A LIFE-CYCLE MODEL FOR CONTRACTED INFORMATION EXCHANGE

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ABSTRACT

This paper will introduce a process-based building data model that tracks key building information through the facility's life cycle. The specification of batch and transactional exchanges, upon which this process model is based, uses the buildingSMART's Facility Management Handover Model View Definition (FM MVD) as the foundation for transforming paper-based deliverables into usable building information. The FM MVD is the first internationally recognized MVD for the exchange of non-geometric building information.

Keywords: Building Information Model, BIM, Facility Management, FM, Handover, Model View, COBie

1. INTRODUCTION

The Construction-Operations Building information exchange (COBie) schema provides an open framework for the exchange and delivery of construction handover information (East 2007). The Engineer Research and Development Center and the buildingSMART alliance have, to date, sponsored four public demonstrations of commercial COBie software implementation (East 2010). The December 2009 event introduced the buildingSMART (international) Facility Management Handover Model View Definition (FM MVD) as the international version of COBie, through which facility and asset management data may be captured and delivered (buildingSMART 2009). The BimServices tool translates between spreadsheets XML ifcXML, and IFC-STEP and automatically verify COBie files (East et. al. 2009). The expected delivery of COBie information during a project has been estimated to provide substantial cost reduction over traditional paper and e-paper delivery of facility handover documents (East et. al. 2010).

The COBie model, illustrated in Figure 1, shows both the relationships among the model entities and the overall staging of COBie information delivery. Designers provide spatial and building service decompositions. Contractors identify the specific products installed. Commissioning agents provide the information needed to operate and maintain the facility. All participants provide common information such as points of contact and related documents. At the March 2010 COBie demonstration commercial software systems were shown to be able to exchange complete building models between planning, design, construction, and operations phase (East 2010).

In the United States, federal government agencies have included COBie specification for delivery of construction handover information for over two years. Anecdotal reports suggest that the delivery of COBie files is often waived during construction because this requirement has not been sufficiently explained to construction contracting personnel. The authors’ hypothesis is that the adoption of a process-based specification for COBie-based information delivery will contribute to the wider adoption of COBie. Rather than change the content of existing paper-based contract deliverables, changing that deliverables format from paper to an open electronic format is the only practical means of implementing exchange formats such as COBie.

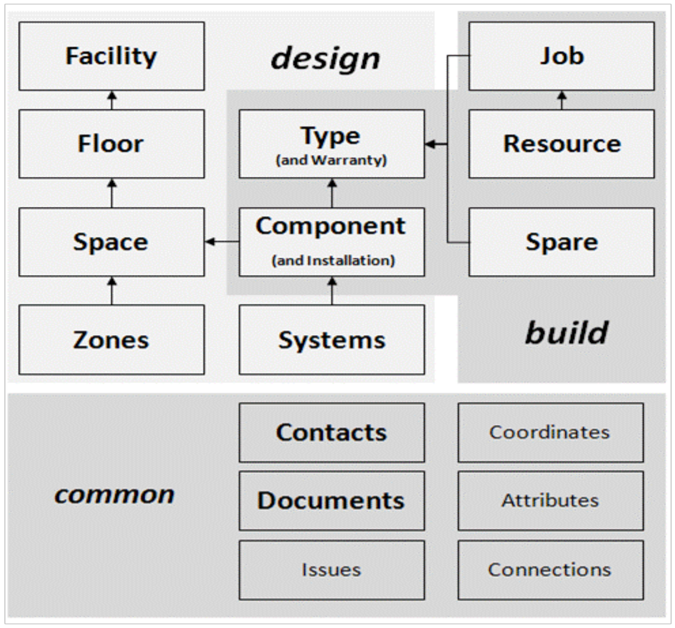

Figure 1 Illustrated COBie Data Model

2. APPROACH

This research began with a literature review to determine the applicability of prior art to the delivery of contracted information. Next, existing contract deliverables that contain COBie information were identified. The subset of COBie data needed to represent the content of each deliverable was then specified and classified. Once this model was created, two sample projects were developed to demonstrate of the content of each deliverable. Transformation and reporting tools extending BimServices were created to demonstrate the use of these proposed information exchanges. The authors are currently working with several project teams to secure further case study opportunities.

3. LITERATURE REVIEW

Results of a literature review revealed interest in capturing building information throughout the project life-cycle. One approach proposed a phased delivery of building information between specific proprietary software (Stephens 2005). Another approach suggested the use of a central web server (Jardim-Goncalves 2010). However, when the authors of the papers discussed their specific research, the majority focused on the capture of a certain type of information such as the geometric representation of the building and its components (Sacks 2010, Nour 2010) or product information and properties (Jeong 2009).

The ifc-mBomb project (Stephens 2005) demonstrated the capture of room and HVAC information during the design phase and delivery of that information, ultimately, to facility management. This effort validated using BIM for design/build/operate organizations and generated specifications for building and space data, risk registers, and maintenance jobs. Unfortunately, the project demanded tight integration with a specific IFC model server to glue-together proprietary software systems. Such connectivity is not typically available at the construction trailer. The skills required to complete this tight integration were also well beyond the capacity of typical commercial firms. Furthermore, applications did their merging live into the model, which hard coded business process assumptions.

Current research under the MEFISTO project (MEFISTO 2010) focuses on a shared model server to gather building information throughout the design and construction phases of a project, not the entire life-cycle, in order to simulate design alternatives. The results are used to improve the risk management of the building team and increased design and construction team profitability.

The Integrated Life Cycle Design (Hakkinen 2007) project focuses on the selection of materials and products contained in industrialized residential buildings rather than to create an overall model that could be applied to generalized design and construction processes. A critical focus of this paper is to ensure that the design team is able to evaluate predicted long-term life cycle costs.

The SEEMseed project (Jardim-Goncalves 2010) is also focusing on the development of a system to capture building information throughout the life cycle of a project for improved handover to facility maintenance personnel. This work describes an integrated picture; however, it is still in the conceptual stage. It does not specify the information to be included in the different transactions and assumes that the content of the information will automatically work together as long as there is interoperability between the different software programs being used.

While researchers are beginning to discuss the potential benefits of capturing building information throughout the life-cycle of a project, the majority of the work to date has either conceptual in nature, focusing on specific project phases, or has primarily considered the application of proprietary software. As one would expect in any emerging area of research, the analysis needed to define open standards has lagged specific proof of concept exemplars. The contribution of this paper is to provide a life-cycle model for the open-standard exchange, focused primarily on non-geometric building information, that can be applied without changing the content of existing contract deliverables.

4. CONTRACTED EXCHANGES

Table 1 summarizes the correlation between existing contract deliverables and subsets of the COBie model. The first two columns identify the phase and contracting setting. The third column recommends the name of the COBie deliverable file that may be specified in lieu of current paper deliverable.

As part of the "Criteria" phase, shown at the top of Table 1, many owners have standard requirements for specific types of buildings and for specific design disciplines (NIBS 2010). Criteria also may be needed to define organizational goals such as sustainability, accessibility, or security. Creating computable criteria differs from automating building codes due to the essential difference between code and criteria documents. Code documents are legal documents used to restrict or ease access to specific product classes or even a specific manufacturer's products. Criteria and specifications are, at least on the majority of public projects, written to provide clear representation of performance requirements. As a result, many of these criteria may be represented in COBie through the specification of required model objects, minimum required properties, and required attributes (or ranges).

During the "Initiation" and "Requirements" phases customers apply criteria to a given set of building requirements. The requirements for the number and type of spaces in the new building and the types and properties of equipment to be installed in that building are delivered as the basis of design. As the design proceeds, these requirements become organization of spaces and zones whose services are provided by specific types of equipment. As the building design activities become distributed across a variety of technical specialists, the design review process assists to ensure that the work accomplished by each of the specialists contributes to the ultimate service of project requirements.

From the perspective of the core set of building information, i.e. spatial and system decomposition, the construction process serves to "fill out" the design concept by describing the products and services needed to fulfill a design's concept. Given the design room and equipment schedule, related deliverables are commonly found in construction contracts. Products to be installed are selected and checked. Information about each installed product, including serial numbers and testing reports, is provided. Reports showing "tagged" products that may or may not have their own serial numbers are compiled. Finally, the information needed to operate and maintain installed products and systems is compiled.

Table 1. Contracted Information Exchanges (by Phase)

Project Phase	Contracting Phase	Contracted Exchanges	OmniClass Table 31–Phase	OmniClass Table 34–Actor	OmniClass Table 32-Service	buildingSMART alliance Draft Tree
Criteria	Criteria	Facility Criteria	not provided	34-21 14 00 Owner	not provided	2.44 Develop Site Criteria
		Discipline Specifications	not provided	34-21 14 00 Owner	not provided	2.43 Develop Design Criteria
Initiation	Definition	Project Definition	31-10 11 14 Description Phase	34-21 14 00 Owner	32-11 11 15 Development	2.5 Develop Project Execution Plan
Requirement	Programming	Space Program	31-10 14 21 Programming Phase	34-21 17 00 Planner	32-11 14 24 Programming	3.413 Configure Layout of Rooms and Zones
		Product Program	31-10 14 21 Programming Phase	34-21 17 00 Planner	32-11 14 24 Programming	3.41 Perform Systems Development and Layouts
Design	Documents	Design Early	31-20 10 14 Conceptual Design	34-25 21 00 Architect	32-11 14 00 Designing	3.4 Develop Design
		Design Schematic	31-20 10 17 Schematic Design	34-25 21 00 Architect	32-11 14 00 Designing	3.4 Develop Design
		Design Coordinated	31-20 20 11 Detailed Design	34-25 21 00 Architect	32-11 14 00 Designing	3.4 Develop Design
		Design Issue	31-20 20 21 Engineering Analysis	34-25 21 00 Architect	32-11 14 00 Designing	3.52 Perform Design Reviews
	Specification	Product Type Template	31-20 20 24/37/31 Product, Material Equipment Selection	34-25 41 00 Specifier	32-11 45 00 Specifying	3.32 Coordinate to Find Compatibles
		Product Template	31-20 20 24/37/31 Product, Material Equipment Selection	34-25 41 00 Specifier	32-11 45 00 Specifying	3.412 Select Building Materials and Equipment
Construction	Bidding	Bid Issue	31-30 30 21 Proposal Preparation	34-35 14 00 Contractor	32-21 21 11 Bidding	1.43 Prepare Bid and Submit
	Selection	Product Type Selection	31-40 20 27 Submittal Processing	34-35 14 00 Contractor	32-21 00 00 Execution Services	4.2 Provide Resources (Goods and Services)
		System Layout	31-40 20 27 Submittal Processing	34-35 14 00 Contractor	32-21 00 00 Execution Services	4.11 Develop Construction Plan
	Installation	Product Installation	31-40 40 11 17 Installation	34-35 14 00 Contractor	32-21 17 41 Installing	4.3 Build Building
		Product Inspection	31-40 40 91 17 Evaluation	34-35 14 00 Contractor	32-21 17 00 Constructing	4.34 Inspect and Approve Work
		Construction Issue	31-40 40 91 17 Evaluation	34-21 14 00 Owner	32-21 17 00 Constructing	4.34 Inspect and Approve Work
	Commissioning	Product Type Parts	31-40 50 00 Commissioning	34-35 17 00 Sub Contractor	32-21 00 00 Execution Services	4.4 Perform Commissioning
		Product Type Warranty	31-40 50 00 Commissioning	34-35 17 00 Sub Contractor	32-21 00 00 Execution Services	4.4 Perform Commissioning
		Product Type Maintenance	31-40 50 00 Commissioning	34-35 17 00 Sub Contractor	32-21 00 00 Execution Services	4.4 Perform Commissioning
		System Operation	31-40 50 00 Commissioning	34-35 17 00 Sub Contractor	32-21 00 00 Execution Services	4.4 Perform Commissioning
O & M	O & M	Space Condition	31-50 20 21 Facility Inspection	34-41 11 00 Facility Manager	32-41 51 11 Inspecting	5.3 Evaluate Conditions and Detect Problems
		Product Parts Re-placement	31-50 20 11 Facility Operation	34-41 21 00 Maintenance	32-41 47 11 11 Facility Repairing	5.4 Develop Solutions
		Space Occupancy	31-50 10 17 Use	34-41 11 00 Facility Manager	32-41 47 21 Space Planning	5.7 Perform Use of Facility/Building
		Space Activity Renovation	31-50 30 11 Facility Renovation	34-41 11 00 Facility Manager	32-41 47 21 Space Planning	5.8 Perform Facility/ Building Renovation
Repurpose	Programming	Remodel	31-50 30 14 Facility Remodeling	34-41 11 00 Facility Manager	32-41 47 11 17 Facility Upgrading	5.9 Perform Facility/ Building Remodeling
		Expand	31-50 30 17 Facility Expansion	34-41 11 00 Facility Manager	32-41 47 11 17 Facility Upgrading	5.10 Perform Facility/ Building Expansion
		Demolish	31-60 35 00 Recycling	34-41 11 00 Facility Manager	32-41 47 11 17 Facility Upgrading	5.11 Disposal, Reuse, Recycling

During its life-cycle a variety of changes can be expected to occur to a given building. Tenants are likely to change, and renovations will be needed to support changes to space requirements. Once the building is no longer able to accomplish the required purpose, decisions regarding significant renovation, updating specific systems, or demolishing and recycling the building are made, and the building life cycle begins again. The COBie contracted information exchanges, illustrated in Table 1, show how existing contracts may be used to deliver life cycle building information. The following paragraphs provide an overview of these exchanges.

Discussion of required exchanges of building information have often begun only after the owner contracts for a specific building. Table 1 provides the mechanism for owners to directly capture the decisions leading to the execution of specific building contracts. Both space and equipment requirements are considered since these criteria will directly impact the facility. In medical treatment rooms, for example, it is often the medical equipment requirements that drive spatial requirements. During the Criteria phase, requirements for spaces and required equipment of types standard facilities can be identified and expressed in a computable format, in lieu of providing paper criteria documents.

At the Initiation Phase, an owner determines that they need to build a new facility. It is at this point that a unique identifier and possible project name is assigned to the project. The documentation of this information is critical to owners with large facility inventories since these owners are required, for accounting and asset management purposes, to track all project information back this unique identifier. Based on the facility criteria the owner, possibly in conjunction with master planners and tenants, develops the architectural and equipment programs for the building. In cases where owners have standard project designs, the program brief will be quite specific and include the number specific types of rooms and the properties of the rooms that must be included in the building. Since some owners could have slightly different decision points, for example, waiting until a program has been developed prior to deciding to initiate the project, the phases listed here must be considered to be flexible until applied in a specific facility owner context. The objective of Table 1 is not to mandate a specific life-cycle process, but to identify the minimum life-cycle information artifacts needed to define a core building information model for all buildings.

The inclusion of the steps leading up to the engagement of design and/or design-build teams within the life-cycle building model is critical since the capture of the owner's decisions in a computable format can allow the automated verification of the design against the program and allows the project information to directly flow into the owner's financial and accounting systems. The use of open standards has additional long term benefits for the owner. The owner is able to increase the number of potential bidders on contracts since multiple software systems are supported through open standards. Finally, the owner is able to rely on their own data in lieu of being forced into a information technology procurement cycle for information that can only be read by (non-backwardly compatible) proprietary software.

While many of the exchange names identified in column three can be immediately understood in common international practice, e.g. "Product Installation" and "Product Type Warranty," other terms, particularly those occurring during the design stage, have multiple synonyms and flexible contents that depend on the project context. The contracted exchange called "Early Design" denotes the delivery of the design artifact that contains blocking and stacking diagrams and limited architectural elements. The "Schematic Design" is the deliverable that contains architectural and structural building information. The "Coordinated Design" contains the complete range of building services, in addition to architectural and structural. Explicit definitions of the specification of these design products may be found in the draft COBie specification document (WBDG 2010).

To provide additional perspectives on the sources and uses of the proposed information exchanges, Table 1 Construction Specification Institute's OmniClass columns provides a taxonomic reference (CSI 2010). The values identified are consistent with the design-bid-build process, although these classifications may be easily adapted to other project delivery methods. The final column in Table 1 is a reference to a taxonomy to be released by the buildingSMART alliance, the United States chapter of the buildingSMART, in January 2011 (bSa 2010a). The "node tree" diagram will provide a common picture for all information exchanges that become part of the National Building Information Model Standard, United States. Once contracted information exchanges are mapped to the node tree, potential users will be able to easily identify contracted information exchanges related to the services provided by the user.

To explore implications of the exchanges listed in Table 1 it is useful to organize the exchanges according to extent to which a given exchange replaces or updates prior building information. During the design process deliverables typically completely replace the prior building design information. Exchanges that completely replace previous project information, listed in Table 2, are called "batch exchanges." Other types of exchanges found in Table 1 are meant to update prior building information. Exchanges that update or add information to existing building models, listed in Table 3, are called "transactional exchanges."

The distinction between batch and transactional exchanges depends on the position of the entity defining these information exchanges. For example design batch exchanges may be decomposed into more specific transactions. It is the authors' related hypothesis that design collaboration activities must be decomposed into contracted information exchanges before repeatable business processes using BIM can be established. Further exploration of this hypothesis is beyond the scope of this paper, since we are only considering the "owners" point of view in defining the exchanges consistent with those found in typical owner design and construction contracts.

Table 2 Batch Exchanges (by subject)

Subject	Batch Exchange Name
Project	Project Definition
	Space Program
	Product Program
	Remodel
	Expand
	Demolish
Design	Design Early
	Design Schematic
	Design Coordinated
Issues	Design Issue
	Bid Issue
	Construction Issue

Table 3 Transactional Exchanges (by subject)

Subject	Transactional Exchange Name
Space	Space Activity Renovation
	Space Condition
	Space Occupancy
System	System Layout
	System Operation
Product Type	Product Type Template
	Product Type Parts
	Product Type Warranty
	Product Type Maintenance
	Product Type Selection
Product	Product Template
	Product Installation
	Product Inspection
	Product Parts Replacement

For practical implementation of the information exchanges identified in Table 1 there are two necessary conditions. First, these exchanges must be included in contracts as changes to the format of existing contract deliverables. Second, implementation of these exchanges must reduce costs compared to current processes. Current plans call for sample contract language for each exchange and customized business process models describing the work flow and cost impact of these new exchanges to be published in 2011.

5. LIFE-CYCLE MODEL

Public COBie challenge events have evaluated commercial software products against the ability to deliver batch sets of building information, such as those listed in Table 2. To specify the minimum required deliverables of each of these batch files, a sub-specification of the COBie model was created. This sub-specification identified what information is required at each phase of the project. For example, the designer could not be expected to provide the serial number for installed components. Table 4 provides the framework for each of the proposed contracted exchanges expressed using the COBie format. A transformation between COBie to IFC using BimServices could be easily accomplished as needed.

In Table 4, each proposed contracted information exchange is cross-referenced against the COBie data needed to deliver that information. Table 4's legend (under the "COBie Worksheet" column heading) shows that four types of building information exchanges are needed: "N"ew information added to the model, "U"pdated modeling information (that might include updates and new information), "O"ptional information that may be provided as specified, "r"eferences other COBie worksheet data that may be needed by the new, updated, or optional information, finally the "-" symbol indicates that that specific worksheet is not needed for the purpose of the listed exchange. New information is identified in Table 4 whenever there is a mandatory requirement for that new information to be provided. For example, in the "Early Design" exchange the designer would be required to identify the floors, spaces, and some of the product types, and some of the specific products for the first time. As a result, the these columns are identified as "N" for new information. Later in the design that information may be updated, changed, or deleted, however, those activities are coded as "U" reflecting the need to update (including adding or deleting) prior information. Reference information is required to ensure that the delivery of the required information is consistent with the COBie format and target building model.

While these information exchanges are expected to be implemented in commercial software, the authors would also assume that some users want to directly use COBie in spreadsheet form to make these changes using the associated BimServices functions. Such a light-weight solution could be easily accomplished by hiding non-used (Table 4, "-" coded) and referenced (Table 4, "r" coded) cells. Many of the cells within the required worksheets could also be hidden, leaving just the identifiers and data to be updated. For example, "Product Installation" could be accomplished with two visible COBie worksheets. The other worksheets are provided, but hidden from the user's review (unless they choose to make them visible). The first visible worksheet would be the Component worksheet. On the Component worksheet the Description, SerialNumber, InstallationDate, and optional WarrantyStartDate columns only need be shown. The three fields showing the underlying building model software, object, and GUID may be hidden from the user. The second visible worksheet would be the optional Attribute worksheet. This worksheet could be shown and values for the specific component only may be listed keeping the user from having to look through the entire set of building model attributes for every object in the model.

As the project proceeds through design, the required batch information creates the baseline building information upon which updated designs, and then construction and operational information, may be mapped. Implementation of transactions assumes that there is a building model of record from which referenced information may be correctly obtained and used through the transaction. The current set of building information, can then be reproduced by any authorized party simply by applying the needed information exchanges. Rather than being a central model server through which all design and construction decisions are made, the central model server required to implement the specified contractual exchanges is the owner's deliverable building model. The framework provided in Table 4 allows the owner to begin to eliminate paper file cabinets in lieu of more useful "electronic file cabinets" containing the structured information content of the building.

6. IMPLEMENTATION

Using two sample projects, a duplex apartment building and a medical clinic, example files for representative exchanges in Table 4 were created. These files will be released through the buildingSMART alliance website following the presentation of this paper. The BimServices lightweight model server (East et. al. 2009), previously to test model compliance during public COBie Challenge events, was updated to include the relevant functions to implement the life-cycle exchanges. The first of these changes pertained to exchange verification routines. The requirement for "hands-free" checking of model files is, from the authors' perspective, a precondition for implementing any information exchange effort. The following checking routines are implemented in BimServices: (1) proper format of incoming information, (2) internal consistency of incoming information exchange, and (3) consistency of incoming information with current model information. Note that this effort does not define the authentication and authorization wrappers for these information exchanges. The development of needed web service environments is left to such projects as the AGCxml initiative (Tardiff 2010).

Table 4. Overall Specification of Contracted Exchange

Project Phase	Contracting Phase	Contracted Exchanges	COBie Worksheets (N=New, U=Update, O=optional, r=reference, “-“=not reqd.)														
			Facility	**Floor**	**Space**	**Zone**	**Type**	**Component**	**System**	**Spare**	**Resource**	**Job**	**Document**	**Attribute**	**Connection**	**Coordinate**	**Issue**
Criteria	Criteria	Facility Criteria	r	O	N	N	O	O	O	-	-	-	-	N	O	-	-
		Discipline Specifications	r	-	-	-	N	-	N	-	-	-	-	N	O	-	-
Initiation	Definition	Project Definition	N	O	-	-	-	-	-	-	-	-	-	-	-	-	-
Requirement	Programming	Space Program	U	N	N	O	-	-	-	-	-	-	-	N	-	-	-
		Product Program	r	-	-	-	N	-	-	-	-	-	-	N	-	-	-
Design	Documents	Design Early	r	N	N	O	N	N	-	-	-	-	-	N	-	O	-
		Design Schematic	r	U	U	O	U	U	O	-	-	-	-	U	O	O	-
		Design Coordinated	r	U	U	U	U	U	U	-	-	-	-	U	O	U	-
		Design Issue	r	r	r	r	r	r	r	-	-	-	O	r	r	r	N
	Specification	Product Type Template	r	-	-	-	U	-	-	-	-	-	-	U	-	-	-
		Product Template	r	-	-	-	N	-	-	-	-	-	O	N	-	-	-
Construction	Bidding	Bid Issue	r	r	r	r	r	r	r	-	-	-	O	r	r	r	N
	Selection	Product Type Selection	r	-	-	-	U	-	-	-	-	-	U	U	-	-	-
		System Layout	r	r	r	-	U	U	U	-	-	-	-	U	U	U	-
	Installation	Product Installation	r	r	r	-	r	U	-	-	-	-	-	U	-	-	-
		Product Inspection	r	-	-	-	r	r	-	-	-	-	O	r	r	r	N
		Construction Issue	r	r	r	r	r	r	r	-	-	-	O	r	r	r	N
	Commissioning	Product Type Parts	r	-	-	-	r	-	-	N	-	-	O	-	-	-	-
		Product Type Warranty	r	-	-	-	U	-	-	-	-	-	N	-	-	-	-
		Product Type Maintenance	r	-	-	-	r	-	-	-	N	N	N	-	-	-	-
		System Operation	r	-	-	-	r	r	r	-	N	N	N	-	-	-	-
O & M	O & M	Space Condition	r	r	r	-	-	-	-	-	-	-	-	N	-	-	-
		Product Parts Replacement	r	-	-	r	r	-	-	O	-	-	O	N	-	-	-
Repurpose	Programming	Remodel	r	U	U	U	U	U	U	-	-	-	-	U	O	U	-
		Expand	r	U	U	U	U	U	U	-	-	-	-	U	O	U	-
		Demolish	r	r	r	r	r	r	r	-	-	-	-	r	-	-	-

The next extension of BimServices was to allow merging of updates into the current building model. One interesting class of such changes exchanges are those requiring the export of selected building information into a format that the user could update and then return to the model. The authors have termed such exchanges:

"surveys." Examples of such surveys in Table 4 are Product Installation and Product Inspection exchanges. To conduct a survey, BimServices exports only that subset of the needed building information. The user adds the required data to the survey and then the information is sent back to the model server to be merged with the building model. Another extension was to allow the importation of attached documentation such as warranty certificates and jobsite photos when these documents are referenced within contracted information exchanges. Finally, transformations to create HTML reports were provided. These transformations are able to create any type of customer-specific reports, via XML transformation and style sheets, such as those official reports required for public project funding requests or formal transfer of title reports.

7. A BRIEF EXAMPLE

The example provided here relates to the updating of the models Space Condition information for one of the rooms in the building in the duplex apartment building project used to motivate the exchange of specific transactions and to appropriately scope the demonstration. The process begins with backing up the current building model, in this case "DuplexApartment_before_SpaceCondition_F1-203." Survey transactions, such as the one in this example, export the necessary building information from the model into a format that can be easily understood and completed by all project stakeholders without the need for specialized BIM software. The form contains the project and item details already completed, including the hidden project and context information such as Globally Unique Identifiers. The survey form allows users to enter the expected information. These surveys can also be qualified depending on the requirement of the model attribute. For example selection lists with allowable choices may be exported. For the "SpaceCondition" survey the "Condition" field is a selection list containing three values, "Red", "Yellow," or "Green."

Once completed, the survey form is sent back to the model server. The incoming data is verified. BimServices testing includes checking to determine whether the data file is in a valid building model format, and if there is sufficient integrity in the file to proceed. There are additional BimServices assessments for contractual compliance and completeness. Once the file is checked, the associated objects are matched and the attributes of F1-203 related to SpaceCondition are changed to the user's selected value. Currently the merge process is able to handle changes relating to the individual objects and to the attributes associated to the individual objects. Progressively more capability can be added to respond to the specific stage and to accommodate more fundamental changes, such as the changing room zoning or system components.

Finally, the building model backed up again, for example as "DuplexApartment_after_SpaceCondition_F1-203". A comparison command is used to generate a comprehensive schedule of differences. This comparison is generated by comparing the objects and properties in the logical hierarchy of the project. Other reports, such as schedules of spaces, zones, systems or types are generated to present the outcome depending on the type of exchange.

8. CONCLUSIONS

The objective of this project was to identify building information sources and uses for the automated capture of facility handover information. In the course of this work, a set of contractual information exchanges have been proposed. The application of these open-standard information exchanges does not require changes in the scope of current contract deliverables, only changes to the format of the information delivered. Since contracting methods, risk allocations, or contracting procedures are not changed, the life-cycle model proposed in this paper provides a practical and cost-effective means to deliver as-built and as-maintained BIM. The development of a life-cycle model for building information exchange that includes well formed batch and transactions has a number of potentially profound impacts upon the capital facilities industry.

Moving from batch exchanges to transactions implies that the information packets must update a current version of a building data. Some have proposed a single shared building model. In the authors' view, requiring project team members to resolve the complex web of contractual and security structures to host shared model servers will result in the failure of life-cycle building information modeling. Transmission of standard packets to authorized users entirely removes a requirement for central model servers.

The creation of standard transactions also decreases the footprint of commercial applications used to interact with building information. The delivery of open standard deliverables should also result in the elimination of proprietary software specifications. With such standards owners will actually own their data instead of having it locked up in proprietary software formats. When coupled with ubiquitous nature of XML processing tools, the adoption of these standards should span an entire new market in the creation of open-standards applications that could appear on devices such cellular phones. The provision of formats that allow the consistent capture, without a centralized model server, of requirements and project-specific implementations should also a significant impact upon the types of design reviews that need to be accomplished. With automated reviews of logically organized project- and discipline-specific criteria, reviewers will have more time to evaluate the constructability and operability of the each new project.

9. RECOMMENDATION

To validate this model, the authors are working with design and construction project teams to identify opportunities for documentable case studies. Currently, the authors' efforts at developing such case studies has been quite uneven given the duration of capital projects, uncertainty associated with innovation, and proprietary technology stacks. Current difficulties aside, the high level of interest from commercial software firms to allocate resources to deliver COBie exchanges anticipates future demand.

The authors are currently expanding and extending the results of this work. Future publications on this topic will include a discussion of how the provided information may be used by facility managers to assess the operational capacity of their facilities and to provide examples of automated criteria and construction contract specification checking. Several of the exchanges described in Table 1 support implementation of ongoing buildingSMART alliance projects (bSa 2010b). The exchanges "ProductTypeTemplate," "ProductTemplate," and "ProductTypeSelection" all related to the Specifiers Properties information exchange (SPie) project. The "SystemLayout" exchange relates to the Equipment Layout information exchange (ELie) project.

By openly publishing the BimServices tool and life-cycle data sets for non-commercial and academic use, the authors hope that future research may begin to directly capitalize on these life-cycle data sets. Researchers could contribute back to this repository by publishing extensions based on additional use cases, creating supplementary building information, extending the capabilities of freeware tools such as BimServices, and create their own XML transformation programs for any variety of novel analysis and modeling tools.

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11. DISTRIBUTION

BimServices is provided by free download (Nisbet 2010). The location for the distribution of all sample exchange files will be announced at the conference. Technical support is provided through AEC3 UK Ltd.

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