Representing Requirements of Construction from an IFC Model

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ABSTRACT

This paper presents a generalized, flexible and formal framework for representing various requirements to support the needs of the construction process using the Industry Foundation Classes (IFC) model specification. These are termed construction requirements. The importance of considering construction requirements as a representation of construction knowledge within the context of construction planning and scheduling will be discussed, allowing readers to gain an understanding of the applicability of construction requirements.

An ontological model for describing these construction requirements will be proposed in this paper, which will aid in formulating a uniform representation schema for construction requirements. This model will define the attributes of the construction requirements ontology from the perspectives of spatial, temporal and ordinal characteristics. From these attributes, various construction requirements may be represented as construction requirement entities. These construction requirement entities demonstrate how the functional and non-functional characteristics of a building element system may be captured for constructability analysis.

This paper concludes by explaining how the construction requirements may be extended to represent construction methods, and underlines its applicability to automated constructability analysis, as well as automatic schedule generation.

INTRODUCTION AND REVIEW OF REQUIREMENTS MODELLING

Construction Requirements are the capabilities and conditions which the construction process system and the in-progress facility product must conform to (Song and Chua 2006). In other words, construction requirements represent the key pre-conditions for construction (Chua and Yeoh 2011). This then forms the basis for representing construction knowledge; the knowledge embedded within the construction requirements drive the planning process by providing a key tool for constructability analysis of a construction project.

Despite the aforementioned importance of construction requirements, little attention has been accorded to the impact of construction requirements on project schedules through associated schedule (temporal) constraints. This is largely due to a lack of a formalized representation framework for these requirements, and can be attributed to the ambiguity which arises from using natural language to represent construction requirements. Hence, the knowledge embedded inside these construction requirements are not explicitly represented, and cannot be explicitly reused in knowledge-based frameworks (Fischer 2006).

Traditional modelling frameworks from the domains of software engineering and mechanical design typically segregate the requirements model into functional and non-functional types (Deng 2002). Functional requirements describe the capabilities of the system, while non-functional requirements describe the performance constraints, and include items which limit the capabilities of the system.

In engineering design, functional requirements are captured in the function modelling process to elicit, express and evaluate the design intentions. Reasoning on the engineering design rationale is then used to derive the necessary product features (Chandrasekaran and Josephson 2000). The non-functional requirements are seldom addressed, nor are the processes deemed impactful on the design. This is not the case for construction. The non-functional construction requirements like information availability may directly affect the completion of the product. Moreover, construction methods, often captured within process models, are key considerations in any construction project and should not be ignored (Fischer and Aalami 1996).

A major challenge in representing construction requirements is the need to define a generic domain-independent representation framework. Construction requirements may arise from various domains, e.g. safety, regulatory, structural, etc., and the requirements from one domain may differ from that in another. Thus, the representation of these construction requirements should be domain independent, and generic enough to capture the knowledge from these various construction domains.

This paper will discuss the important characteristics of construction requirements, and subsequently present an ontological framework for representing construction requirements, based on the product and process data schema found within the IFC4 model specifications.

AN ONTOLOGICAL MODEL OF CONSTRUCTION REQUIREMENTS

In this section, the ontological taxonomy for construction requirements based on defining a general and immutable schema will be presented, which will allow new construction requirements to be formally represented.

Proposed Approach to Defining Construction Requirements. The proposed taxonomical schema is inspired by DOLCE (Masolo et al. 2003), which attempts to address generic domains, allowing it the advantage of generality for describing natural language. The taxonomy developed herein adapts the varied taxonomical categories in DOLCE to suit the spatial, temporal and ordinal nature of requirements. This allows a medium for mutual understanding and interoperability between agents from different domains, which is relevant for construction requirements. As construction requirements may be expressed in many forms, from contractual conformance requirements to site requirements expressed in natural language between contractors, it is vital to enable a common flexible and extendable language for encapsulating the knowledge represented in the requirement.

The approach adopted (shown in Figure 1) starts with the characterization of a core immutable set of attributes. These core attributes are then instrumental in defining the entities making up the construction requirement, by providing a fundamental basis for describing their key characteristics. Basic entities like "work package" entities and "value" entities are introduced, which in turn form the knowledge constructs of a requirement. New taxonomies for construction requirements from different domains may be built from this schema, allowing flexibility and generality typically not present in current domain-centric ontologies.

Figure 1. Approach Adopted for defining Construction Requirements

Core Attributes of Construction Requirement Entities. A construction requirement is defined by its constituent entities. An entity may be defined by establishing one or more of the following characteristics:

- Tangibility (Spatial): Tangible entities are entities which have spatial attributes. A construction requirement usually requires entities with these attributes to represent spatial relationships arising from the construction product.
- Perdurant or Endurant behavior (Temporal): Perdurantism and Endurantism describe the temporal behavior of the entity in a construction requirement. Endurant entities are static at all times, while Perdurant entities are dynamic and may change as time passes.
- Measurability (Ordinal): Measurability refers to the perceptible measure of some entities related to the construction requirement. This measure may refer to concepts like distance, clearance, etc.

The above establishes a *"requirement"* of requirements, and describes the main characteristics of the entities; in turn, these entities define the tangibility, perdurant/endurant nature and measurability of the construction requirement.

The spatial attribute describes the physical geometric attributes, which may be represented using the *IfcProductExtension* schema. The temporal characterization of the construction requirement may be modelled using the *IfcProcessExtension* schema, where the start, finish and duration of the entity may be inferred from the corresponding *IfcTask*. Whether the entity is perdurant or endurant is reflected in the relationships between the entities, which will be demonstrated in a later section.

The ordinal attribute is used to define measurable features like the clearance between objects, weight of loads or cost. It may also be used to define abstractions of key resources. The relevant data may be referenced from the IFC model, through constructs such as *IfcCostItem* and *IfcConstructionResource*, or else defined using object or object type property sets as defined within the IFC schema.

Construction Requirements Entities. A construction requirement entity can encompass any combination of the three attributes defined previously. Table 1 sets out some possible construction requirement entities:

Table 1. Entities as Combinations of Construction Requirements Attributes

Entity	Tangibility	Perdurant/Endurant	Measurability
Work Package Entity	Y	Y	Y
Time Interval Entity	-	Y	Y
Value Entity	-	-	Y

For illustration, the work package is introduced; this construct is defined to serve as a link between *IfcTask*, *IfcResource* and *IfcBuildingElement*. Thus, a work package is a type of construction requirement entity, with spatial, temporal and ordinal attributes. Figure 2 describes the relationship between these attributes using a set of relationships defined by a taxonomy which will be introduced next.

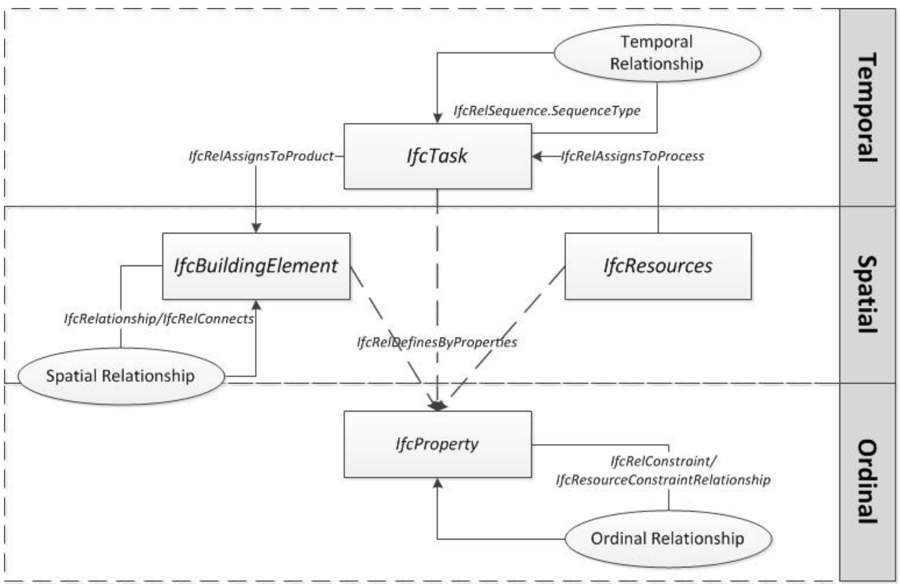

Figure 2. Components of the Work Package Entity

Inter-Entity Relationships. The attributes of the construction requirement entities are related to one another through the spatial relationships, temporal relationships and the ordinal relationships.

For spatial topological relationships, the taxonomical approach between any two component entities by Nguyen and Oloufa (2001) has been adapted in this paper. The spatial interactions are classified according to five categories as shown in Figure 3: Adjacency, Containment, Separation, Intersection, and Connectivity.

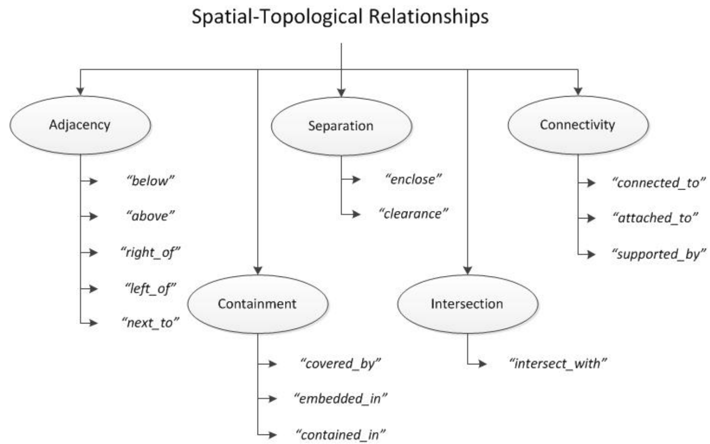

Figure 3. Spatial Topological Relationships

The temporal attribute inter-relationships are modelled by temporal relations. These temporal relations capture the process considerations and the activity sequences. PDM++, developed by Chua and Yeoh (2011), is used to model some of these complex relationships (Figure 4).

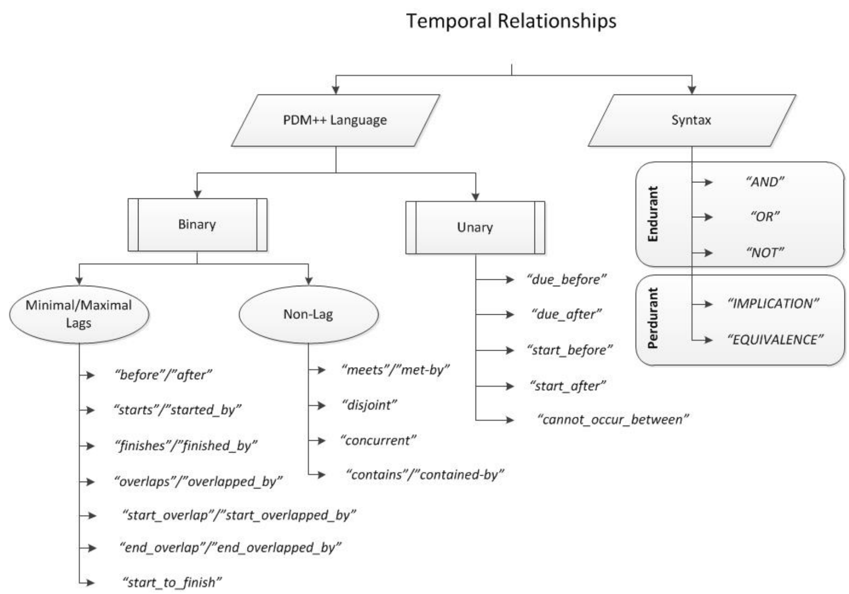

Figure 4. Temporal Relationships

To better represent the perdurant and endurant temporal behavior of the construction requirement, the syntax relationships are introduced. Endurant temporal characteristics imply that the need to be fulfilled or satisfied remains invariant and necessary. This typically represents the construction requirements that must be realized, regardless. These may include safety regulations like "Painting should not be done simultaneously with hotwork". The use of "AND", "OR", and "NOT" logical operators are used to capture this. In contrast, perdurant construction requirements are those requirements whose need to be satisfied is conditional upon the fulfilment of other requirements. For example, "It is expedient to carry out wall painting after adjacent pipes are installed, otherwise, additional temporary protective staging for the paintwork must be provided". Hence, such requirements require the representation of conditional pre-requisites, and the "Implication" and "Equivalence" logical operators are employed.

Ordinal attribute inter-relationships describe the comparison of the measurable entities between one another, and the taxonomy of these relationships is shown in Figure 5. These relationships relate one ordinal entity with another, and establish a mechanism for comparing entities.

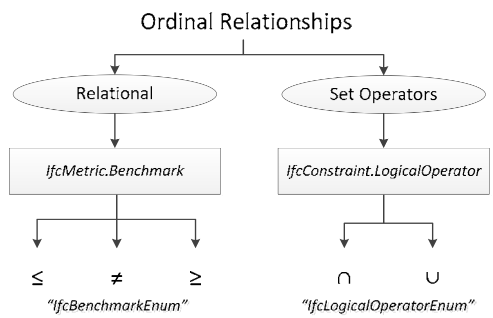

Figure 5. Ordinal Attribute Relationships

The importance of the ordinal attribute relationships is that it allows a mathematical description to be established within the construction requirement. The ordinal attribute may then be used to represent goals of a construction requirement and the relationship will enable the conditions of fulfilling the goal to be stated. These relationships may be referenced from *IfcMetric.Benchmark* and *IfcConstraint.LogicalOperators*.

CONSTRUCTING A FLEXIBLE REQUIREMENTS TAXONOMY

A basic taxonomy for describing construction requirements can be established, by realizing the requirement is an interaction between its purpose and operation. Hence, the taxonomy of a construction requirement can be defined as: Purposive, Operational and the necessary conditions defining the interaction between the two.

Purposive. The purpose for a construction requirement may be defined as fulfilling a desired intention. This intention takes the form of a function, goal, or soft goal. A function is the action of performing an intention, and directly involves both spatial and temporal dimensions (entities). For example, requirement R1 could be "R1: *IfcColumn* C1 Supports *IfcBeam* B1". The "Support" indicates a physical relationship by the function provider C1, and used by the function user B1.

The goal and soft goal describe the performance of the requirement, where the goal and soft goal are entities with ordinal attributes. More specifically, the goal is considered as an obligation to be satisfied. Soft goals are considered as subjective preferences whose fulfilment is desired, but which may not be achieved. In the IFC schema, *IfcObjective* is introduced to model the purpose of requirements, where *IfcObjective.ConstraintGrade* is used to distinguish between the hard and soft constraint types. An example of a goal is "R2: Welding activity W1 has a labor requirement of 3 men for optimal productivity", whereas an example of a soft goal is "R3: Optional provision of aesthetically pleasing hoarding such that on-going construction activities are not apparent to the public".

Operational. The operational aspect of the requirement depicts the exhibited characteristics of the construction requirement entities. Using the example R1, a useful behavior of the column C1 in the case example is the material load bearing capacity leading to the structural strength necessary for supporting B1.

For other value entities, the operational aspect may be measured using performance metrics which reference *IfcMetric* entities. Such performance metrics are usually suggested by the actor (originator) of the requirement.

Necessary Conditions. The necessary conditions are the conditions which must be fulfilled before the requirement is available for proceeding. These conditions are modelled using the spatial, temporal and ordinal relationship taxonomies proposed.

EXAMPLE: ILLUSTRATING A LOAD BEARING REQUIREMENT

A load bearing requirement is a functional requirement having a set of user work packages, and a set of provider work packages (Song and Chua 2006). The user work packages define the purpose and demand a function, which has to be fulfilled by the operational behavior of the provider work packages. To illustrate the representation of the load bearing construction requirement, the functional requirement R1 is modelled using the proposed schema in Figure 6.

Functional Requirement R1:

Purpose: Function: B1 requires Support
Function User: B1
User Work Package: *IfcBeam(B1), IfcTask(Weld_B1)*

Operational: Function: C1 provides Support
Function Provider: C1
Provider Work Package: *IfcColumn(C1), IfcTask(Erect_C1)*

Necessary Conditions:
Spatial: Supported_by (B1, C1)
Temporal: "Erect_ C1" Before "Weld_B1"

Figure 6. Functional Requirement Example

The purposive and operational aspects of the requirement are identified with the user and provider work packages defined: B1 requires a support, and this support is provided by C1. The task intervals associated with the requirement are denoted in quotation marks. The necessary conditions for the fulfilment of R1 are that the spatial topology between B1 and C1 are met with a "Supported_by" relationship, and there is a precedent temporal relationship between "Erect_C1" and "Weld_B1".

CONCLUSION AND FUTURE WORK

This paper has formalized the definition of construction requirements from an ontological perspective. The key advantage of the proposed model is its ability to flexibly represent various types of construction requirements consistently.

In summary, the proposed approach in this paper identifies a "requirement" of construction requirements, which is termed the core characteristics. Three core characteristics of the construction requirements were identified which encompasses the spatial, abstract and temporal attributes. These attributes may be referenced from an IFC model's entities and relationships. This ontological perspective then allows the basic entities of the requirement to be formulated from these characteristics.

The authors believe that the identification of construction requirements is an important first step to formulating knowledge based construction method models. Specifically, construction methods may be represented as sets of construction requirements. With an appropriate declarative query language, future work involving automated constructability analysis, code conformance and automatic schedule generation from the construction knowledge embedded within the requirements, will be possible from IFC models. The authors are currently working on a case study to demonstrate the applicability of the methodology in a real construction context.

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