CERL. At the time of publication, Donald K. Hicks was Chief, CEERD-CF-N; L. Michael Golish was Chief, CEERD-CF; and Martin J. Savoie, CEERD-CV-ZT, was the Technical Director for Installations. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

COL Kevin J. Wilson was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
mils	0.0254	millimeters
pounds (mass)	0.45359237	kilograms
square feet	0.09290304	square meters
yards	0.9144	meters

1 Introduction

1.1 Background

Previous efforts by the US Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) to develop a life-cycle building model have resulted in the definition of a "core" building information model that contains general information describing facility assets such as spaces and equipment (East, Love, and Nisbet 2010). To describe how facility assets (i.e., components) function together, information about assemblies of assets and their connections must also be defined. The definitions of assets, assemblies, and connections for the various building-information domains are discipline-specific. Taken together, studies of all essential building-information domains will create a unified framework for developing automatic design checks, ensuring construction compliance, improving operations and maintenance efficiency, and evaluating alternatives for redesign within completed facilities.

COBie (East 2012a) was the first step in analyzing information exchanges in the life cycle of a building. Since March 2012, COBie has been part of the National BIM Standard–United States (NBIMS-US). COBie defines the format for providing information about building assets from the planning phase through design, construction, and operations. Properties of these assets may also be captured in the COBie date exchange format. The *COBie Guide*, a commentary on the COBie standard (public draft downloadable at link from http://www.nibs.org/?page=bsa_cobieguide), does not prescribe how to model specific assemblies of components or how components and assemblies are connected (East 2007, East 2012a). Those aspects of modeling and information exchange require a domain-specific ontology for every system needed to construct a functional building.

The work documented here addresses the process flow and data exchange requirements for the design of water distribution systems in typical Army facilities. This ontology advances the state of the art by

1. defining an Industry Foundation Class (IFC) Model View for water distribution system design
2. supporting end users in developing compliant BIM models
3. suggesting potential areas of automation in water system design.

1.2 Objectives

The objectives of the present work were to identify and document the requirements for building water distribution system design for the purpose of creating formal specifications that can be directly applied to open-standards building information models (BIM) at the coordinated design stage of building construction.

1.3 Approach

To document the process and exchange requirements, the team followed the Information Delivery Manual (IDM) and Model View Definition (MVD) procedures defined by the International Organization for Standardization (ISO) and buildingSmart International (e.g., Wix 2007, Hietanen 2008). Validation of the process diagrams and exchange requirements followed the process outlined below:

1. Create drafts of process diagrams and task descriptions for each of three phases of the design process—Criteria (i.e., Programming and Concept Design), Schematic Design (i.e., Design Development), and Coordinated Design (i.e., Construction Documents). The draft process diagrams included suggested steps for the typical Army design process, and the task descriptions included suggested information requirements needed to accomplish the task step.
2. Assemble a group of subject matter experts (SMEs) to review and comment on the draft process diagrams and task descriptions. This group included three architects, two engineers, and two specifiers with experience in the design of interior plumbing systems.
3. Meet with the SME reviewers to explain the process and review criteria.
4. Send the process diagrams and task descriptions to the SMEs for their review.
5. Analyze the SME comments and contact the SMEs for clarification and additional comments, as needed.
6. Revise the process diagrams and task descriptions based on the SME comments.

The specific selection and sequencing of tasks was intended as a starting point that would be refined using the SME reviewers' feedback. The task forms included the information summarized in Table 1.

Table 1. Task form description.

Item	Description
Task ID	Sequential ID number for the task.
Task Name	A short descriptive name for the task
Information Provider (Roles Involved)	The role or roles that provide the input information necessary to do the task.
Information Provider (Phase)	The stage in the process when the required information is created.
Actor (Roles Involved)	The role or roles that complete the task.
Actor (Phase)	The stage in the process at which the task requires the information.
Information Required	The input information necessary to complete the task.
Current Methods	A short description of the task and its inputs and outputs.

The experts were asked to review the tasks with the following questions in mind:

- Do the task forms accurately and completely detail all information needed to perform the task?
    - If not, what is missing?
    - Who provides the additional inputs?
- Are current methods of performing the task accurately described?

For the process diagrams, the reviewers were asked:

- Although every project has unique circumstances, are the tasks shown in the typically correct order?
- Have we missed any tasks?
- Are there any unnecessary tasks?
- Are all tasks assigned to the correct phase(s)?
- Are all tasks assigned to the correct actor?
- Are all actors that provide the Information Required indicated?
- Are any extraneous actors indicated?

The SME reviewers are listed in Table 2.

Table 2. Subject matter experts.

Name	Organization	Area of Expertise
Joseph O. Amos II, Assoc. AIA	FKP Architects, Inc.	Architect
Omar H. Bailey, AIA, LEED AP	Bailey Edward Architecture	Architect
	Architect with 13 years of experience.	
Darcie K. Kopischke		Architect
	BArch degree from Iowa State University. Six years' work experience, primarily with JSSH Architects in Minnetonka, Minnesota, on projects varying from schools to multi-housing projects.	
Damon Cameron, EIT LEED AP BD+C, CPD	dbHMS	Engineer
	Plumbing engineer with 6 years of Design Build and Consulting engineering experience with a commercial and healthcare focus, hands on construction experience, and experience implementing Revit MEP into design.	
Jim Forester	Newforma, Inc.	Engineer
	California P.E. license M24307. Co-Founder and Senior Technical Advisor at Newforma, Inc. Original member of the buildingSmart International Model Support Group. Involved with the many of the original definitions of the building services concepts and how they are connected, including the underlying graph representations supporting both symbolic and physical connectivity that would support mass and energy flow simulations.	
Mark Kalin FAIA FCSI LEED	Kalin Associates	Specifier
	Registered architect, CSI-certified construction specifier, LEED-accredited professional, and one of only 27 individuals ever advanced to fellowship in both the American Institute of Architects and the Construction Specifications Institute. Author of numerous publications on specifications, product selection, and green specs, who has presented more than 100 sessions at regional and national conventions. He has taught architectural specifications at Harvard University Graduate School of Design and is currently chair of the Sustainable Facilities Practice Group of the Construction Specifications Institute.	

<table>
<tr><th>Name</th><th>Organization</th><th>Area of Expertise</th></tr>
<tr><td rowspan="2">Stuart Bailin</td><td>Water Harvesting Solutions</td><td>Specifier</td></tr>
<tr><td colspan="2">Director of Engineering for Water Harvesting Solutions (wahaso). Stuart has over 30 years of experience with the pumps, valves, tanks, instrumentation, controls and process designs used in water harvesting systems. He enjoys using his system design and CAD skills to create custom solutions for challenging client requirements. It is the close tie between client needs, process design and system build & install that ensure a project will work as specified.</td></tr>
</table>

1.4 Scope

The scope of the present work was to diagram the water distribution system design process, and to identify and document the relevant data exchanges. A separate report (ERDC/CERL CR-13-5) applies this ontology to the updating of three previously developed experimental BIM models using commercial off-the-shelf (COTS) software. Those models represent three types of typical low-rise Army facilities: a duplex apartment, an office building, and a medical clinic. The experimental application work identifies some current product limitations in achieving successful information exchange.

1.5 Mode of technology transfer

Documentation of this ontology will be used as the basis for a ballot submission to the National BIM Standard–United States. Model files created for the related validation application (ERDC/CERL CR-13-5) will be made publicly available for testing and evaluation of the proposed open BIM standard that results from this work.

2 Water System Design Process Models

2.1 Overview

Building design is a highly iterative process during which information is gathered, design options are evaluated and selections are made. The goal is to achieve a final design in which aesthetics, cost and systems performance are all optimized. During design, each choice has multiple effects. Optimized design can only be achieved through multiple iterations of interdependent analyses.

Today's designers and owners seek to optimize multiple aspects of a building, including first cost, life cycle cost and environmental impact. Early adopters of building information modeling technology have demonstrated that the use of computable building models, coupled with the availability of analysis software, facilitates and reduces cycle times of the iterations necessary to achieve such optimization (Fallon and Palmer 2007). The purpose of this water systems ontology is to define a standardized computable description of all water system parameters necessary for a complete design. The availability of such a standardized, computable description supports the development and use of water system design automation software.

2.1.1 Water system design process

The design of building water systems iterates through multiple steps, involving the provision of data by multiple parties and the repeated refinement of the design as it moves from generalized concepts and equipment types to detailed construction documents with the required equipment specified.

The process diagrams in this document focus on the design tasks and data exchanges involving the Architect and Plumbing Engineer. Data required from other project participants are also documented.

2.1.2 Water system design phases

The water system design process is divided into three general phases, typical of the Design-Bid-Build process for USACE projects. Although the sequence of tasks and even the actors for each task can vary, depending on project delivery approach and on the internal organization of the professional services provider company(ies), the tasks that must be completed and the information required remain constant.

2.1.2.1 Criteria (Programming and Concept Design)

The Criteria phase requires gathering the necessary information that will define the project's scope, budget, and overall goals. The Owner's Project Requirements (OPR), building codes, site location, and sustainability goals are all indentified during this phase. Once the building program has been developed, the Facility Occupancy Model can be determined. This information allows the Architect and Plumbing Engineer to develop a Concept Design. Typically, several options are created to compare designs or system alternatives.

2.1.2.2 Schematic design (Design Development)

The Schematic Design phase requires using the information developed during the Criteria phase to develop the building design further. For water systems design, most of the information is generated by the Plumbing Engineer. The Architect provides information regarding plumbing fixture counts, fixture locations and room sizes. Other consultants will provide water and waste requirements for other building systems. This information allows the Plumbing Engineer to determine the overall water demand. During this phase, specifications for the anticipated equipment are developed in addition to the drawings. The specifications identify performance requirements for the various plumbing system components.

2.1.2.3 Coordinated design (Construction Documents)

The Coordinated Design phase involves finalizing the documents in preparation for bidding and construction. Primarily, this involves updating the drawings and specifications completed in the previous phases with more detailed, accurate information about the building and systems. Again, this requires that the Plumbing Engineer receive input from the Architect and any others involved whose particular discipline could have an impact on the plumbing system design.

2.2 Specification of processes

This section contains three Process Diagrams covering the water system design phases of (1) Criteria (Programming and Concept Design), (2) Schematic Design (Design Development) and (3) Coordinated Design (Construction Documents). These phases have been assigned an arbitrary sequential number (10, 20, or 30) to aid in tracking and coordinating tasks. Following each of the three diagrams are tabular descriptions of the tasks shown in each diagram.

The diagrams and task descriptions have been revised to reflect the reviews, and comments made by the SMEs in response to the draft process diagrams and task descriptions. Several of the reviewers suggested alternative process flows, based on their experience with specific types of projects and project delivery approaches — Design-Build versus Design-Bid-Build, for example. These suggestions were evaluated and, in some cases, the original flow was modified. Even where the workflow differed, however, it was determined that the design tasks and information requirements remained the same.

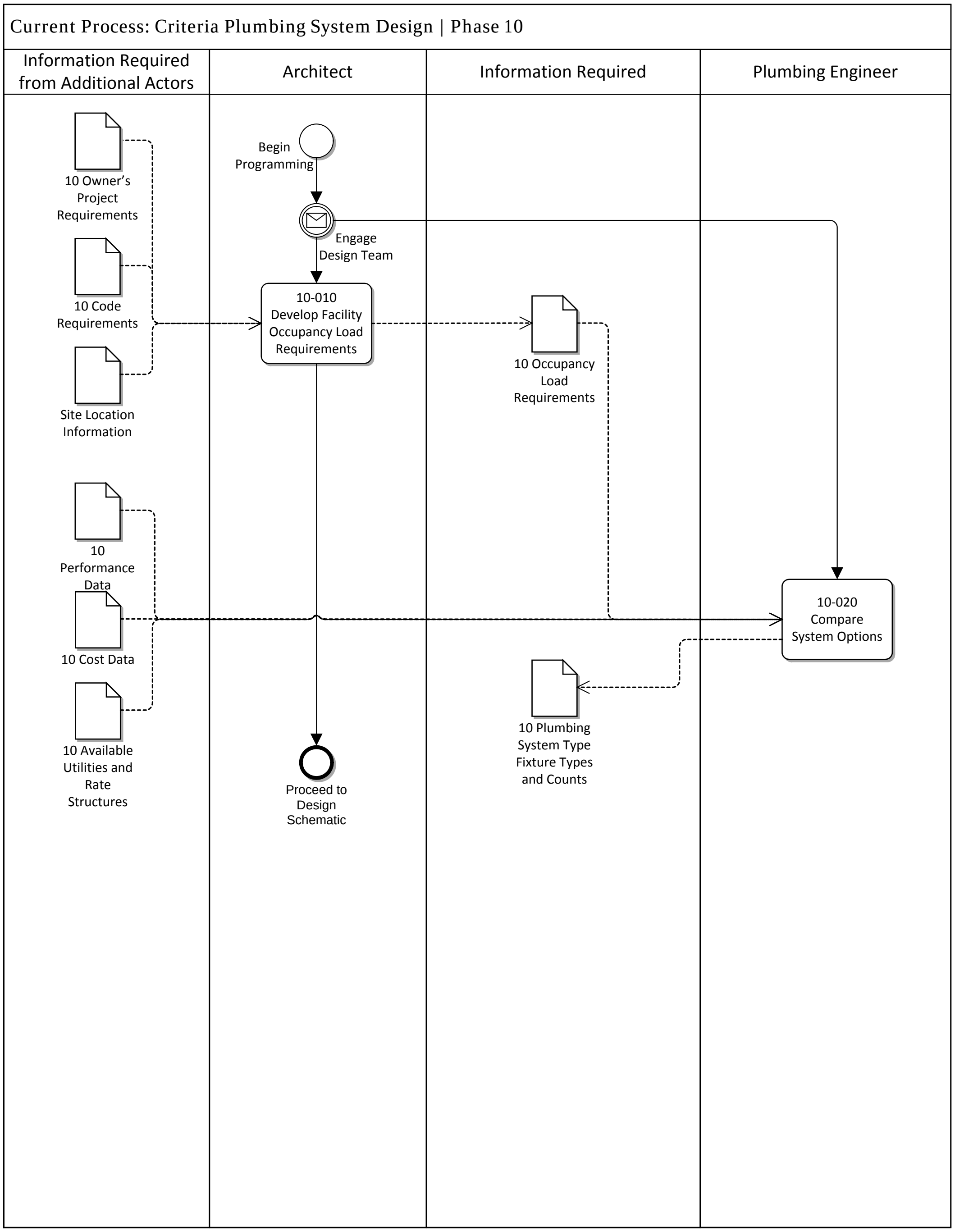
The solidification of the design involves an iterative process, where the owner, architect, the plumbing engineer and other specialists must reconcile their needs with those of others. An explicit understanding of the process and its information requirements can help streamline the process by focusing on what exchanges take place and who is affected. It can also be used to help define new ways of reviewing multiple design options and integrating them into the overall process.

The detailed Exchange Requirements derived from the following task descriptions are described in the next chapter.

2.2.1 Criteria Phase plumbing system design

The Criteria Phase comprises the following tasks, shown diagrammatically in Figure 1.

Figure 1. Process diagram for Criteria Phase plumbing system design.



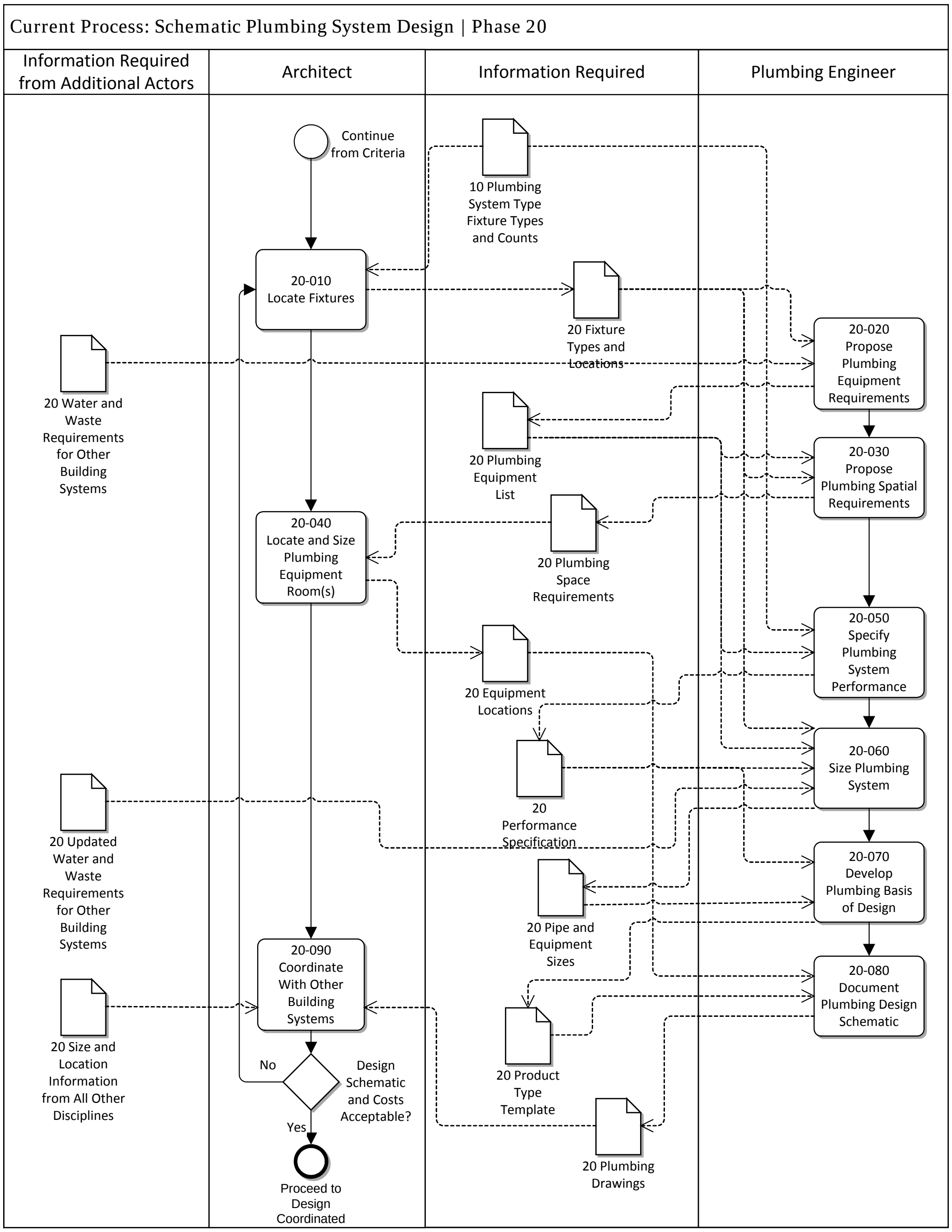
Task Form				
Task ID	10-010	**Task Name**	Develop Facility Occupancy Model	
Participants	**Roles Involved**			**Phase**
Information Provider	Building Owner, Building Codes			10
Actor	Architect			10
Information Required	Owner's Project Requirements ▪ Facility Type, Space Types, Area Standards, Occupant Load, Hours of Occupancy and design priorities Building Code Requirements ▪ Fixtures Per Occupant Site Location Information			
Current Methods	Architect receives document(s) from the Owner. Architect uses these documents, in conjunction with Building Code guidelines and standards, to develop the Facility Occupancy Model.			

Task Form				
Task ID	10-020	**Task Name**	Compare System Options	
Participants	**Roles Involved**			**Phase**
Information Provider	Architect, Building Codes, Utilities			10
Actor	Plumbing Engineer			10
Information Required	Facility Occupancy Load Requirements Performance Data ▪ Flow rate for fixtures ▪ Flow test ▪ Volume Per Visit ▪ Visits per Person per Period ▪ Minutes in Use ▪ Numbers of Users ▪ Efficiency Label ▪ Volume Per Day ▪ Input / Output Ratio ▪ Water Input Grade ▪ Water Output Grade ▪ Operating Pressure ▪ Distance to Source – Civil Plans ▪ Water Supply Fixture Unit (WSFU) ▪ Pressure Drop Building Heating Fuel Source ▪ Gas ▪ Fuel Oil System Budget ▪ Cost of System based on project type ▪ Cost of System based on anticipated water input Available Utilities and Rate Structures			
Current Methods	Paper-based. Plumbing Engineer uses the Facility Occupancy Model, along with standard cost and performance information, to compare plumbing system options and recommend one or more plumbing system type(s) and a preliminary schedule of fixture types and counts.			

2.2.2 Schematic Design Phase plumbing system design

The Schematic Design Phase comprises the following tasks, shown diagrammatically in Figure 2.

Figure 2. Process diagram for Schematic Design Phase plumbing system design.



<table>
<tr><th colspan="4">Task Form</th></tr>
<tr><td>Task ID</td><td>20-
010</td><td>Use Case Name</td><td>Locate Plumbing Fixtures</td></tr>
<tr><td></td><td colspan="3"></td></tr>
<tr><td>Participants</td><td colspan="2">Roles Involved</td><td>Phase</td></tr>
<tr><td>Information Provider</td><td colspan="2">Plumbing Engineer</td><td>20</td></tr>
<tr><td>Actor</td><td colspan="2">Architect</td><td>20</td></tr>
<tr><td>Information Required</td><td colspan="3">Water Supply Type(s)
▪ Cold Water
▪ Hot Water
▪ Grey Water
▪ Black Water
▪ Rainwater Harvesting
▪ Waste
▪ Specialty Waste
▪ Pure water
▪ Other liquid, gas, or fuel services
▪ Hot water fuel source
Preliminary Schedule of Plumbing Fixture Types
▪ Bath, Bidet, Toilet Tank, Water Closet, Shower, Sink, Drinking Fountain, Urinal
Plumbing Fixture Counts</td></tr>
<tr><td>Current Methods</td><td colspan="3">Architect uses the recommendations and preliminary schedule from the Plumbing Engineer to indicate locations of the plumbing fixtures in the initial schematic plans.</td></tr>
</table>

<table>
<tr><th colspan="4">Task Form</th></tr>
<tr><td>Task ID</td><td>20-
020</td><td>Task Name</td><td>Propose Plumbing Equipment Requirements</td></tr>
<tr><td></td><td colspan="3"></td></tr>
<tr><td>Participants</td><td colspan="2">Roles Involved</td><td>Phase</td></tr>
<tr><td>Information Provider</td><td colspan="2">Architect</td><td>20</td></tr>
<tr><td>Actor</td><td colspan="2">Plumbing Engineer</td><td>20</td></tr>
<tr><td>Information Required</td><td colspan="3">Water Supply Type(s)
▪ Cold Water
▪ Hot Water
▪ Grey Water
▪ Black Water
▪ Rainwater Harvesting
▪ Waste
▪ Specialty Waste
▪ Pure water
▪ Other liquid, gas, or fuel services
▪ Hot water fuel source
Water and waste requirements from other building systems
Plumbing Fixture Count
Owner Equipment
Plumbing Fixture Locations
▪ Plumbing Plan</td></tr>
<tr><td>Current Methods</td><td colspan="3">Plumbing Engineer uses the information provided by the Architect on the plumbing system and other water and waste systems to develop one or more proposal(s) for plumbing equipment requirements.

Plumbing Engineer creates a Plumbing Equipment List.</td></tr>
</table>

<table>
<tr><th colspan="5">Task Form</th></tr>
<tr><td>Task ID</td><td>20-030</td><td>Task Name</td><td colspan="2">Propose Plumbing Spatial Requirements</td></tr>
<tr><td></td><td colspan="4"></td></tr>
<tr><td>Participants</td><td colspan="3">Roles Involved</td><td>Phase</td></tr>
<tr><td>Information Provider</td><td colspan="3">Architect</td><td>20</td></tr>
<tr><td>Actor</td><td colspan="3">Plumbing Engineer</td><td>20</td></tr>
<tr><td>Information Required</td><td colspan="4">Preliminary schedule of fixture types
▪ Bath, Bidet, Toilet Tank, Water Closet, Shower, Sink, Drinking Fountain, Urinal
Plumbing equipment list/schedule
▪ Water Heater, Washing Machine, Sterilizer, Water Softener System, Grease Trap, Garbage Disposer, Pumps, Solar Heating System, Storage Tanks, Gutters, Downspouts
Plumbing Equipment Sizes
Location of Fixture
▪ Plumbing Plan</td></tr>
<tr><td>Current Methods</td><td colspan="4">Plumbing Engineer uses the Plumbing Equipment List and preliminary architectural plans to develop proposed Plumbing Space Requirements.</td></tr>
</table>

<table>
<tr><th colspan="5">Task Form</th></tr>
<tr><td>Task ID</td><td>20-040</td><td>Task Name</td><td colspan="2">Locate and Size Plumbing Equipment Room(s)</td></tr>
<tr><td></td><td colspan="4"></td></tr>
<tr><td>Participants</td><td colspan="3">Roles Involved</td><td>Phase</td></tr>
<tr><td>Information Provider</td><td colspan="3">Plumbing Engineer</td><td>20</td></tr>
<tr><td>Actor</td><td colspan="3">Architect</td><td>20</td></tr>
<tr><td>Information Required</td><td colspan="4">Plumbing Space Requirements
▪ Equipment Sizes
▪ Equipment Clearance requirements</td></tr>
<tr><td>Current Methods</td><td colspan="4">Architect uses the proposed plumbing spatial requirements developed by the Plumbing Engineer to locate and size any needed plumbing equipment rooms in the schematic plans.</td></tr>
</table>

<table>
<tr><th colspan="5">Task Form</th></tr>
<tr><td>Task ID</td><td>20-050</td><td>Task Name</td><td colspan="2">Specify Plumbing System Performance</td></tr>
<tr><td></td><td colspan="4"></td></tr>
<tr><td>Participants</td><td colspan="3">Roles Involved</td><td>Phase</td></tr>
<tr><td>Information Provider</td><td colspan="3">Plumbing Engineer</td><td>20</td></tr>
<tr><td>Actor</td><td colspan="3">Plumbing Engineer</td><td>20</td></tr>
<tr><td>Information Required</td><td colspan="4">Plumbing system type(s)
▪ White
▪ Grey
▪ Rainwater Harvesting
Schedule of Fixture Types
▪ Bath, Bidet, Toilet Tank, Water Closet, Shower, Sink, Drinking Fountain, Urinal
Plumbing Equipment List/Schedule
▪ Water Heater, Washing Machine, Sterilizer, Water Softener System, Grease Trap, Garbage Disposer, Pumps, Solar Heating System, Storage Tanks, Gutters, Downspouts
Fixture Counts</td></tr>
<tr><td>Current Methods</td><td colspan="4">Plumbing Engineer uses the supplied information to calculate Plumbing System performance values and create a performance specification.</td></tr>
</table>

Task Form			
Task ID	20-060	**Task Name**	Size Plumbing System
Participants	**Roles Involved**		**Phase**
Information Provider	Plumbing Engineer, Architect		20
Actor	Plumbing Engineer		20
Information Required	Plumbing System performance specifications ▪ Pipe section: size, location, flow rate, and pressure drop ▪ Pipe fitting: size, location, connection type, and pressure drop Schedule of Fixture Types ▪ Bath, Bidet, Toilet Tank, Water Closet, Shower, Sink, Drinking Fountain, Urinal Plumbing Equipment List/Schedule ▪ Water Heater, Washing Machine, Sterilizer, Water Softener System, Grease Trap, Garbage Disposer, Pumps, Solar Heating System, Storage Tanks, Gutters, Downspouts Location of Fixture ▪ Plumbing Plan Updated requirements from other building systems.		
Current Methods	Plumbing Engineer uses this information to size the elements of the Plumbing System.		

Task Form			
Task ID	20-070	**Task Name**	Develop Basis of Design
Participants	**Roles Involved**		**Phase**
Information Provider	Plumbing Engineer		20
Actor	Plumbing Engineer		20
Information Required	Plumbing System performance specifications ▪ Pipe section: size, location, flow rate, and pressure drop ▪ Pipe fitting: size, location, connection type, and pressure drop Schedule of Fixture Types ▪ Bath, Bidet, Toilet Tank, Water Closet, Shower, Sink, Drinking Fountain, Urinal Plumbing equipment list/schedule ▪ Water Heater, Washing Machine, Sterilizer, Water Softener System, Grease Trap, Garbage Disposer, Pumps, Solar Heating System, Storage Tanks, Gutters, Downspouts Plumbing Equipment Sizes		
Current Methods	Plumbing Engineer uses the supplied information to develop a Basis of Design for the Plumbing System. The Basis of Design is exemplar products with the correct capacities and performance characteristics.		

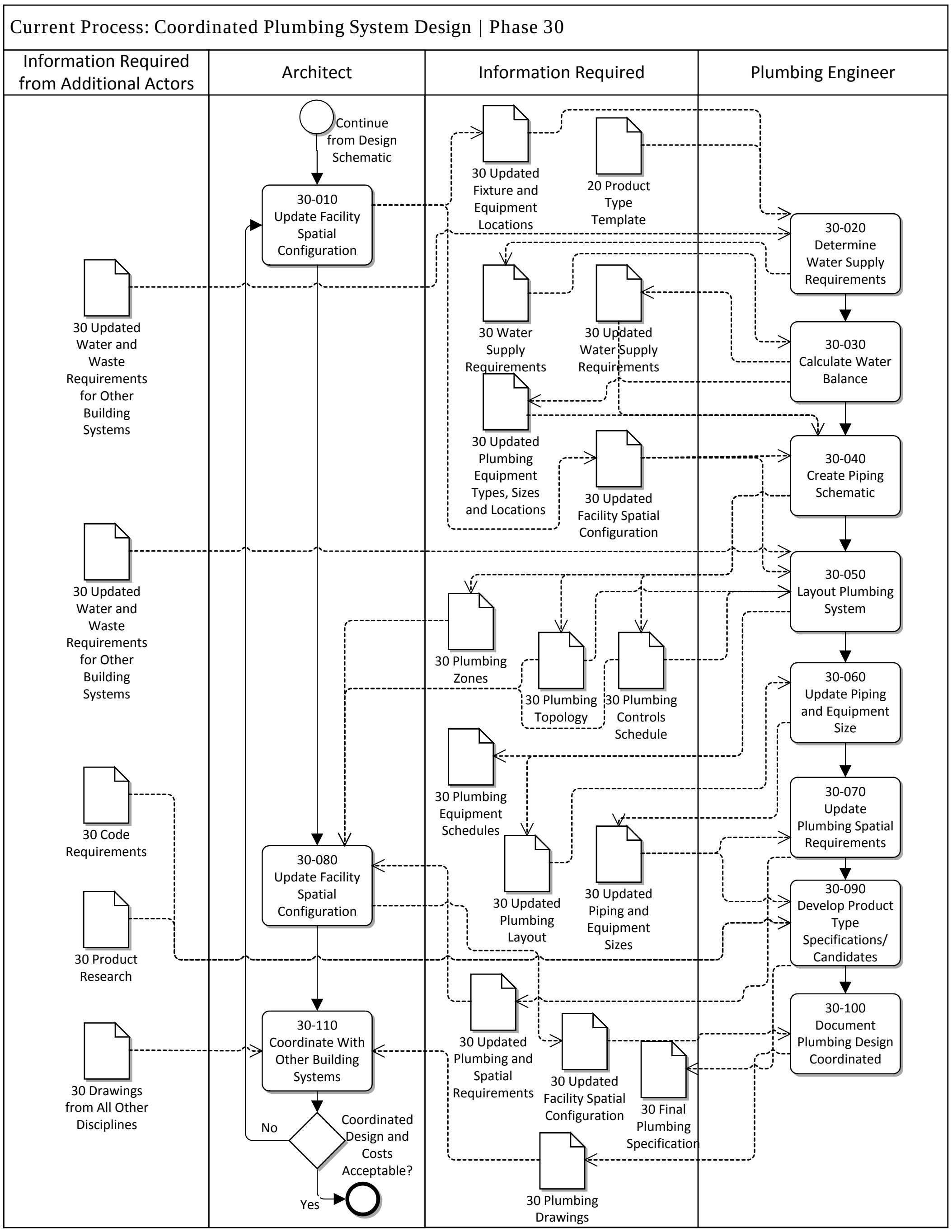
Task Form			
Task ID	20-080	**Task Name**	Document Plumbing Design Schematic
Participants	**Roles Involved**		**Phase**
Information Provider	Plumbing Engineer, Architect		20
Actor	Plumbing Engineer		20
Information Required	Architectural plans showing equipment locations Plumbing Product Type Template - Plumbing System performance specifications ▪ Pipe section: size, location, flow rate, and pressure drop ▪ Pipe fitting: size, location, connection type, and pressure drop Plumbing equipment list/schedule ▪ Water Heater, Washing Machine, Sterilizer, Water Softener System, Grease Trap, Garbage Disposer, Pumps, Solar Heating System, Storage Tanks, Gutters, Downspouts Plumbing Equipment Sizes		
Current Methods	Plumbing Engineer creates updated plumbing drawings and schedules that illustrate the Design Schematic plumbing layout.		

Task Form			
Task ID	20-090	**Task Name**	Coordinate With Other Building Systems
Participants	**Roles Involved**		**Phase**
Information Provider	Plumbing Engineer, Other Disciplines		20
Actor	Architect		20
Information Required	Plumbing schematic drawings and specifications: Plumbing plans showing equipment locations as well as pipe routing and connectivity Plumbing Product Type Template Plumbing System performance specifications ▪ Pipe section: size, location, flow rate, and pressure drop ▪ Pipe fitting: size, location, connection type, and pressure drop Schedule of Fixture Types ▪ Bath, Bidet, Toilet Tank, Water Closet, Shower, Sink, Drinking Fountain, Urinal Plumbing equipment list/schedule ▪ Water Heater, Washing Machine, Sterilizer, Water Softener System, Grease Trap, Garbage Disposer, Pumps, Solar Heating System, Storage Tanks, Gutters, Downspouts Plumbing Equipment Sizes Drawings from all other disciplines Size and location information for: ▪ Structural ▪ Mechanical ▪ Electrical ▪ Fire Protection		
Current Methods	Plumbing Engineer sends the plumbing drawings to the Architect. Typically, piping runs are shown as a single line and may not be annotated as to elevation. Architect takes drawings from all disciplines and either visually compares them (by such means as a light table or computer overlays) or utilizes clash detection software to identify and resolve spatial conflicts between building systems.		

2.2.3 Coordinated Design Phase plumbing system design

The Coordinated Design Phase comprises the following tasks, shown diagrammatically in Figure 3.

Figure 3: Process diagram for Coordinated Design Phase plumbing system design.



Task Form				
Task ID	30-010	**Task Name**	Update Facility Spatial Configuration	
Participants	**Roles Involved**			**Phase**
Information Provider	All Design Disciplines			20
Actor	Architect			30
Information Required	Coordinated drawings from all other disciplines Size and location information for: ▪ Structural ▪ Mechanical ▪ Electrical ▪ Fire Protection ▪ Vendor Drawings and Cut sheets			
Current Meth-ods	Architect revises the facility spatial configuration plans based on the results of the coordination that took place at the end of Design Schematic.			

Task Form				
Task ID	30-020	**Task Name**	Determine Water Supply Requirements	
Participants	**Roles Involved**			**Phase**
Information Provider	Architect, Plumbing Engineer, Other disciplines			30
Actor	Plumbing Engineer			30
Information Required	Product Type Template: Plumbing System performance specifications ▪ Pipe section: size, location, flow rate, and pressure drop ▪ Pipe fitting: size, location, connection type, and pressure drop Schedule of Fixture Types ▪ Bath, Bidet, Toilet Tank, Water Closet, Shower, Sink, Drinking Fountain, Urinal Updated Plumbing equipment list/schedule ▪ Water Heater, Washing Machine, Sterilizer, Water Softener System, Grease Trap, Garbage Disposer, Pumps, Solar Heating System, Storage Tanks, Gutters, Downspouts Updated Plumbing Equipment Sizes Updated Location of Plumbing Fixtures & Equipment ▪ Plumbing Plan System Type ▪ Cold Water, Hot Water, Sanitary, Treated, Waste, Storm, Vent Updated water and waste requirements for other building systems			
Current Methods	Plumbing Engineer uses the Product Type Template, updated plans and other-discipline information to determine total water supply requirements.			

Task Form			
Task ID	30-030	**Task Name**	Calculate Water Balance
Participants	**Roles Involved**		**Phase**
Information Provider	Plumbing Engineer		30
Actor	Plumbing Engineer		30
Information Required	Water Supply Requirements ▪ GPM for fixtures ▪ Volume Per Visit ▪ Visits per Person per Period ▪ Minutes in Use ▪ Numbers of Users ▪ Efficiency Label ▪ Volume Per Day ▪ Input / Output Ratio ▪ Water Input Grade ▪ Water Output Grade ▪ Operating Pressure ▪ Distance to Source ▪ Water Supply Fixture Unit (WSFU)		
Current Methods	The Plumbing Engineer performs manual calculations to determine the potential demand and supply of grey water in a facility based on usage by all disciplines. Plumbing Engineer updates the Water Supply Requirements and listing of plumbing equipment types, sizes and locations, if needed.		

Task Form			
Task ID	30-040	**Task Name**	Create Piping Schematics
Participants	**Roles Involved**		**Phase**
Information Provider	Plumbing Engineer, Architect		30
Actor	Plumbing Engineer		30
Information Required	Updated facility spatial configuration ▪ Architectural Plan		
Current Methods	The Plumbing Engineer revises riser diagram(s) of the plumbing system based on updated facility spatial configuration provided by the Architect. This is completed by referencing the 2-D plans provided and manually creating a 2-D elevation, generically showing the entire piping system. The Plumbing Engineer creates or updates plumbing topology, plumbing equipment schedule, plumbing controls schedule and plumbing zone diagrams and forwards the drawings and schedules to the Architect.		

Task Form			
Task ID	30-050	**Task Name**	Lay Out Plumbing System
Participants	**Roles Involved**		**Phase**
Information Provider	Architect		30
Actor	Plumbing Engineer		30
Information Required	Updated Facility Spatial Configuration ▪ Architectural Plan Plumbing Zones Plumbing Controls Plumbing Topology ▪ Riser Diagram(s) Updated water and waste requirements for other building systems		
Current Methods	The Plumbing Engineer creates updated plumbing layout drawings based on architectural floor plans, the updated requirements of other building systems and previously-created piping schematics.		

Task Form			
Task ID	30-060	**Task Name**	Update Piping and Equipment Sizes
Participants	**Roles Involved**		**Phase**
Information Provider	Plumbing Engineer		30
Actor	Plumbing Engineer		30
Information Required	Updated Plumbing Layout Plumbing Plan(s) – Fixtures, Equipment, Pipe routing, distribution sources		
Current Methods	Plumbing Engineer updates the schedules of piping and equipment sizes.		

Task Form			
Task ID	30-070	**Task Name**	Update Plumbing Spatial Requirements
Owner			
Participants	**Roles Involved**		**Phase**
Information Provider	Plumbing Engineer		30
Actor	Plumbing Engineer		30
Information Required	Updated Plumbing Layout ▪ Plumbing Plan(s) – Fixtures, Equipment, Pipe routing, distribution sources Updated Piping and Equipment Sizes		
Current Methods	Plumbing Engineer updates the spatial requirements for the needed plumbing equipment based on any architectural design changes. The Plumbing Engineer communicates any increases or reductions in plumbing spatial requirements to the Architect.		

Task Form			
Task ID	30-080	**Task Name**	Update Facility Spatial Configuration
Participants	**Roles Involved**	**Phase**	
Information Provider	Plumbing Engineer	30	
Actor	Architect	30	
Information Required	Updated plumbing layout ▪ Plumbing Plan(s) – Fixtures, Equipment, Pipe routing, distribution sources Updated plumbing spatial requirements		
Current Methods	Architect revises the facility spatial configuration plans based on the updated plumbing layout and spatial requirements provided by the Plumbing Engineer.		

Task Form			
Task ID	30-090	**Task Name**	Develop Product Specifications and Candidates
Participants	**Roles Involved**	**Phase**	
Information Provider	Architect, Plumbing Engineer, Standard References	30	
Actor	Plumbing Engineer / Specifier	30	
Information Required	Updated piping and equipment sizing information Building Code Requirements ▪ Health & Safety requirements ▪ Fittings & Connection requirements Product research ▪ (3) Equal Product Type Candidate for each fixture / equipment component		
Current Methods	On projects where the product specifications are performance-based rather than proprietary, and the project delivery method is design-bid-build, the Architect downloads multiple manufacturers' product information to compare properties of fixtures. Based on the fixture specification the Architect selects three (3) equal products and e-mails the manufacturers' cut sheet information to the Plumbing Engineer or Specifier. The Plumbing Engineer or Specifier manually creates the 3-part specifications based on information received.		

Task Form			
Task ID	30-100	**Task Name**	Document Plumbing Design Coordinated
Participants	**Roles Involved**	**Phase**	
Information Provider	Architect, Plumbing Engineer	30	
Actor	Plumbing Engineer	30	
Information Required	Updated facility spatial configuration Updated Plumbing Layout ▪ Plumbing Plan(s) – Fixtures, Equipment, Pipe routing, distribution sources Plumbing Topology ▪ Riser diagram(s) Plumbing Controls Schedule Calculations and Equipment Schedules/List Final Plumbing Specification ▪ Product Type Candidates		
Current Methods	The Architect provides the building configuration, plumbing fixture locations types and counts on plan and elevation drawings. The Plumbing Engineer revises plumbing plans, riser diagrams, calculations and equipment schedules based on the architectural information.		

Task Form				
Task ID	30-110	**Task Name**	Coordinate With Other Building Systems	
Participants	**Roles Involved**			**Phase**
Information Provider	All Design Disciplines			30
Actor	Architect			30
Information Required	Updated Plumbing drawings showing physical size and location of all elements in the plumbing system Final Plumbing Specifications Updated Drawings from all other Disciplines			
Current Methods	Plumbing Engineer sends the plumbing drawings to the Architect. Typically, piping runs are shown as a single line and are mainly not annotated as to elevation. Architect takes drawings from all disciplines and visually compares them (by such means as a light table, computer overlays or clash detection software in the case of a 3D model) to identify and resolve spatial conflicts between building systems.			

3 Fundamental Concepts

3.1 Overview

This chapter documents common concepts of information modeling applied to various object types found in data exchanges. Each individual concept template may also be referred to as a *functional part*, and describes a graph of object classes and attributes. Such templates are further refined at each applicable object class to indicate specific values or types that may be used. For a complete presentation of the MVD, including IFC instance diagrams and tables indicating how the concepts are used by entities for exchanges, see http://docs.buildingsmartalliance.org/MVD_WSIE.

For a complete presentation of the MVD, including IFC instance diagrams and tables indicating how the concepts are used by entities for exchanges, see http://docs.buildingsmartalliance.org/MVD_SPARKIE.

3.2 Concept templates

Various concept templates have been introduced in this specification, and existing concept templates have been adapted from the IFC4 specification of BuildingSmart International (www.buildingsmart-tech.org).

NOTE: This specification is also available in HTML and MVDXML form, where the online specification contains additional content including instantiation diagrams and exchange requirements tables.

This specification consists of a schema defining data types, along with common concepts indicating use of data types for particular scenarios. This chapter defines such common concepts, which are applied at entities having specific use. Such concepts also form the basis of MVDs, which are supplementary specifications that adapt the scope and rules of this schema for targeted domains within the building industry.

Each concept template defines a graph of entities and attributes, with constraints and parameters set for particular attributes and instance types. Various entities within this schema reference such concept templates and adapt them for particular use according to parameters. For example, the 'Ports' concept template defines distribution system connectivity for mechanical, electrical, and plumbing systems and a pipe segment defines an application of the 'Ports' concept, having one port as an inlet and another as an outlet.

3.2.1 Roots

All entities having semantic significance derive from IfcRoot, where instances are identifiable within a data set using a compressed globally unique identifier (IFC-GUID). This identifier must never change during the lifetime of an object, which allows data to be merged, versioned, or referenced from other locations.

Resource-level instances (not deriving from IfcRoot) do not have any identity, such that two instances having identical state are considered equal. For example, if an object has coordinates described by an IfcCartesianPoint instance, another object with the same coordinates may have a separate instance of IfcCartesianPoint or share the same instance; such difference is a matter of data storage optimization and does not imply any semantic relationship. This also implies that non-rooted instances may only exist if referenced by at least one rooted instance through either a direct attribute or inverse attribute, or following a chain of attribute references on instances.

The distinction between rooted and non-rooted (resource-level) entities achieves several goals:

- File size may be reduced by interning (sharing) non-rooted data instances;
- Database retrieval may be more efficient by storing non-rooted data local to rooted data instances;
- Storage size may be reduced by avoiding IFC-GUID storage for items not requiring direct retrieval;
- Comparisons of differences may be done at a higher level where the context of such change is apparent;
- Implementations may treat non-rooted data instances as immutable for efficiency or simplified usage.

3.2.1.1 Identity

An object needs to be identifiable for accurate processing by both human and automated processes. Identification may be through several attributes such as Identification, Name, Description or GUID. The GUID is compressed for the purpose of being exchanged within an IFC data set - the compressed GUID is referred to as "IFC-GUID". While the IFC-GUID is normally generated automatically and has to be persistent, the Identification may relate to other informal registers but should be unique within the set of objects of the same type. The Name and Description should allow any object to be identified in the context of the project or facility being modeled.

Various objects may have additional identifications that may be human-readable and/or may be structured through classification association.

Various file formats may use additional identifications of instances for serialization purposes; however there is no requirement or guarantee for such identifications to remain the same between revisions or across applications. For example, the IFC-SPF file format lists each instance with a 64-bit integer that is unique within the particular file.

3.2.2 Project

All files contain a single IfcProject instance indicating overall context and a directory of objects contained within.

3.2.3 Project Declaration

The project provides a directory of objects contained within using declaration relationships.

3.2.3.1 Object type definitions

Declaration of object types, such as element types utilized by the element occurrences within this project, within the context of the project.

3.2.3.2 Property set templates

Declaration of property set templates, including the property templates that are used as property definitions. Such templates define the applicable properties, their names, descriptions, measure types and property type (single, enumerated, bounded list or table value).

3.2.3.3 Project units

The project context includes the definition of the default units within the IFC data set. Default units are those units that apply:

- To all geometric representation items within the geometric representation contexts;
- To all attributes with a defined datatype indicating a measure datatype;
- To all properties and quantities with a defined datatype indicating a measure datatype and with no local unit definitions provided.

3.2.3.4 Project context

A project representation context indicates the coordinate system orientation, direction of true north, precision, and other values that apply to all geometry within a project or project library.

3.2.4 Actor

An actor is a person or organization participating in a project. Actors may fulfill one or more roles such as engineers, contractors, manufacturers, building occupants, etc.

3.2.4.1 Contact

Contact information indicates roles and addresses of people and organizations.

3.2.5 Control

A control is a directive to meet specified requirements such as for scope, time, and/or cost.

3.2.5.1 Calendar

Calendar information is used to filter other objects to indicate time periods during which the control applies.

3.2.6 Product

A product is an occurrence of a physical or virtual object with finite spatial extent.

3.2.6.1 Product placement

Product occurrences can be placed in 3D space relative to where they are contained. Placement is defined by a relative position (X, Y, Z coordinates), a horizontal reference direction, and a vertical axis direction. At the outermost level, relative directions are defined according to representation context; for example, +X may point east, +Y may point north, and +Z may point up.

Placement follows aggregation and containment relationships as follows:

- At the outermost level, a site is globally positioned according to latitude, longitude, and elevation;
- For spatial structures, positioning is relative to aggregation. For example, a site may aggregate multiple buildings, each building may aggregate multiple building stories, and each building story may aggregate multiple spaces;
- For building elements, positioning is relative to the containing spatial structure. For example, a building story may contain slabs, walls, columns, and beams;
- For aggregated parts, positioning is relative to aggregation. For example, a staircase may aggregate one or more stair flights;
- For feature elements, positioning is relative to the affected building element. For example, an opening element is positioned relative to the wall it voids, which in turn is positioned relative to a building story;
- For fillings, positioning is relative to the filled opening. For example, a door is positioned relative to an opening which in turn is positioned relative to a wall;
- For distribution ports, positioning is relative to the containing distribution element. For example, an air terminal may have a port connection for a duct segment or fitting;
- For distribution elements, positioning is relative to the containing spatial structure, however may be constrained by port connections. For example, an electrical junction box may fill an opening within a wall, and the junction box may contain ports for contained outlets or switches; the placement of such connected elements is constrained relative to connected port of the junction box. As another example, an air terminal may fill a ceiling covering which is placed relative to a space; the placement of a connecting duct fitting may be constrained relative to the air terminal.

If a containing spatial structure contains a grid, then placement may also be based relative to grid coordinates.

3.2.6.2 Product representation

The shape of products may be represented in multiple ways for different purposes. Each representation has a well-known string identifier and a particular representation context. There may be multiple representation contexts to describe a shape at various levels of detail. Most building elements have a 'Body' representation which defines or approximates the physical shape and volume. In addition to physical building elements, non-physical elements may have representations such as spaces and openings.

3.2.6.3 Axis geometry

Elements following a path provide an 'Axis' representation indicating a line segment or any arbitrary open bounded curve. Examples of such elements include walls, beams, columns, pipes, ducts, and cables. For elements that have a material profile set association indicating cross-section, a 'Body' representation may be generated based on the axis curve and material profiles. Curve styles may indicate particular colors, line thicknesses, and dash patterns for 2D rendering.

3.2.6.4 Footprint geometry

Elements filling a boundary provide a 'Footprint' representation indicating a rectangle or any arbitrary set of outer and inner boundary curves. Examples of such elements include slabs and spaces. For elements that have a material layer set association indicating material thicknesses, a 'Body' representation may be generated based on the footprint and material layers. Fill area styles may indicate particular colors, tiles, or hatching for 2D rendering.

The representation identifier of the footprint geometric representation is:

- IfcShapeRepresentation.RepresentationIdentifier = 'FootPrint'

3.2.6.5 Surface geometry

Elements may have a 'Surface' representation describing the outer surface of the object. Such representation may be used for hit-testing objects having part composition such as framed walls.

3.2.6.6 Body geometry

Elements may have a 'Body' representation describing the volumetric shape of the object. Such representation may be used for 3D rendering or quantity take-off. Geometry may be based on boundary representations describing outer faces, primitives such as spheres or cones, swept solids such as profile extrusions or revolutions, Constructive Solid Geometry (CSG) such as clippings or subtractions of other shapes, or Non-Uniform Rational B-Spline (NURBS) geometry. Surface styles may indicate particular colors, textures, and reflectance for 3D rendering.

The representation identifier of the body representation is:

- IfcShapeRepresentation.RepresentationIdentifier = 'Body'

3.2.6.7 Clearance geometry

Elements requiring surrounding space for clearance provide a 'Clearance' representation. The reason for clearance space may be due to ventilation, maintenance, or other purpose. Examples of such elements include boilers and chillers. Such representation may be used for interference checks, where the 'Clearance' representation must not intersect with the 'Body' representation of other objects, though may intersect with the 'Clearance' representation of other objects.

3.2.6.8 Site location

The site location may be used to determine climate conditions and applicable building codes.

3.2.6.9 Building location

The building location may indicate the address as found on a map.

3.2.6.10 Building story elevation

The building story elevation may be used to determine water pressure requirements and allowance for pumps to regulate pressure.

3.2.7 Product type

Product types define explicit product models or parametric product families, that may be instantiated in buildings.

3.2.7.1 Product type representation

Product types may have representations indicating shape representation for geometry, clearance, or other concepts.

The shape representation attached to a type is defined using the relationship *RepresentationMaps* of data type IfcRepresentationMap. It provides the means to store several representation maps for different purposes. In order to utilize the representation map at each occurrence of the product type, the product occurrence has to use the concept 'Mapped Geometry'.

NOTE See IfcProductType for further information and figures explaning the concepts 'Product Type Representation' and 'Mapped Geometry'.

3.2.7.2 Body geometry

The Body representation defines the physical shape of the product type.

3.2.7.3 Clearance geometry

For elements that require clearance such as for safety, maintenance, or other purpose, this represents the 3D clearance volume of the item having RepresentationType of 'Surface3D'. Such clearance region indicates space that should not intersect with the 'Body' representation of other elements, though may intersect with the 'Clearance' representation of other elements.

3.2.8 Resource

A resource represents usage of something, having costs and environmental impacts.

3.2.8.1 Resource cost

Resources can have associated costs indicating financial costs and environmental impacts incurred according to a specified base quantity.

Each cost value may be defined using a constant amount or calculated according to specified formula.

3.2.8.2 Resource quantity

Resources may be defined according to a base quantity, where assigned tasks consume such amount of resource relative to an output quantity.

For work-based resources such as labor and equipment, quantities are based on time. For product-based resources, quantities are based on count. For material-based resources, quantities are based on volume.

3.2.9 3.2.8 Resource type

A resource type represents a template of usage of something, having cost rates and environmental impact rates.

3.2.9.1 Resource cost rate

Resource cost rates are provided for anything that may be sold in quantity, such as product models that may be ordered, or common services that may be priced by unit.

3.2.10 Association

Association refers to relating objects to external information such as documents, databases, and classifications.

3.2.10.1 Classification

Objects, type objects, properties, and some resource schema entities can be further described by associating references to external sources of information. The source of information can be:

- A classification system;
- A dictionary server;
- Any external catalogue that classifies the object further;

- A service that combine the above features.

An individual item within the external source of information can be selected. It then applies the inherent meaning of the item to the object or property.

3.2.10.2 Material

Any product or product type can have associated materials indicating the physical composition of an object. Materials can have representations for surface styles indicating colors, textures, and light reflectance for 3D rendering. Materials can have representations for fill styles indicating colors, tiles, and hatch patterns for 2D rendering. Materials can have properties such as density, elasticity, thermal resistance, and others as defined in this specification. Materials can also be classified according to a referenced industry standard.

An object can be comprised of a single material or a set of materials with a particular layout. Several examples include:

- A slab may have an associated layer of concrete;
- A beam may have an associated I-Shape profile of steel;
- A door may have associated constituents for framing and glazing;
- A port may have an associated profile and/or material flowing through it such as hot water.

EXAMPLE: Material information can also be given at object type, defining the common material data for all occurrences of the same type. It is then accessible by the inverse *IsTypedBy* relationship pointing via *HasAssociations* and via *IfcRelAssociatesMaterial.RelatingMaterial* to the material information. If both are given, then the material directly assigned to object occurrence overrides the material assigned to object type.

3.2.10.3 Material layer set usage

Material layer set usage defines layout at occurrences to indicate a direction and offset from the 'Axis' reference curve, and a reference extent such as for a default wall height.

3.2.10.4 Material profile set

Material profile sets are associated with elements or element types where materials are placed in cross-sections of specified dimensions following a path defined at occurrences of the type. Examples of such products are beams, columns, members, reinforcing, footings, piles, pipe segments, duct segments, and cable segments.

Material profile sets are associated by using the relationship IfcRelAssociatesMaterial having the RelatingMaterial pointing to an IfcMaterialProfileSet. The RelatedObjects either point to a single or multiple occurrences of IfcElement, or to a single or multiple IfcElementType.

EXAMPLE: Material profile sets can be provides at the *IfcColumnType*, defining the common material information for all occurrences of the same column type. It is then accessible by the inverse *IsTypedBy* relationship at *IfcColumn* pointing to *IfcColumnType* having the *HasAssociations* inverse relationship to IfcRelAssociatesMaterial with *RelatingMaterial* refering to theIfcMaterialProfileSet. If an individual material association is provide at the *IfcColumn* and the *IfcColumnType*, then the material directly assigned to *IfcColumn* overrides the material assigned to *IfcColumnType*.

3.2.10.5 Material profile set usage

Material profile set usage defines layout at occurrences to indicate the offset from the 'Axis' reference curve according to cardinal point, and a reference extent such as for a default column height.

3.2.10.6 Material constituents

Material constituents are associated with products where materials are placed arbitrarily (unlike 1D material profiles or 2D material layers). The mapping of materials to geometry may be accomplished using IfcShapeAspect.

3.2.11 Definition

Objects may be defined by having a number of properties, where such properties may be organized partially (into property sets) or fully (into templates).

3.2.11.1 Object typing

Object occurrences can be defined by a particular object type, using the Object Typing concept. A pair of entities is defined for most semantic objects - an object occurrence entity and a corresponding object type entity.

EXAMPLE: The *IfcTank* is the object occurrence entity that has a corresponding *IfcTankType* being the object type entity.

On instance level, an object occurrence instance may have:

- Similar state as its object type instance by applying all characteristics defined at the type;
- Overridden state for particular characteristics;
- No defined object type instance.
- Characteristics defined at the object type level may include:
- Common naming and predefined type;
- Common properties within a type driven property set;
- Common geometry representations, applied as mapped representation to each occurrences;
- Common material assignments (with exception of material set usages);
- Common definition of a decomposition structure.

Many object occurrence and object type entities have an attribute named PredefinedType consisting of a specific enumeration. Such predefined type essentially provides another level of inheritance to further differentiate objects without the need for additional entities. Predefined types are not just informational; various rules apply such as applicable property sets, part composition, and distribution ports.

EXAMPLE: For scenarios of object types having part compositions, such parts may be reflected at object occurrences having separate state. For example, a *wall type* may define a particular arrangement of studs, a *wall occurrence* may reflect the same arrangement of studs, and studs within the wall occurrence may participate in specific relationships that do not exist at the type such as being connected to an electrical junction box.

The object type is attached using the IfcRelDefinesByType objectified relationship and is accessible by the IsTypedBy inverse attribute. Only a maximum one, or zero, object types can define an object occurrence. If the object type has aggregated elements, such objects are reflected at the object occurrence using the IfcRelDefinesByObject relationship.

3.2.11.2 Property sets

Any specialization of object can be related to multiple property set occurrences. A property set contains multiple property occurrences. The data type of property occurrence are single value, enumerated value, bounded value, table value, reference value, list value, and combination of property occurrences.

3.2.11.3 Property sets for types

For object types, property sets are defined directly.

3.2.11.4 Property sets for performance

For performance history, properties are in the form of time series, for tracking data at points in time.

3.2.11.5 Quantity sets

Any specialization of object can be related to multiple quantity set occurrences. A quantity set contains multiple quantity occurrences. The data type of quantity occurrence values are count, length, area, volume, weight, time, or a combination of quantities. Each quantity is defined by its name, value, and optionally a description and a formula.

The quantity set is expressed by instances of IfcElementQuantity, where the *Name* attribute determines the common designator of the quantity set. This specification contains a number of predefined quantity sets, a template definition is provided for each of them. The name of the template has to be used as the value of the *Name* attribute. The *MethodOfMeasurement* attribute specifies the method, by which the values of the individual quantities are calculated. For the quantity set templates included in this specification, the value of *MethodOfMeasurement* shall be "BaseQuantities".

4 Model View Definition

4.1 Overview

This chapter documents use cases for exchanging information related to electrical disciplines for building design and construction. Industry Foundation Classes (IFC) is the international standard for exchanging Building Information Modeling (BIM) data, which defines hundreds of classes for common use in software, currently supported by approximately 150 applications. A Model View Definition (MVD) defines a subset of the IFC schema that is needed to satisfy one or many Exchange Requirements of the AEC industry. Together with the IFC schema subset, a set of implementation instructions and validation rules, called MVD Concepts, are published. The electronic format to publish the concepts and associated rules is mvdXML. While IFC defines how building information can be represented electronically in general, an MVD defines which information is required for particular scenarios.

4.2 Exchanges

Information required at various stages of a building project is organized into Exchanges. Each exchange defines what information is required, optional, inapplicable, or restricted. Application software may support filtering data to be imported or exported for a particular exchange, and contracts for projects may refer to such exchanges to identify the scope and format of information required for delivery.

4.2.1 Facility occupancy model

4.2.1.1 Requirements

The facility occupancy model describes the site location, owner's project requirements, and building requirements.

The site location indicates the geographic location for determining climate information, and the legal address for determining the jurisdiction and applicable building codes.

The owner's project requirements consist of a facility type and a set of space types, each indicating occupancy loads, hours of occupancy, design priorities, and climate control requirements.

4.2.1.2 Usage

The IfcProject indicates overall context including default units. The IfcProject is aggregated by an IfcSite which indicates the geographic location and postal address. The IfcSite is aggregated by an IfcBuilding which indicates overall building requirements in the form of property sets. The IfcProject declares IfcOccupant instances (via IfcRelDeclares) for each class of building occupant which may correspond to a number of people as indicated within the Pset_ActorCommon property set. Each IfcOccupant may have IfcWorkCalendar assignments using IfcRelAssignsToActor. The IfcProject declares IfcWorkCalendar instances (via IfcRelDeclares) for each calendar of occupancy. Each IfcWorkCalendar may have IfcBuilding assignments using IfcRelAssignsToControl.

Prototypes for required plumbing fixtures are indicated as resources using IfcConstructionProductResource with IfcSanitaryTerminal assigned using IfcRelAssignsToResource. The sanitary terminal may represent an arbitrary quantity (as indicated by the resource) and is not physically placed in a building and has no placement or representation at the early design stage. The resource is assigned to an IfcTask with PredefinedType of *ATTENDANCE*, where the task is assigned to an IfcSpatialStructureElement (typically the overall IfcBuilding at early design or IfcBuildingStorey to track pressure differences).

4.2.2 Compare system options

4.2.2.1 Requirements

Domestic water requirements are based on occupancy load requirements and performance data for equipment.

The following information is captured for each class of fixture:

- Flow rate
- Flow test
- Volume Per Visit
- Visits per Person per Period

- Minutes in Use
- Numbers of Users
- Efficiency Label
- Volume Per Day
- Input / Output Ratio
- Water Input Grade
- Water Output Grade
- Operating Pressure
- Distance to Source – Civil Plans
- Water Supply Fixture Unit (WSFU)
- Pressure Drop

The following information is captured for available systems that may provide the energy source for water heating:

- Gas
- Oil
- Electrical

The following information is captured for water distribution systems:

- Cost of System based on project type
- Cost of System based on anticipated water input
- The following information is captured for project cost control:
- System Budget

4.2.2.2 Usage

Domestic water systems are described using IfcDistributionSystem having PredefinedType set to *DOMESTICCOLDWATER*. Each top-level system is declared on the IfcProject using IfcRelDeclares. Devices within each system (e.g., IfcSanitaryTerminal, IfcValve, IfcPump) are assigned using the IfcRelAssignsToGroup relationship, where property sets indicate flow requirements on devices.

Each fixture prototype is indicated using IfcSanitaryTerminal and assigned to an IfcConstructionProductResource as a placeholder for indicating arbitrary requirements. Property sets indicate required flow characteristics.

Systems for available energy sources are indicated using IfcDistributionSystem having PredefinedType set to *GAS*, *OIL*, *FUEL*, or *ELECTRICAL*.

Systems provided by utilities are assigned to the utility company using IfcRelAssignsToActor where an IfcActor identifies the IfcOrganization of the utility having an IfcActorRole set to the user-defined value of *'UTILITY'*. Utility-level systems typically contain IfcPump and IfcFlowMeter elements.

Each available service is indicated using IfcTaskType indicating a process model with PredefinedType set to *OPERATION*. Such process model may have nested recurring tasks (IfcTask) via IfcRelNests with time periods indicating when the service applies using IfcTaskTimeRecurring. Costs of each rate structure are indicated by IfcSubContractResourceType where BaseCosts contains one or more IfcCostValue instances. Each IfcSubContractResourceType is assigned to the IfcTaskType or nested IfcTask using the IfcRelAssignsToProcess relationship. The utility (represented by IfcActor) is assigned to the subcontract resource type using the IfcRelAssignsToResource relationship.

4.2.3 Locate plumbing fixtures

4.2.3.1 Requirements

A preliminary schedule of plumbing fixture types may be indicated:

- Bath
- Bidet
- Toilet
- Shower
- Sink
- Drinking Fountain
- Urinal

For each fixture type, system connections must be indicated including:

- Cold Water
- Hot Water
- Grey Water
- Black Water

- Rainwater Harvesting
- Waste
- Specialty Waste
- Pure water
- Other liquid, gas, or fuel services
- Hot water fuel source

4.2.3.2 Usage

Each fixture type is indicated using IfcSanitaryTerminalType and declared within the IfcProject using the IfcRelDeclares relationship. Property sets may be defined on fixture types indicating product requirements. Ports on each fixture type are indicated using IfcDistributionPort and nested within each IfcSanitaryTerminalType using the IfcRelNests relationship. Each port must indicate flow direction, port type, and system type.

Fixture occurrences are indicated using IfcSanitaryTerminal and may be placed within an IfcSpatialStructureElement (typically IfcSpace) in the initial schematic plans where geometric placement is optional (if not yet known). Fixture occurrences indicate types (either specific product model or parametric requirement model) using the IfcRelDefinesByType relationship. Physical connectivity (such as to wall, floor, or cabinet) may be indicated using the IfcRelConnectsElements relationship.

4.2.4 Plumbing equipment requirements

4.2.4.1 Requirements

Plumbing equipment is determined according to water quality and flow properties of allocated sanitary terminals.

Valves are determined according to system transitions (such as from Domestic Cold Water to Irrigation) where backflow preventers or release valves may be required. While not every valve must be elaborated at this stage, those that significantly impact pressure (such as backflow preventers) are required such that pumps may be sized appropriately.

Pumps are determined according to required pressure at fixtures, placement elevations, and pressure drop throughout downstream piping, valves, filters, and pumps.

Water heaters and holding tanks are determined according to required temperature and consumption based on occupancy patterns, and heat loss throughout downstream piping.

Water filtration equipment is determined according to required water quality at fixtures and incoming water quality from the water source (such as utility, community well, or private well).

4.2.4.2 Usage

Valves are indicated using IfcValve, where the flow regulation characteristics are indicated on the outgoing IfcDistributionPort. Pumps are indicated using IfcPump, where the incoming and outgoing pressure are indicated on each IfcDistributionPort. Heaters are indicated using IfcBoiler, where the incoming and outgoing temperature are indicated on each IfcDistributionPort. Filteration equipment is indicated using IfcFilter of PredefinedType set to *WATERFILTER*.

4.2.5 Plumbing spatial requirements

4.2.5.1 Requirements

Once space requirements have been determined, space locations and dimensions are allocated, where they are then adjusted according to specific disciplines to fulfill more detailed requirements.

4.2.5.2 Usage

Each device is indicated using a subtype of IfcDistributionFlowElement where either the occurrence or defined type may indicate geometry. Fixtures for drinking or sanitation are indicated using IfcSanitaryTerminal. Appliances such as clothes washers and dishwashers are indicated using IfcElectricAppliance. Pumps are indicated using IfcPump. Water heaters are indicated using IfcBoiler. Water filters are indicated using IfcFilter.

4.2.6 Locate and size plumbing equipment rooms

4.2.6.1 Requirements

Equipment rooms may be sized according to clearance volumes of boilers, pumps, filters, and appliances. While the final sizes are not yet known at this stage (piping layout and thermodynamic analysis has not yet been done), space allocation is only accurate according to the general equipment requirements.

4.2.6.2 Usage

Pumps are indicated using IfcPump. Water heaters are indicated using IfcBoiler. Water filters are indicated using IfcFilter. Appliances are indicated using IfcElectricAppliance.

4.2.7 Specify plumbing system performance

4.2.7.1 Requirements

For this exchange, performance requirements are elaborated for every water terminal, which may be used to size the plumbing system.

Each element requires the following at incoming water connections:

- Pressure range
- Volumetric flow range
- Pipe diameter
- Water quality
- Temperature range
- Environmental temperature range (such as exterior for freeze protection)

Each element requires the following at outgoing drainage connections:

- Volumetric flow range
- Pipe diameter

4.2.7.2 Usage

The IfcProject declares one or more IfcPerformanceHistory instances, where the lifecycle phase should be set to DESIGNDEVELOPMENT to indicate development-level estimation precision. Top-level IfcPerformanceHistory instances (typically one) refer to water usage at a main utility port, typically corresponding to that on the SINK side of an IfcFlowMeter water meter, where such IfcDistributionPort may be assigned to the IfcPerformanceHistory via the IfcRelAssignsToControl relationship. The IfcPerformanceHistory makes use of the Pset_DistributionPortPHistoryPipe property set for indicating water flow rate at periods of time, where each IfcPropertyReferenceValue points to IfcIrregularTimeSeries.

4.2.8 Size plumbing system

4.2.8.1 Requirements

This exchange indicates required quantities and sizes of plumbing equipment (pumps, valves, boilers, filters) based on system performance. It does not account for particular piping layout, therefore calculated pressure drop is approximated based on elevation and nominal horizontal routing.

4.2.8.2 Usage

Property sets indicate flow characteristics at each IfcDistributionPort.

4.2.9 Plumbing basis of design

4.2.9.1 Requirements

Document process model, constraints, formulas, and tables used for making decisions on plumbing design.

- Water calculations showing required and designed flow rate, pressure, and temperature
- Estimated water heater loading
- Estimated water treatment loading
- Estimated water pump loading
- A projection/summation of the pump loads to justify the sizing of the pumps
- Estimated water source loading
- An economic analysis to justify the selection of utility water, community well, or private well (if in rural areas)

4.2.9.2 Usage

To indicate multiple scenarios within a project, each scenario is indicated using IfcWorkPlan declared on the IfcProject using the IfcRelDeclares relationship. Once a plan is approved for usage, it may be nested within an approved IfcProjectOrder. Such work plan may have a nested IfcPerformanceHistory record indicating projected energy usage, which may be nested into sub-components corresponding to subsystems. The particular systems are indicated using IfcDistributionSystem and are assigned to the IfcPerformanceHistory energy projection using the IfcRelAssignsToControl relationship.

4.2.10 Document plumbing design schematic

4.2.10.1 Requirements

The plumbing design schematic indicates system connectivity among fixtures and indicate pipe sizes, but does not indicate particular paths of pipes.

4.2.10.2 Usage

Each pipe connection is indicated using the IfcRelConnectsPorts relationship, where the RealizingElement attribute may be set to an IfcPipeSegment. The pipe segment does not have geometry, but does have cross-section information provided using IfcRelAssociatesMaterial and IfcMaterialProfileSetUsage. The pipe size may be determined from IfcCircleHollowProfileDef for circular sections or IfcArbitraryClosedProfileDef for other shapes.

4.2.11 Coordinate with other building systems

4.2.11.1 Requirements

For coordination with other building systems, plans are created showing equipment locations as well as pipe routing and connectivity. Plumbing schedules for equipment, fixtures, and pipes are derived.

4.2.11.2 Usage

Equipment is indicated primarily by subtypes of IfcFlowTerminal, IfcFlowController, and IfcEnergyConversionDevice. Equipment specific to a space is placed within an IfcSpace, while equipment that serves multiple spaces is placed within an IfcBuildingStorey. Pipes connecting equipment are attached to ports (IfcDistributionPort) on each device using IfcRelConnectsPorts.

Slabs, walls, coverings, openings, and system furnishings are included for coordination, as most fixtures and piping is anchored or embedded within such structures using the IfcRelConnectsElements relationship, where dimensions must be known for proper sizing and locating of pipes and/or sizing of enclosing structures. The anchoring of elements is significant, as it indicates construction precedence: for example, a sink connected to a floor covering implies the floor must be installed prior to the sink installation, whereas direct connection to a slab implies otherwise.

- IfcSlabStandardCase is used for slabs on grade where water and drainage lines must be coordinated before pouring such slabs.
- IfcSlabElementedCase is used for framed floor levels where piping is fit underneath and may be drilled after construction.
- IfcWallStandardCase is used for concrete or CMU walls where piping is typically coordinated before forming such walls.
- IfcWallElementedCase is used for framed walls where piping may be routed provided adequate clearance and structural support.
- IfcCovering is used for drywall (of a wall or ceiling) or flooring where fixtures are commonly attached.
- IfcSystemFurnitureElement is used for cabinetry where plumbing fixtures are commonly attached.

For scenarios where pipes must traverse through walls or slabs, the IfcRelInterferesElements relationship is used. It is recommended that software generate such relationships automatically wherever there is interference, and the users responsible for each element approve of the solution for voiding or rerouting.

4.2.12 Facility spatial configuration

4.2.12.1 Requirements

This exchange enables an architect to revise the facility spatial configuration plans based on the results of the coordination that took place at the end of Design Schematic. Required information includes:

- Spatial Elements (Buildings, Levels, Spaces, etc.)
- Building Elements (Walls, Slabs, Doors, Windows, etc.)
- Distribution Elements (Electrical, HVAC, Plumbing, etc.)
- Spatial Zones
- Systems & Circuits
- Connectivity (Space Boundaries, Ports, Connections, Interferences)
- Actors & Assignments

4.2.12.2 Usage

Project participants responsible for particular systems are indicated using IfcActor with assignments through IfcRelAssignsToActor.

Interferences with other building elements are indicated using IfcRelInterferesElements, where priorities may be indicated at such intersection.

4.2.13 Water supply requirements

4.2.13.1 Requirements

In this exchange, a plumbing engineer uses the product type templates, updated plans, and other discipline information to determine total water supply requirements. For each plumbing fixture, compatible product types are selected for each product occurrence (or if required, three compatible product types are selected that are suitable). The project delivery method may require the owner's approval for final product selection. The total water supply requirements are calculated on each branch according to concurrent design load.

4.2.13.2 Usage

For each plumbing device, the specified type or range of types is defined using IfcRelDefinesByType. Overall water supply requirements are established at property set on IfcDistributionSystem of type *DOMESTICCOLDWATER*.

4.2.14 Calculate water balance

4.2.14.1 Requirements

Calculations are performed to determine the potential demand and supply of grey water in a facility based on usage by all disciplines. Water Supply Requirements are updated to reflect a revised listing of plumbing equipment types, sizes and locations, if needed.

- Flow rate for fixtures (e.g., GPM gallons per minute)
- Volume per Visit
- Visits per Person per Period
- Minutes in Use

- Numbers of Users
- Efficiency Label
- Volume per Day
- Input / Output Ratio
- Water Input Grade
- Water Output Grade
- Operating Pressure
- Distance to Source
- Water Supply Fixture Unit (WSFU)

4.2.14.2 Usage

For each plumbing device, the specified type or range of types is defined using IfcRelDefinesByType. Overall water supply requirements are established at property set on IfcDistributionSystem of type *DOMESTICCOLDWATER*.

4.2.15 Piping schematic

4.2.15.1 Requirements

This exchange provides detailed information for connectivity and placement of pipes, including the following:

- Sanitary Terminal: Location, Load, Controls
- Valve: Location, Load
- Pipe Segment: Location, Connections, Load, Length, Material (copper, PVC, etc.)

All products may have defined types indicating Manufacturer, Model, and Specifications. Such types may also have assigned tasks and resources for procurement, where resource types indicate Supplier, Location, and Cost.

4.2.15.2 Usage

All plumbing devices are connected together via ports (IfcDistributionPort having PredefinedType of *PIPE*, where the relationship IfcRelConnectsPorts has RelatingPort set to the water source (having FlowDirection of *SOURCE*) and RelatedPort set to the downstream connection (having FlowDirection of *SINK*). Product types are indicated via subtypes of IfcDistributionElementType. Costs rates for product types are indicated via subtypes of IfcConstructionResourceType assigned to

IfcTaskType assigned to the IfcDistributionElementType. The task type qualifies the scenario for which the cost applies.

Pipes are indicated using IfcPipeSegment with IfcDistributionPort at each end indicating connectivity. Pipe materials are indicated using IfcRelAssociatesMaterial and IfcMaterialProfileSetUsage indicating material and cross-section. Pipe paths are indicated using the 'Axis' representation consisting of a subtype of IfcBoundedCurve.

4.2.16 Layout plumbing system

4.2.16.1 Requirements

Pipe segments and fittings are detailed in this exchange, with full geometry and connectivity elaborated.

4.2.16.2 Usage

Each pipe is indicated using IfcPipeSegment and each transition is indicated using IfcPipeFitting. Pipe sizes are indicated at IfcPipeSegment using IfcRelAssociatesMaterial and IfcMaterialProfileSetUsage. Connection sizes and types are indicated at IfcDistributionPort using IfcRelAssociatesMaterial and IfcMaterialProfileSetUsage.

4.2.17 Piping and equipment sizes

4.2.17.1 Requirements

Based on final allocation of pipe routing, pipes and equipment sizes may be adjusted.

4.2.17.2 Usage

Pipe segments are indicated using IfcPipeSegment, where pipe size information is indicated via IfcRelAssociatesMaterial and IfcMaterialProfileSetUsage. Flow properties at each pipe are captured at IfcDistributionPort using property sets.

4.2.18 Product type specifications

4.2.18.1 Requirements

For this exchange, the engineer selects specific plumbing equipment models (or an approved list from several manufacturers).

4.2.18.2 Usage

Plumbing equipment occurrences are indicated by various IfcDistributionElement subtypes, where the selected model is defined by IfcDistributionElementType defined using the IfcRelDefinesByType relationship. To indicate multiple accepted models, the top-level model (IfcDistributionElementType) indicates an abstract template (not having a model defined via Pset_ManufacturerTypeInformation) and has candidate types assigned using IfcRelAssignsToProduct. Each candidate type has model information defined via the Pset_ManufacturerTypeInformation property set.

4.2.19 Document coordinated design

4.2.19.1 Requirements

The coordinated design contains full detail for all plumbing devices and their placement and interaction with other services within the building.

4.2.19.2 Usage

Plumbing elements are defined using subtypes of IfcDistributionElement, with ObjectPlacement and Representation set for all instances. Water distribution ports are indicated using IfcDistributionPort, where all ports of type *PIPE* must be connected. Unlike electrical ports that can simply not have a connection, an open pipe port indicates a leak in the system which must be terminated by a pipe fitting cap or other equipment.

The coordinated design requires full 2D ('Axis' and 'FootPrint' representations) and 3D ('Body' representation) where IfcProduct must have its Representation include each.

5 Conclusions

In developing MVDs, the challenge is to extract detailed information from industry experts yet find commonalities that could be applied generally across varying project delivery methods, participants, and localities. During this project there were varying levels of input. Some experts would work within the assumptions of the preliminary structure, others would alter various steps, and some created new process diagrams from scratch. Each party had different project delivery methods. Therefore, dependencies were factored out by making each exchange role-based, not contract-based. Achieving this level of granularity required many more exchanges than traditionally used in IFC MVDs. For example, information sent to a utility for obtaining rate structures and connection information is one specific exchange, rather than being lumped into a higher level category such as “early design.” The definition of role-based exchanges supports a variety of project delivery methods. Where possible, exchanges were aggregated into higher levels when appropriate.

Once each exchange was defined, the specific information needed down to the attribute-level of detail was described, leveraging the existing scope of the IFC data model where possible. While most product geometry information was already well-defined within IFC version 2x3 and implemented by many vendors, there were many concepts that required some of the lesser-supported IFC data structures and some that required the expanded MEP scope in IFC version 4 to achieve adequate levels of detail. There were also many cases of data constructs already in possible in the IFC schema but never detailed in the documentation. While realizing that many of these concepts were not supported by existing COTS software, the MVD has been defined to allow partial compliance for now, but with allowances to later relax or replace some requirements after testing models produced by existing software.

In detailing functional parts used within the model view, this project also contributed new concepts back to IFC4 that appeared to have wider uses in other disciplines (as IFC4 was not yet finalized at the time). For example, a functional part for generically mapping data to spreadsheets was formalized to support common tables such as lighting schedules, while also supporting other MVDs such as COBie; this functional part also involved advancing the parametric capability of IFC with the ability to generically reference object attributes. Similarly, as details on connections between equipment were elaborated, such uses also made their way into expanded port specifications within IFC4.

Once the MVD was complete, existing IFC files were tested with the mvdXML electronic validation format. Concepts that were supported by existing software and those that required new functionality were noted. There were some very basic limitations such as not capturing the physical building address, which is required for determining applicable codes and utilities, and more complex limitations such as detailing projected utility usage. In trying to find a balance that would encourage faster adoption by vendors, critical concepts were strongly enforced while others were relaxed by making certain attributes optional.

Going forward, the IFC4 release and supporting technology has provided for integrated MVDs where the IFC specification and all published MVDs will be made available online in an integrated form. This will enable developers of IFC to instantly cross-reference usage of entities across multiple model views and to create templates to be defined once where they are reused across model views. The supporting mvdXML technology provides for computer-interpretable validation, content filtering, sub-schema generation, and data adaptation. This enables new IFC software vendors to support information models with a substantially lower barrier of entry, and enables established software vendors with full IFC support to handle new MVDs automatically without additional work. This MVD is one of the first to leverage the growing ecosystem of mvdXML and has influenced the future direction of IFC with the various supporting concepts.

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14. ABSTRACT

Previous efforts by the US Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) to develop a life-cycle building model have resulted in the definition of a "core" building information model that contains general information describing facility assets such as spaces and equipment. To describe how facility assets (i.e., components) function together, information about assemblies of assets and their connections must also be defined. The definitions of assets, assemblies, and connections for the various building-information domains are discipline-specific.

The work documented here addresses the process flow and data exchange requirements for the design of water distribution systems in typical Army facilities. This ontology advances the state of the art by defining an Industry Foundation Class (IFC) Model View for water system design, supporting end users in developing compliant BIM models, and suggesting potential areas of automation in water system design.

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information exchange, interior plumbing systems, product data templates, guide specifications, Construction Operations Building information exchange (COBie), Building Information Modeling (BIM)

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