FACILITY CAPACITY ANALYSIS

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ABSTRACT

Many public owners maintain large of building requirements in standard criteria publications. These criteria represent the combined knowledge of building owners based on their experience over decades of working on such buildings. While this information, such as, room data sheets are used during the architectural programming stage, the project team cannot use these criteria later to ensure that the facility continues to meet its intended function into construction and operations. Without knowing the capacity of building spaces, there is no way for building owners to effectively manage their facility portfolio. As the delivery of building information models becomes more prevalent, tools are needed to allow project stakeholders to evaluate the validity of those models. This paper presents model for facility capacity analysis based on an open specification for the expression of facility criteria and the application of that criteria using light-weight building information modeling tools.

KEYWORDS

Building Information Modeling, BIM, Industry Foundation Class Model, IFC, Code Checking, Criteria Checking

1. INTRODUCTION

The literature has recognized the difficulty in capturing client functional requirements [Akin 1995]. [Rivard 2002] identifies these requirements and solutions as “design units” that may be reused based on relevant criteria. Many large owners have published detailed criteria requirements and specific design solutions for reuse on standard building types [DoD 2009]. In some cases, these criteria are used in automated systems that support project programming decisions [DVA 2010]. In addition to general criteria, large public agencies also have entire standard designs to be site-adapted for specific geotechnical, climatic, and regional criteria. Building spaces are pre-designed to define services and finishes needed for the activities that typically occur in that room category. Some of the most specific examples of these design solutions are for rooms whose activities are highly constrained. For example, medical treatment rooms require sheet vinyl flooring and glazed drywall finishes reducing the potential for bacterial growth.

In addition to the description of specific spaces, additional criteria often in the form of “adjacency matrices,” describe how spaces can be organized [DoD 2010]. Typical adjacency requirements address the need for co-location of spaces and their limits. In a hospital operating suite, for example, there is a need for an ante-room to the operating room that allows gowning and hygiene. Pediatric and psychiatric areas of a hospital are zoned for access control, prohibiting the existence of public stairs or elevators within those zones.

While large owners require compliance with such objective standards, half of commercial buildings begin design without the development of an architectural program [Duerk 1992]. Of those buildings with architectural programs, subsequent design decisions results frequently result in deviations from these requirements. Three quarters of all projects do not evaluate later design stages against the original requirements [Duerk 1992]. One of the major causes of this disconnect is the lack of interoperable standard that carry design intent through to later stages of the project [Ozkaya 2007].

The objective of this paper is to describe initial investigation of an open format for the exchange of owners' building criteria, based on the Industry Foundation Class (IFC) model. With a common means of expression, it is expected that building owners will be able to evaluate new buildings, proposed renovations, and operational use of buildings against shared structured criteria.

2. PREVIOUS RESEARCH

The use of rule-based systems to evaluate the general case of building design has been largely proven ineffective as much of the content of building codes in the United States cannot be represented in first-order logic [Garrett 1995]. Even if the first-order barrier can be broken, there remain problems with externally validating algorithms and ensuring that these algorithms are available when needed [Han 1997]. For that portion of codes that may be checked using rule-based systems, a key challenge to operational programs is to ensure the required information is available for testing in the building model being examined [Solhim 2006].

Within the United States building codes are an inherently political process. Over 6,000 public jurisdictions engage a variety of constituents who adopt and modify codes for a variety of different purposes. Codes created through such a process vary widely between jurisdictions and have been shown, at times, to be self-contradictory. Fortunately for large owners, documents describing facility criteria are not designed as political artifacts but clear enunciations of the precise technical demands of each allowed type of space and associated equipment in a building.

Criteria contain both tabular and non-tabular sets of requirements. While there are non-tabular sets of information in these criteria document, these sections are provided as justification or orientation to the technical details provided for each space. Rather than prove the accuracy of a building against a legal standard, the evaluation of deviation of building spaces from fixed criteria over time, as described in [Ozkaya 2006], is the objective of the work described in this paper.

The early design business processes where design criteria are first encountered were documented in a international project to evaluate facility capacity, blocking and stacking models, and comparative analysis of alternatives [Nisbet 2006]. The "AR-5" project defined the requirements for the representation of early designs: Name, Function, Spatial Relationships, Activity Level, Occupancy, Area, Equipment, and Design Considerations. Aside from general model documents, there was little effort to work with implementers to produce the lightweight versions of the STEP models described in the project.

In July 2008 the Spatial Compliance information exchange (SCie) project was introduced during a meeting at the U.S. National Academies of Engineers. This project described the potential implementation of AR-5 requirements for the exchange of early design information (excluding spatial relationships) in what would become the buildingSMART FM Handover Model View Definition (FM Handover MVD) [buildingSMART 2010]. This MVD is also known as the Construction-Operations Building information exchange (COBie).

Internationally, a demonstration of information exchanges related to architectural programming were later undertaken as a buildingSMART aquarium project [Guttmann 2009]. During this technology demonstration project, information was created in custom developed spreadsheets and database applications then imported through the Onuma System to layout and size spaces. Additional client requirements were added through the dRofus and Affinity systems which ultimately provided the information to Revit to begin design work. Due the lack of rigor of the aquarium process, the spreadsheets and databases developed were not published, nor was the IFC Early Design Model View Definition, proposed under AR-5, tested or extended.

3. OBJECTIVE

A compiled set of space capabilities for a given facility can be said to represent the capacity of that facility to perform its intended function, and the adaptability of that facility to successfully respond to future changes to activities within the facility or across a facility portfolio. This paper presents an open specification for the expression of facility criteria and provides an example of the use of these criteria in the analysis of a mid-sized medical facility.

4. FACILITY CAPACITY ANALYSIS

Current owner criteria are contained in a variety of computer and paper formats. A review of these documents shows several problems with the accuracy and format of this information. The multiple systems that contain this information such as databases, PC-based software, and paper criteria documents do not contain a synchronized set of information. This occurs because there is no consensus about the official source of the information and differences in publication schedules would result in de-synchronization. The format of the information also results in difficulties when checking or using the information. The most obvious form of this problem can be found in room data sheet tables. Forced by the need to publish paper-formatted documents, these tables contain a variety of ad hock coding schema identifying allowable range values, possible options for selections, and relevant units of measure to name just a few. An example of criteria for a Biomechanical Electronic Repair room is shown in Table 1. In this example, the values for codes are provided rather than the original, coded table values.

The transformation of the Table 1 criteria into a computable building model requires the mapping of each criterion to specific spaces or associated objects. For example floor, wall, and ceiling finishes may be mapped to ‘ifcCovering’ objects. A first pass at transforming the criteria into a standard format is to unpack the owner’s criteria and map the objects and attributes to relevant IFC objects. Semantic differences in the source information and IFC model do not allow for a direct translation of all objects and attributes. For example, the “Floor Base and Finish” room attribute cannot be directly mapped to building model elements. There are several alternative representations for such mappings, however, the one what is most relevant for floor finish is ‘Ifc Covering’ with a property “Base” set to “Resilient Base.” A standard target building model and precise mapping rules are needed to ensure that mappings are not uniquely created for every model checker and every set of user criteria on each different building type.

Attribute	Value
Room Code	BMER1
Description	BIOMEDICAL, ELECTRONIC REPAIR
Floor Base and Finish	Vinyl composition tile with resilient base
Wall Material	Gypsum Wallboard
Wall Finish Material	Painted
Ceiling Material	Acoustic Ceiling tile
Ceiling Finish Material	Standard Finish
Maximum Ceiling Height	2600
Door Size	1200mm (4'-0")

Table 1. Portion of Translated Room Data Sheet

Another problem with the criteria provided in Table 1 is that that measurement standards and units are not explicit. As an example, the “Door Size” attribute contains both Metric and Imperial units. “Maximum Ceiling Height” has no units. Making this more difficult for those not using Metric units is that the trade size and the nominal sizes must both be represented explicitly. This is because the requirements for “hard” or “soft” conversions will differ on specific projects and specifications. Non-numeric values are also sufficiently vague to require human interpretation. An example of such a vague value is “Standard Finish.”

Imbedded in the room data sheet are many of the rules required to assess building performance. While some rules appear to be clear, on further evaluation additional specification is required. For example a parameter “Structural load” does not provide the same level of useful design constraint as the minimum structural properties of “live load” and “dead load.” Another set of references that will almost always have to be clarified is room area measurement standard. Despite recent harmonization of ASTM and ANSI codes related to room measurement both codes specify a sufficient number of variants of area measurement to demand additional clarification. To support local and regional variations in codes and standards all referenced standards must be explicitly provided.

Room data sheets beyond the example in Table 1, identify measurements related to room shape, travel distances, operating environmental conditions, and minimally required equipment. Room shape, or footprint, not only applies to area but also to the specification of minimum/maximum side dimensions. Distance measurements include adjacencies and shortest distances. The operating environment of a space includes the structural loading, temperature and humidity, lighting, and acoustics. There is also specific identification of equipment. The equipment requirements may include requirements for other related equipment or services such a specific power requirements or further specification of temperature and humidity. [Kamara 2001] classifies these requirements as functions, attributes, constraints, and preferences.

Large owners with geographically distributed facilities will also be interested in comparing the requirements of similar rooms in different facilities to attempt to optimize their supply chains. The example data from Table 1 cannot be used for such a purpose since there is no independent classification of this Electronic Repair Room. Without such a unified classification schema an inventory-wide evaluation of facility capacity is not possible.

5. RESULTS

The following paragraphs described the open format developed in this project for criteria information exchange and provide an example of its implementation using a light-weight model server tool, bimServices [East 2009].

5.1 Rule Implementation

Tabular space criteria information that would appear in room data sheets can be easily represented in the COBie format. The criteria implementations required two types of extensions. The first type was properties pertaining to all instances of a given type. Following the normal COBie usage, values for the 'Target Area' and 'Target Perimeter' were added as extended properties on the COBie.Space sheet (Table 2). Units for the values are defined in the COBie.Facility sheet as square meters. A specific rule was developed to map area and perimeter values and visualize the geometric spread-values.

Name	Description	Target Area	Target Perimeter
BMER1	BIOMEDICAL, ELECTRIC REPAIR	9.299	15280.7

Table 2. Additional Columns for COBie.Space

The second type of criteria, those pertaining to specific spaces, was added as a set of requirements in the COBie.Attributes sheet (Table 3). Exact requirements relate to text values such as enumerated types of finish. Most numeric criteria with units are minima, except where the attribute is tagged as a 'Maximum requirement'. The specification of operators such as "equal," "greater than," "less than," etc… should, upon implementation of this effort, be clarified in the Name of the attribute and not left as an assumption. The structure of COBie helps to enforce proper documentation, particularly of units, and on whether requirements are minima, targets or maxima. This representation was reviewed and approved by the building type domain experts who participated in this project.

Name	Stage	Value	Unit
Ceiling Material	Exact Requirement	Acoustic Ceiling tile	n/a
Door Size	Minimum Requirement	1200	mm
Maximum Ceiling Height	Maximum Requirement	2600	mm

Table 3. Additional COBie.Attributes for Space BMER1

This approach described above captures room data sheet criteria using the two standard approaches for extending COBie models. The first is adding columns to worksheets where these new columns apply to the majority of the objects in the model. The second is to add new COBie.Attribute values for values that are not shared with all objects. Reports allowed users to document design criteria in an easy to understand spreadsheet, but also communicate these criteria in HTML reports produced with simple XSLT transformations of the SpreadsheetML data.

Using the bimServices toolkit, the COBie constraint model representation was converted to become a full IFC building information model, containing one example of each space type in an ideal medical clinic. This mapping creates a file which incorporates the transition from holding ideal space types (such as BMER1) to an expectation that can be tested against an actual space (a room with classification of BMER1). Each functional requirement, such as area or door width, was mapped to a checkable metric conditional on a metric confirming the applicability of the requirement to the functional assignment of the space.

5.2 Criteria Checking Functions

The compliance checking engine developed for this project iterates over both the requirements model and the facility model to evaluate the constraint provided from the ideal building constraint model. A set of precompiled constraint checking algorithms process the required criteria to extract the necessary antecedent from the building model. These constraints are implemented as a lookup functions which sub-contract the interpretation of terms to a number of generic functions.

5.3 Criteria Checking Example

The checking tool was able to check all rooms against all applicable criteria, checking a specific rule against all matching objects, and find rooms matching specific criteria. Each of these processes was implemented by selective filtering from the entire rule-set and/or each corresponding building model entity. In the example provided in Figure 2, the outcome of evaluating all relevant criteria on 1BER15 of a Medical Clinic was non-compliant against the required “Door Size” criteria.

5.4 Open Specification for Criteria

Three distinct representations have been used to for spatial criteria. Each of these representations is freely available to the design team (and researchers interested in this topic). The COBie facility model is easily populated from the requirement documents and can be reviewed by design professionals. In the example a specific transformation automated what could have been a tedious and error prone manual process for a substantial set of 580 space types and 36 requirement categories. The IFC facility model can be obtained from COBie or from an ideal facility model prepared in any BIM authoring tool. This is particularly useful for the capture of geometric measures, and for capturing requirements from previous design projects. Lastly, the IFC constraint model can be generated from both IFC facility models and from other sources such as marked up regulations.

Figure 2. Selective Compliance Checking Execution Log

```
C:\> Compliance1 rule=asreq_BMER1 item=1E16B
        constraints\ClinicalRequirements_fromCOBie2_asRequirements.ifc models\MedicalClinic.ifc

> Compliance1 bimServices v2010-12-28:12:00:00 by AEC3 UK Ltd using TNO IfcEngine
> Metric space :
>Target Area found as 9.298 on Space 1E16B Electrical Repair/Calibration greater than or equal to : 8.833
> Metric space : Target Perimeter found as 15280.7 on Space 1E16B Electrical Repair/Calibration greater
than or equal to : 14516.6
> Metric space : Door Size found as 915.0 on Space 1E16B Electrical Repair/Calibration greater than or
equal to : 1140.0
> Objective FAILED
> Non-compliance by Space 1E16B Electrical Repair/Calibration to Objective asreq_BMER1 was detected.
> Finished.
```

It might be expected that a generic COBie or IFC model comparison tool could have been applied to generate a structured comparison report. However, it was anticipated that the requirements model and the facility model might contain differing levels of detail. In the example case, a generic comparison tool would be unable to handle a situation where the requirements model had a minimum 'Door Width' Attribute associated to the Space, whereas the facility model has two door Components associated to the Space. In order to support multiple semantic representations the requirements model is transformed into a constraint model.

5.5 Criteria Checking Tool Kit

The bimServices application does not contain any specific knowledge but are configured using external files. The criteria checking toolkit comprises a transformation pipeline serving the compliance checking engine. The transformation specifications covered mapping the COBie facility model to IFC and mapping an IFC facility model to become an IFC constraint model. The compliance checking engine accepts the IFC constraint model and an IFC facility model. It uses a user-defined DLL containing a dictionary of methods to implement terms found in the IFC constraint model as queries on the IFC facility model. It generates an ifcApproval model containing the results of the checking algorithm. A further transformation pipeline was used to publish these results in a variety of formats and presentations.

6. CONCLUSIONS

This paper presented an open format for the capture and use of facility criteria. Given a successful critique of design criteria this research will next critique spatial topology informed by [Arvin 2002]. Many authors have viewed the specification of computable criteria as one necessary condition for design generation. The example of area and perimeter measurement hints at an objective function that is able to respond to subtle changes in design layout. This conclusion is echoed by [Kamara 2001] who described the potential use of dynamic criteria weighting. Until those results, the application of objective criteria will, however, be immediately useful in verification of accurate designs [Eastman 2009].

Practitioners are beset with the need to chase an ever increasing set of design goals. The current list includes accessibility, survivability, sustainability, bidability, constructability, operability, and many more. Rather than create a new “mission readiness” program of study with associated ontologies, complex tools, and new schemata this work has demonstrated the simplicity with which simple tools, such as XLST, and open building models, such as COBie, have the potential to provide significant life-cycle value. Solving the current and future basic information exchange needs of our industry does not have to be a difficult process, provided that some minimum set of shared structured information can be reliably delivered.

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8. 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.

9. REFERENCES

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