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FRAMEWORK FOR SEMANTIC RECONCILIATION OF CONSTRUCTION PROJECT INFORMATION

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SUMMARY: *The characterization of the AEC domain through the employment of conceptual schemas and standards is challenged with significant problems for exchanging, sharing and integrating information between actors. Semantic gaps or lack of meaning definition at the conceptual and technical level, for example, are problems fundamentally originated through the employment of representations to map the 'world' into models in an endeavor to anticipate other actors' views, vocabulary, and even motivations.*
In this paper, the role of information technologies, actors, and representations is first presented within a framework of communication with the purpose of further illustrating the encountered problems in interrelating sources of information. Secondly, interoperability is examined within the context of interrelating sources of information. This explanation supports the claim that the description of concepts into some form of representation does not guarantee the understanding by other members of the community of what is described. Thirdly, an illustration of semantic reconciliation is presented through an engineering example. An approach to semantically reconcile representations is proposed through the study of the internal role of the representations. The research assumption is that if the internal role of a representation is recognized, the treatment of the conveyed semantics can be facilitated, revealing important aspects of the meanings to provide proper understanding during the transition from the source to the interpreter. Particularly, this investigation searches for the fundamental problems of semantically reconciling sources, and introduces theoretical notions from other disciplines to suggest alternative approaches for the encountered problems. Our contribution is to provide clarification of the challenge of reconciling information and to bring attention to the need for further research on the relationship of actors as social subjects and on the representation of information to the community. We anticipate the inclusion of this relationship in the research efforts will lead to a more effective sharing, exchanging, integrating, and communication of information among actors through the employment of IT.

KEYWORDS: *Semantics, communication, ontology, conceptual role semantics, conceptual models.*

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1. INTRODUCTION

Specialty engineers, programmers, other professionals at the lowest technical level, and actor or software users at the application level are examples of actors that accommodate the needs of communicating information from multiple sources in projects. In communicating information, these actors solve coordination errors; partially or totally rework representations; re-enter data during data-transfer operations; perform conformance tests, and build agreements on ownerships of representations, among others activities. These information-processing activities involve sharing, exchanging, and integrating information between the information sources within a construction project. Conceptually, these activities *per se* are subsumed within a framework of communication. These activities are human intensive and require a high cost in terms of resources, including the employment of specialized labor. The reduction of human processing activities, therefore, implies a more efficient approach to process information in sharing, exchanging, and integrating information.

The relationship between humans and the representations (for short, actor-representation relationship) is a major research concern to study information processing activities. The study of the actor-computer representation relationship for sharing, exchanging, and integrating information is, therefore, required in the Architecture, Engineering, and Construction (AEC) domain. Witness that this challenge has been addressed is the innovative research in social networks in the AEC domain (Chinowsky et al. 2011, Mutis 2009, 2010, Taylor 2007, Taylor et al. 2009), which adds a social dimension to the approach of connecting actors through a network. Our research examines the actor-representation relationship with the purpose of communicating information, in particular the semantics of the representation. One step towards advancing this inquiry is the study of the obstacles in (1) understanding and (2) processing information that is generated from other sources. Such investigations should involve the understanding of the role of the representations as social object through information technology (IT), as the technology supports information processing activities to facilitate communication and collaborative use of project information. In particular, this paper focuses on the first part of the inquiry: the understanding of the information generated from different sources.

To present a general perspective of the problem, a framework for understanding the stakeholders' communication through the use of information technologies is illustrated in the first part of this paper. It is expected to get clarification of the relationship between humans and the representations within information processing activities. The understanding of the framework components will encompass the significant challenges for reducing human intervention in exchanging, sharing, and integrating project information among different sources. This framework is the introduction to understanding the challenges of communicating semantics through the characterization of the domain through conceptual models and standards in the scenario when two conceptual models are originated from different sources.

After introducing the framework, we present the claim that standards to characterize a domain are limited solutions to reduce human intervention. Standards minimize human intervention to communicate project information through multiple data formats, structures, and schemas by specialty engineers, specialty programmers, or communication engineering professionals. However, the developers' and domain actors' ability to reach consensus is hindered by the actors heterogeneity and the degree of fragmentation of the project. Constructing a unique conceptual model from one particular standard is a very complex task, especially for the simplicity required for its successful adoption among practitioners. There will be also differences in the conceptual model syntax, structure, and levels of detail when conceptual models are constructed by different sources and by different stakeholders. Finding relationships between conceptual models generated from different sources that characterize the domain that are constructed to share and exchange information is a highly intensive human information processing activity. Actors or developers are required to harmonize their models with the intention of integrating their data models with other actors for interoperability activities. The harmonization strategy consists of finding common concepts of the universe of discourse of the domain. The identification of these relationships is known as *semantic reconciliation*. This analysis is developed in the interoperability problem section of this paper. Subsequent sessions present the examination of the reconciliation of two sources by investigating the fundamentals of the problem concerning the complexity of the reconciliations.

Associating semantically two or more nodes from one to the other structure does not indicate an accurate association if they are syntactically expressed as similar. There are other aspects to consider for identifying closer and similar, semantic associations between two data structures or two models. The study of reasoning for reconciliation implies the inclusion of the relationship between the construction project actor as a cognitive agent and the explicit forms of representation. This research suggests studying the actor-representation relationship rather than investigating approaches by mapping models, schemas, or conceptual models, to find semantic reconciliations. This research proposes an alternative strategy to facilitate such reconciliation of information from different sources through the proposition of the use of Conceptual Roles Semantic theory (CRS). This strategy is a visionary work from the authors to satisfactorily cope with the semantic reconciliation problem. Specifically, this paper addresses the semantic reconciliation of forms of representations through ontologies as information sources. Conceptual Role Semantics studies the internal role of the representations as abstract, mental structures of an entity, events, or relations of a domain. The internal role of these abstract, mental structures for conclusive semantics is called conceptual role semantics.

In summary, this research advances the understanding of the reconciliation of models such as ontology, taxonomies, and schemas. Particularly, this investigation searches for the fundamental problems of semantically reconciling sources, and introduces theoretical notions from other disciplines to suggest alternative strategy through conceptual role semantic to the encountered problems. Our contribution is to get clarification of the challenge of reconciling information and to bring to the attention the need for further research on the relationship of actors as social subjects and on the representation of information to the community. We anticipate the inclusion of this relationship in the research efforts will lead to a more effective sharing, exchanging, integrating, and communication of information among actors through the employment of information technologies.

2. GENERAL FRAMEWORK OF COMMUNICATION IN CONSTRUCTION

The actors' interaction through information technologies with other construction project participants can be understood as a communication process in high layers of abstraction. Communication as an activity can fundamentally be defined in a dimension that aggregates other activities of information handling. Communication is commonly analyzed according to specific frameworks and theories within multiple domains such as sociology, and cognitive psychology. It involves the exchange of information content between actors through language.
All these activities take place person-to-person, person-computer, or any multiple combinations within a network that constraint the flow of information. When actors communicate, they create disseminate and shape data, and they interpret information for others in a way that information flows to them as well away from them (Bartolome, 1999). In specific domains such as in construction, communication is a multidimensional concept so that it can have a variety of meanings for different context, forms and impacts, so that its meaning differs for each person in multiple situations (Dainty et al. 2006). The following session illustrates a framework for communication to illustrate components and its relationship for communicating information. The purpose is to identify the main elements and their roles in the communication process in order to have a better understanding of the information processing activities and their related problems for an effective communication.

2.1 Principal Schema

Figure 1 shows a conceptual illustration of the components of a framework of communication. The distinction shown is fundamentally important to understand the encountered problems in interrelating sources of information in construction. The *first tier* indicates communication of information content through the use of systems of symbols. These systems range from (1) natural languages, (2) visual representations, (3) artificial languages, and (4) structured representations. The *second tier* shows two fundamental components required to interrelate sources of information: (1) the social component represented by actors or construction project participants, and (2) the medium to communicate the information content that ranges from the simple use of natural language through speech acts to the use of a more sophisticated technologies. These information technologies are used to assist the actor's communication. The *third tier* indicates the frameworks to interrelate information through sharing, and exchanging and integrating activities by means of processes, norms and protocols, and routines. These frameworks define the methods for the actors' participation for achieving their inter-relationships.

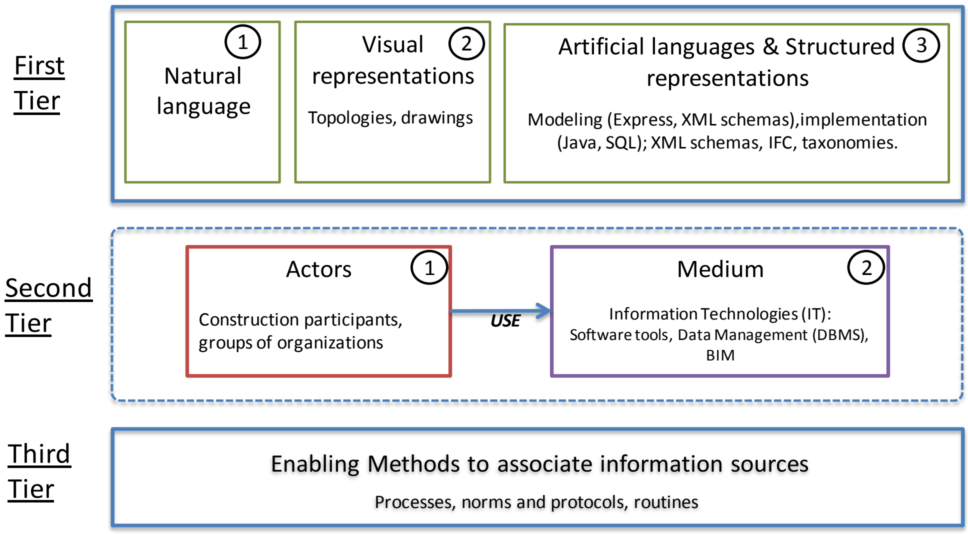


FIG. 1: Framework for communicating information through the use of IT.

The first tier illustrates the system of representations employed to communicate information content by the stakeholders of the project. Communication in construction projects involves interaction between sender and receiver to share meaning and have a mutual understanding (Emmitt & Gorse, 2007), which includes the understanding through computer based forms, similarly to how it occurs in speech acts (Mutis & Issa, 2008).
This first tier includes a set of representation of systematic usage of symbols established through social conventions to communicate meanings. *Natural language* is used by any human in written, spoken, and signed forms. *Visual representations* have significance to the actors or interpreters through a set of geometrical markers and topologies. Typical examples are the geometries used in construction drawings. *Artificial language* is a set of structured system controlled by a set of rules that expresses information. *Artificial languages* range from languages that expresses computations for human and computer processing such as Java and C++ to modeling languages that have rules and constrains for semantics of the resulting structures. The Unified Modeling Language (UML) and EXPRESS-G (ISO 10303-11 2004) are examples of the latter. *Structured representations* comprehend a conceptual layer defined within logic structures or models through explicit relationships, entities, and constraints. They are typically modeled by artificial languages to computationally be processed or to be interpreted by human actors.

The second tier of Figure 1 shows two constructs: the social element and the technical element. The first element represents the construction project participants who have roles associated with the project. These are actors who interact among the fragmented set of construction stakeholders including actors of software tools, designers, builders, suppliers, regulators, manual laborers, manufacturers, among others. Social actors use technologies to assist in their actions for communicating information. They ignore the complexity of the underlying level of the technologies. Individual humans are not the only social elements of the tier. A group of actors that represents organizations or parts of organizations are also social elements. These actors regularly and concurrently perform routine and non-routine activities, and they take action and make decisions at any time and place as individual or as collective entities. Routine and non-routine activities are defined according to the division of labor and they are assigned through explicit responsibilities within organizations.

The second component in the second tier of Figure 1 is an abstraction that helps identify the medium and method to communicate information content. The medium that actors employ in their routine or non-routine activities range from simple speech acts in natural language, visual schemes or drawings in two or three-dimensional representations to sophisticated conceptual models. For example, informal communication through natural language can be established through an exchange of speech acts among actors, while queries requested within a Document Management System (DMS) should be incorporated in formalized set of protocols among participants in the workflow.

The technical element of the medium component includes the group of technologies used to assist actors in their activities of sharing, exchanging and integrating information. These technologies include the services required to enable software tools to share information and to ensure that the semantic of data is correctly interrelated among the models. The technologies are also used to reduce misinterpretations and errors in communicating information. The purpose of assisting actors is to reach efficiencies by reducing manual data re-entry, and use of expert input and validation.

The third tier in Figure 1 refers to the structure and methods that define the relationships of the information sources. This third tier represents the entities that enable the actors' relationships to share, exchange, or integrate information. These entities are frameworks to relate and connect the actors and sources such as the definitions of protocols to exchange information during a construction activity. This configuration can be as simple as the formal organizations by means of rules governing the physical actors' interaction between sender and receiver through speech acts, or as complex as mappings to connect schemas from computer applications to share information within a network. This third tier represents the configuration of business rules and business facts for the actors' interaction, such as the rules of the routines for sharing information that define business operations.

2.2 The Interoperability Problem

Exchanging, sharing, and integrating information are actions of interoperability which is designated as the ability of actors and systems to work and properly interact together. The fundamental elements exhibited in the tiers of the framework in Figure 1, i.e. (1) natural and artificial languages providing visual and structured representation to communicate information content, (2) the social components and technical medium for connecting actors, and (3) the enabling methods and structures to relate the sources of information, are important elements as unit of analysis to understand interoperability. This distinction facilitates the analysis presented in this section to study the problems encountered in interoperability.

Construction firms rely on information technology to represent information about their product, processes, and documents in order to facilitate the exchange and sharing of information between construction project actors. Most of the research efforts have been done on product modeling and process modeling to represent information (Björk 1992, Eastman 1999, Ekholm 1996, El-Diraby 2006, Froese 1996, Lee et al. 2006). These models have contributed to the interoperability research efforts and the development of product and process ontologies for construction (Böhms et al. 2009, El-Gohary & El-Diraby 2010, Gehre et al. 2007).

2.2.1 Data Representations

In order to represent the 'real world', modelers and engineers map their observations into data representations that computer systems are able to read and process. In other words, data representations are logical, coherent structures of information that are processed by computers and are readable for human manipulation. These data representations can be structured or non-structured. They are structured when they reflect information based on logic or reflect a description of the logical relations between data elements in a way that computer languages or systems can process them, while non-structured information is a representation that does not have any kind of logical arrangement (e.g. an image) and that requires sophisticated algorithms to extract structured information to be processed by computers. If the concepts and relationships of a conceptual model are mapped to representations employed by computers, they are mapped to data representations. The study presented in this paper considers data representations in construction as data models. These data models, for example, can be expressions of *product data models* or *process data models* if they are intended to represent products or processes respectively. In any case, these *data models* will fit a predefined conceptual model in order to be understood by other domain actors.

When the structured data representations are organized in a *logical model* that defines data contents and relationships, they form a schema. Schemas that represent a particular domain are called conceptual schemas, which structure the domain in terms of modeling elements, concepts, and their relationship, by creating a general characterization of the domain content. Conceptual schemas can be understood as the result of the modeling process by using notation and diagrams as a language provided by *conceptual models* to express the domain structure (Fonseca & Martin 2007).

Typical notations of *conceptual models*, for example, are Express-G (ISO 10303-11 2004) a graphical notation for product modeling, and Unified Modeling Language (UML) (OMG 2009). A conceptual model indicates the framework of reference where the domain community has formulated their particular definition of concepts and their relationships independently of the implementation. From this reference, a data model can be built. Specialty engineers, information system developers, computer application developers, and other actors, refer to that conceptual model in order to make reference to any aspects of their concepts from their model. Examples of conceptual models in the construction industry classification of construction products are the Master Format Standard (CSI 2004) and Omniclass (CSI 2009).

A consensus strategy for interoperability embraces all standards where the main models of conceptualization are first created and subsequent data models are developed. Actors or developers harmonize their models with the intention of integrating their data models with other actors in the interoperability activity. This strategy consists of finding common concepts of the universe of discourse of the domain. In the case of the construction industry domain, the definition of those concepts is focused not only on construction *products* but also on *construction* processes during a project life cycle (ISO 12006-3 2006). The Industry Foundation Classes (IFC) captures specifications of actors, product, processes, and geometric representation, and provides support as a neutral model for the attachment of properties, classifications, and external library access (BuildingSmart 2010). An example of separate international organizations that combine their efforts into a single object library is the International Framework for Dictionaries (IFD) (Bjørkhaug & Bell 2009).

2.2.2 Interoperability Challenges

The exchanging, sharing, and integration of information through a strategy of consensus are challenged with significant problems. One of these problems, for example, is the semantic difference when actors interpret information from different sources. As was indicated in the framework in Figure 1, actors generate representations of concepts in order to communicate. Therefore the interpreters, such as specialty engineers, manually map the representation based on conceptual models to perform sharing and exchanging activities within a process of communication in order to overcome the divergence on the semantic of the sources. Common problems in interrelating sources of information found are inconsistencies, errors, and different semantics of information, such as the poor semantic content in documents and in electronic files. These problems make interoperability among construction participants burdensome due to their high costs of using additional resources.

Approaches that support exchanging, sharing, and integrating information range from executing agreements in partnering or alliance models between construction participants to integration of BIM-based approaches though the employment of a standard data model. The belief that current technologies fully support interoperability in the AEC domain is a misconception, as practitioners do not understand the level of sophistication of the technologies (Amor 2009). The challenge is not in finding compatibility across software among actors, but primarily it is at the conceptual model compatibility level where the software data-model is developed.

The fragmentation of the AEC domain hinders its characterization within one single model of reference, as the construction industry is also dominated by concepts that overlap with other industries. Therefore, the belief that it is possible to generate a complete, single model of reference for the domain is a misconception per se. For example, in general over all other domains, a single ontology that underlines taxonomy as reference will have problems of inconsistencies in its specifications at lower levels of detail, and it will have harmonization conflicts in revising and changing concepts (Sowa 1999) by impacting other models that employed the ontology as a reference. Classifications and taxonomies as single models of reference such as Masterformat (CSI 2004) are useful guides, but their dilemma is to balance their inconsistencies on prescribing low levels of detail and their sufficient vagueness in the specifications, by virtue of being clear to cover the scope and details of the elements under their classification. These inconsistencies create semantic gaps or lack of meaning definition at the conceptual and technical level within the conceptual models. For example, two independent subcontractors that estimate a project will include different components within the same project item, which reflects lack of semantic definition and vagueness within the standard at low levels of detail.

Alternatively, the domain can be organized through the use of *multiple conceptual schemas*. However, this strategy is challenged with significant problems that emerge when software or specialty engineers need to find relationships between two schemas elaborated by different agents. They find dissimilarities amongst the conceptual models, conceptual schemas, or other forms to organize and categorize information of the domain. Finding relationships through mappings between the elements of each one of the models is a strategy they can use for the harmonization of the models. In databases, mapping is used to determine correspondences between data representations and it is called a matching operation (Rahm & Bernstein 2001). These operations reconcile or harmonize different sources such as applications, data warehouses, web-oriented data integrations, e-commerce, etc. Matching takes two schemas as input and creates a mapping that identifies corresponding elements in the two schemas (Madhavan et al. 2001). Finding relationships through mappings consists of identifying relationships between concepts from the data models or schemas. The identification can be executed through one existing conceptual model, or through a direct manual mapping activity. The criterion to find the relationships is based on finding semantics through similarities of the concepts' syntax and on the mode of structuring the concepts within the schemas. The latter criterion consists of the identification of the organization of the concepts within each schema and of the recognition of common patterns in the composition of concepts. After these analyses are made, a validation has to be performed. This is done through an examination of the schemas to generate an integration model by resolving the conflicts of relating concepts from two different sources. It detects differences, defines correspondences, and creates a new schema or merges the existing ones. The strategy pursues consistency of the final integrated schema, involving more use of manual operations than semi-automatic or automatic operations. Mapping IFC Express schemas and relational databases (Nour 2009) is an example of efforts in the AEC domain.

The organization of the domain through the use of multiple conceptual schemas has significant limitations since mappings are required for this purpose. Mappings intend to find semantic correspondences based on relating concepts through similarities in the syntax and in the structure of the data representations. Finding the accurate relations by using similarities is extremely complex. For example, finding the relations of concepts in the schemas by similarities when aggregated is not possible without the aid of an external agent. Initiatives that harmonize independently defined schemas or models through a reference on a conceptual model require external expert manipulation. To overcome these limitations research efforts have created ontologies that incorporate data models, such as eCognos (Lima et al. 2003, Lima et al. 2005a) and Funsiec (Lima et al. 2005b), or semantic web methods for product related catalogues (Beetz & de Vries 2009, Shayeganfar et al. 2008). These approaches employ IFC and taxonomies as conceptual models and starting points to create single, harmonized products, queries, and control vocabulary. However, they leave out concepts that have not been inferred to the ontology. Other research efforts that employ ontologies are intended to formalize concepts for a particular problem within a subset of the AEC domain (Gu et al. 2005, Kitamura et al. 2004, Peachavanish et al. 2006). In these approaches, essentially the actors have to establish mechanisms to understand that the elements of the information in their conceptual model have the same meaning for them. However, this strategy only distinguishes the set of ontological commitments that the modeler asserts.

All the aforementioned initiatives benefit the exchanging of information in providing useful mappings, however they cannot create inferences to semantically represent the complexity of the domain that has been modeled or represented. They require external expert manipulation, and this consequently hinders their full implementation in practice. Although developing adequate conformance checking practices and standards for software developers will help identify problems in mapping standards and software to interoperate (Amor 2009), including the identification of data transfer between applications through modeling errors checking software, the fundamental problem is yet to be resolved. In summary, the characterization of the AEC domain through the employment of conceptual schemas is challenged by significant problems in promoting interoperability. These problems emerge when relationship are mapped between two schemas that have been created by different agents.

In consequence, the semantic gaps or lack of meaning definition at the conceptual and technical level are fundamentally originated through the employment of representations to map the 'world' into models in an endeavor to anticipate other actors' views, vocabulary, and even motivations. The modelers' apprehension of the mappings invokes philosophical questions concerning the method to represent the 'real world', which is built upon inquires such as "What exists?", an ontological question; "What should be represented to perform interpretations?", which is addressed in phenomenology; or "How should it be represented?", from the area of epistemology. New sciences like cognitive sciences are aimed at contributing to the investigation of the semantic gap in mapping the 'world' into representations to anticipate actors' views, vocabulary, and motivations with insights from philosophy, psychology, linguistics, and computer science disciplines. This research advances the current state of the art by studying reconciliation of models such as ontology, taxonomies, or schemas with the purpose of enhancing the understanding of the essential problems in interoperability. Particularly, this investigation searches for the fundamental problems of semantically reconciling sources, and introduces theoretical notions from other disciplines to suggest alternative approaches to the encountered problems.

3. EXAMINATION OF FUNDAMENTAL ELEMENTS FOR INTEROPERABILITY

The divergence on the understanding of a concept among actors takes place when some actors generate representations of concepts in order to communicate and when others interpret the representations of those concepts. The generation of concepts compromises the understanding by the interpreter of the evidence of some phenomena in the world. The phenomena are defined in symbolic notations such as logic, frames, and semantic networks, among others, and are deliberately organized to define concepts. The characterization of symbols and the manipulation of them is a reasoning process similar to a mathematical manipulation. The characterization of the world through symbolic notation is deliberately organized to communicate the represented concepts. Developers, therefore, address the understanding and characterization of the world into symbols and other forms of representations to be universally understood. The ultimate purpose is that the members of the community understand the shared and exchanged representations. There are additional elements for interoperability other than at the machine level that are important to be defined in order to accomplish this purpose. A further examination of these elements is found in the sections that follow.

3.1 Semantic Interoperability

Two important aspects are emphasized in semantic interoperability: (1) the '*understanding*' of information from different actors, and (2) information used which is symbolized by *representations* such as visual and textual representations. The former aspect defines the understanding of the social actors, which are described in the social component in tier 2 of Figure 1. The latter aspect is described in the first tier of the framework shown in Figure 1. Characterized as a paradigm, *semantic interoperability* is the congruence of domain concepts. It pursues the understanding of multiple actors or participants in defined settings and organization structures. Under this paradigm in the construction domain, the barriers that hinder the full congruence of the construction concepts are particularly addressed. Finding methods to pursue the *effective* exchange, sharing, transfer, and integration of information are studied within *semantic interoperability.*

This paradigm can be approached from two different angles: *information systems* and *problem domain*. The former is researched within the *computer science* domain and the latter by a particular domain (such as heavy construction, building construction, etc.). The challenge then is how the use of the resulting technologies and new theories researched in computer science to benefit the articulation and further understanding of representation of concepts in the AEC domain. For example, the use of Human Computer Interaction (HCI) (Carroll 1997, Winograd 2006) is a computer science area of research that can be articulated to the AEC domain to find solutions for the understanding of information generated from multiple sources. Approaching new theories and frameworks and articulating them to further understand representations of concepts in the AEC domain contributes to the advancement of this semantic interoperability paradigm. To materialize the articulation of framework and theories, HCI has been introduced to AEC through the definition of a speech act framework (Mutis & Issa, 2008) to facilitate research on effective communication of semantics amongst actors. The speech act framework contributes to the understanding of the construction actors' communications through the sharing, and exchanging of information.

Moving this challenge forward in this investigation, interoperability is analyzed within the distinctions shown in Figure 1. The purpose is to investigate the problems encountered in interrelating sources of information through sharing, exchanging and integrating information.

3.2 Representation of Construction Concepts

Construction concepts can be reified and characterized through representations such as drawings or documents in natural language as is shown in the first tier of Figure 1. The use of programmable machines that process, store, and provide information in useful format has changed the method to represent concepts through computer applications that are tightly related to their level of sophistication. Computers gave engineers tools to develop higher precision and more complicated models, replace drawing boards, and provide ubiquity to support collaboration and communication services (Turk 2001). Independent of the methods and technologies employed to represent information, there is a reification process that construction participants employ to characterize construction concepts. Once they are represented, then they can be communicated to other actors. In explaining the first tier in Figure 1, communication of information content employs different channels through the use of languages among construction participants. Natural language in electronic mail, visual representations and symbols assembled in building information models, or formal descriptions of a desired behavior expressed in natural language such as construction specifications, are examples of the different forms of representation used to communicate information to other actors. It is at this point that a reification process occurs.

The methods to represent construction concepts have also evolved with new technologies not only in their format but also in their content. Parametric models and formatting with the Design Web Format (DWF) (AutoDesk 2004), which supports publishing information within a workflow, have evolved to represent the content. Associated information of a geometric object from a BIM model to a database that can be easily accessed by the user, such as the type of material, color, and texture, are examples of the advancement to represent the content. When these methods to represent construction concepts evolve, so does their reification with the expectation that communication of the content would be more effective and efficient.

As language is employed as a medium to communicate representations, the actors' employment of models for sharing, and exchanging information has been used as a method to communicate construction concepts (see Figure 1). These models structure information to define the semantics of the construction concepts. The models are aimed for actors to use as references to the concepts. Actors can subsequently make decisions and take actions from the reference. If the concept has already been represented in a model, the model will describe the series of steps of what is modeled (Sowa 2005). Construction specifications, for example, are formal descriptions of a concept expressed in natural language. They express a designer's desired behavior about a concept. Division 6 of the 2004 Masterformat (CSI 2004) models "Wood, Plastics, and Composites" and classifies the elements made of these composite materials used in a construction project. "Wood, Plastics, and Composites" is the concept represented in the classification. This model, 2004 Masterformat, indicates how the elements should be organized in construction documents. The specifications present a declarative form of describing a concept, and model indicates a procedural form. The specifications of an explicit element represented in the model indicate formal characteristics of that element such as its operating temperature range.

A brief observation of these forms of representations, of the Masterformat taxonomy and of the temperature range expressed in natural language, suggests that the description of a concept captures the modelers' particular intention. The taxonomy describes a set of elements that are made of plastics and the specifications, the intended operating temperature range. Through these representations, the modeler describes the construction participant's manipulation or use of a plastic element within a temperature range for a project. Clearly, the taxonomy explains how the breakdown of the plastic elements concept is defined, and the specifications prescribe an intended temperature constraint. Therefore, the specifications are representations in natural language organized in a taxonomical model that enable actors to have the same view of the concepts and to subsequently take actions based on those views.

3.3 Actor Representation Relationship

From the taxonomy model example, three elements are outlined within the actor-representation relationship: (1) The construction participant or interpreter, (2) the representation, and (3) the information source.

3.3.1 Interpreter

The construction participant or interpreter is the mediator between the domain and the representations or the model. They have different roles according to their level of technical knowledge. Within a lower level of technical knowledge, they act as interpreters of the representation and do not further process information. As shown in Figure 1, these construction participants are actors, or users of software tools when they employ computer applications technologies. Software actors at the application level are examples of actors that characterize this participation. These actors ignore the complexity of the underlying level of the technologies that are required to interrelate sources of information. Engineers, specialty programmers, and communication engineering professionals are example of actors that have higher level of technical knowledge. Actors with high levels of technical knowledge accommodate the needs for exchanging, sharing, and integrating projects. They are interpreters that solve coordination errors; partially or totally rework representations; re-enter data when information is lost from original files during data transfer operations; perform conformance tests (BuildingSmart 2010) and make agreements on ownerships of representations such as BIM models, among others.

3.3.2 Representation

The second element from the actor-representation relationship example prescribes the behavior of the agent and the modelers' intention. The successful interpretation of the representation and the resulting action of its interpretation is called the *interoperability act* (Mutis & Issa 2008). This investigation regards sharing, exchanging, and integrating information as essential activities for interoperability within the social network. The social network approach explores the relationship between the actor and the representation. Unsuccessful interpretations of representations of construction products or processes drive the interpreter to search for additional information sources or to seek out other references to support the actor's interpretation. Individual actors look for bonds within the network to facilitate the search process. This search process is performed between single actors or performed between clusters of actors. The nature of the bond does not refer to the method to connect actors within the network, but to the purpose and intention of the relationship.

3.3.3 Information Source

The third element from the actor-representation relationship is the designer or information source. These actors' build and process the representations to be shared, exchanged, and integrated. The designer for example explicitly sets the constraints of the intended concept with the purpose of anticipating them in the context of the project. These constraints define the concepts that designers communicate. However the designers' assumptions cannot be fully be anticipated due to the infinite and complex nature of their project.

3.4 Reference Models and Modelers' View

The designers use visual representations that are translated into common models, standards, and vocabulary when information systems are used. The purpose is to reach a consensus about the semantics of the information among experts and members of the community. The IFC (BuildingSmart 2010) is an extensible reference model that provides broad definitions of objects from which more specific models can be developed to support exchanges within workflow activities. Actors, for example, generate their information based on a set of rich classes.
The objective is that multiple construction participants ultimately recognize the shared models and set a universal language. The implementation and the use of models and common vocabulary provide the possibility of reusing information by the project actors. However, the *modeler's view* is bounded to his or her *social* and *physical contexts*. Therefore, the consensus on setting a common model or vocabulary bounds the final user's view. Large group of experts from different backgrounds are required to counteract this effect. The generation of information under the actor's view is bounded by the modeler's view. It is particular evident in designs with levels of details and granularity. The set of entities that represent the model has to be further adjusted and extended by the final user to reflect the detail they require from the construction firm for a particular project. The modeler or expert sets up a universal language and common models by consensus. However the social and physical contexts of the individual actors are not fully embraced through consensus. The consensus strategy opposes the *uniqueness* of construction projects, as a feature of their nature.

Product models for example, which are conceptual models that define schemas in which concepts of the construction domain could fit employ a modeling technique that domain experts use to reshape what they observe in the world (Turk 2001). A conceptual model will lack effectiveness, reliability, and reusability if these approaches are developed without a close collaborative input to represent concepts by actors of a social network. Conceptual models are limited to created inferences to semantically represent the complexity of the domain that has been modeled or represented. They require external expert manipulation. A further examination is found in the sections that follow.

Actors are able to use models and common vocabulary as a reference, but they need to represent their view of the concept to be shared, exchanged, and integrated to other actors even if the information is generated from common models and standards. These efforts do not address interoperability from the perspective that relates actor-representation and its social network (Mutis 2009). In consequence, the study of the actor's bonds in a social network to share and exchange information has not been explored. Also, aspects related to the context of actors within the social network, such as the way reference models can be employed to specify the common vocabulary of multiple actors that participate in a construction project, have not been studied in interoperability.

3.5 Models and Limitations

Models involve grouping a set of relations and symbols with the purpose of characterizing some phenomena of the world and of being shared and understood by a community. Symbols refer to some entities of the world with properties and relations apprehended within them. Models hold a symbolic characterization of the world that should satisfy particular world-states. Generally, those satisfactions are defined by the inclusion within a *category*. If a frame has *aluminium* as the main component, it holds a piece of glass, it is joined in a whole piece, and it separates two environments, it belongs to the *glass-window category* and the *glass-door category*. Models assert truth if the developers' assumptions about their characterization are met. From this analytical tradition, then, the identification of meanings of each particular symbol in a model can be distinguished in relation to other symbols that are included within the same model.

Models are a family of *propositions* that constitute *approximations* that resemble instances or events of the world in order to be applied when pre-established conditions are satisfied. In this definition, propositions are *correspondences* that presuppose and assume truth of some phenomena of the world, and *approximations* are simplifications of a complex nature of the phenomena that are applicable when the same cases occur or, in other words, when the identification that satisfies the conditions are met. The simplifications are abstractions that neglect the influx of other factors in the phenomena.

The analysis of symbols has been researched in the AEC domain by Mutis and Issa (2008) through semiotic theory that studies the uses of signs in representations. In this investigation, signs are considered representations that take the form of a visual representation, natural language, or other possible representations within the construction documents. This analysis recognizes the relationship between the interpreter and the material quality of symbols. The study of semiotic theory is an examination of the compromise between the meanings of a representation per se and the concept associated with the understanding of such representation.

In summary, interoperability is analyzed within the distinctions shown in Figure 1, to investigate the problems encountered in interrelating sources of information through sharing, exchanging and integration information. However, the description of concepts into some form of representation does not guarantee the understanding by other members of the community of what is described, since the members have different background, theories and views, including vocabulary used. The choice of representation suggests different kinds of problems primarily influenced by the purposes of the actors in a domain. Sowa (1999) in a brief examination exemplified these problems through logic and ontology representations. The choice of representing a concept in formal logic involves a fixed set of propositions and lack of other subset of logic expressions to determine the meaning of what is intended. The choice of representing a concept through an ontology implies different choices to categorize concepts; different forms to name the same concepts, and different approaches for axiomatization. In addition to this examination, the choice of employing the symbolic approach in order to characterize concepts can be seen as complementarily driven for some purposes, but for other purposes, the same characterization can be seen as contradictory. An ontology that describes the sets of indoor conduits and piping for buildings can be complemented as much as possible with more axiomatization to specify conduits for lighting work, electrical and pressure pipes. The result might be more accurate for modeling conduits built for lighting work, but might be seen as contradictory by the electrical engineers in attempting to reconcile their product model that specifies conduits for communication associated with hazardous services which have ceramic and fire protection properties from the conduits and piping ontology.

4. SEMANTIC RECONCILIATION

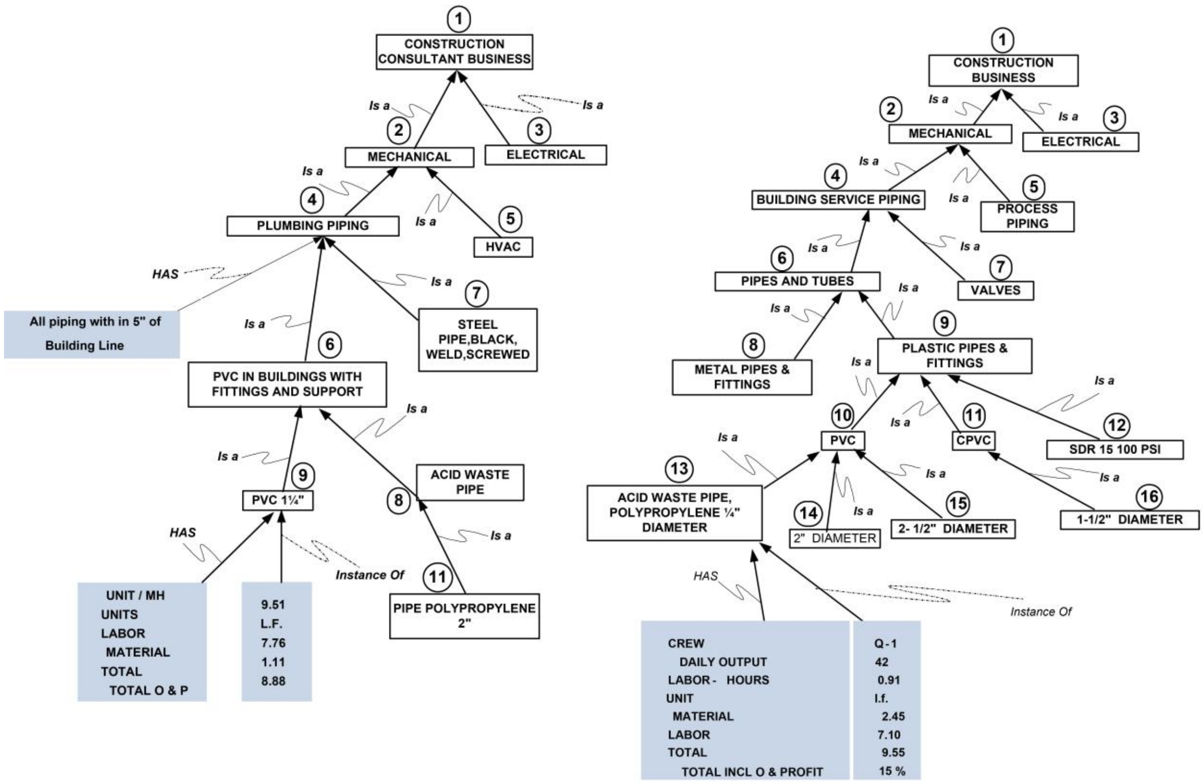
With the purpose of explaining how construction actors convey meaning of concepts to other actors through representations, this section explores a close insight into the problem of semantically reconciling representations of concepts. The semantic reconciliation deals with finding common semantics about sources of information from different actors. In a simple definition, Jonas (2007) noted that semantic conciliation is "recognizing when two objects are the same despite having been described differently." Reconciliation is a fundamental step in the process of convening the meaning of representations generated from different sources in sharing, exchanging, and integrating information, which in turn is related to how actors semantically interoperate.

To illustrate the complexity of semantic reconciliation a case example for the construction domain will be used. This example employs ontologies, which are semantic networks formally structured to represent explicit information, to enable data and information exchange (for example, the Semantic Web), and to provide a conceptual and representational foundation on which to build systems (Gruber 2005). In particular, ontologies have a representation of a simplified view of the world or modelers' world. This means that ontologies are contingent on the requirements and on the intended use of the modelers' domain. The case example used is narrowed to the instance when the meaning from two sources of information is required to be reconciled. The assumption for this example is that the meanings of the concepts from each source has not a priori been shared between the two sources to reach consensus, such as the consensus that it is reached in collaborative settings. As was shown in the communication framework in the Figure 1, the meanings of the concepts from the sources of information are conveyed through representations. The representations, in this case the ontologies, express meanings of concepts from the construction domain through symbols in a semantic network.

In the example shown in Figure 2, the modelers of each one of the ontologies represent concepts from its own personal view of the domain. Modelers and experts of the same domain similarly define meanings of the concepts at upper-levels of the ontology. This means that the formalization and the conceptualizations of the upper level are very similar for each one of the sources. The upper-levels are usually the referents for these experts and modelers. As an analogy, these upper levels can be understood as the upper levels of taxonomic hierarchies of classes and their subsumption relationships. The modelers have the same upper-level taxonomical hierarchies of concepts and the syntax that they define for the represented concepts. At the low levels of the hierarchies, however, differences are observable in the syntax and subsumption definitions. They specify a different formalization of the domain for each one of the sources at these low levels. The example shown in the Figure 2 presents a similar case for ontologies as for the previous taxonomies example, with similar upper-level concepts and dissimilarities in the low levels. However, ontologies do not have the same rigid inheritance structures as such taxonomies.

The reconciliation of concepts from each one of the sources consists of finding semantic relationships between sources. Graphically the relationship can be represented through mappings, which link one or more concepts from one source to one or more concepts from the other. Mapping pattern formalizations have been attempted within AEC domain (Katranuschkov 2001), which have facilitated the understanding of the difficulties of mapping tasks and of the run-time computational complexity.

The adoption of mappings, however, implies the assumption of equating meanings for each one of the represented concepts from the sources. Assessing that two meanings as equal involves subjective criterion of the agent or actor who judges the representation (Diggelen 2007), under the pragmatic nature of such representation. For example, what is meaningful for one actor is not meaningful for others. Within the instance when the meaning from two sources of information is required to be reconciled, finding mappings can be expressed as determining how an actor can semantically map one concept to the most semantically similar concept. The mappings for this example are semantic alignments between two or more concepts.



(a) Ontology 1 (O_1) *(b) Ontology 2 (O_2)*

FIG. 2: Ad hoc construction business ontologies.

The example in the Figure 2 illustrates the complexity of reconciling concepts of two domain ontologies, O_1 and O_2. The nodes in the ontology represent concepts that have levels of specializations from their parent concept. In addition, the reader can identify relationships among concepts, for example, *Isa*(CPVC, Plastic Pipe Fittings) among the Concepts 11 and 9 of O_2, as shown in Figure 2. The '*is a'* relation corresponds to a semantic link between two concepts which have a subsumption relation. The '*part of*' relation corresponds to the relationship that captures a partial order of concept x to another concept y that is always reflexive (1), antisymmetric (2), and transitive (3) (Keet 2006). The '*has'* relation corresponds to a semantic link that constrain the subsumption relation to a directional relation of containment (Brachman 1979, Woods 1975).

Semantic reconciliation is required, therefore, in the semantic interoperability process. For example in integrating information from two different sources, a construction participant is required to construct queries regarding information about the availability and costs of specific items from a material supplier, such as of pipes for internal water distribution in a building. The supplier source and the construction participant's firm have formalized their products through ontologies. The firms' specialty engineer will need to perform a semantic reconciliation to map the most similar concepts between the two ontologies, the one from its own information system (O_1) and the one from the supplier (O_2).

Equating meanings to semantically reconcile, for example, a concept or set of concepts of one representation to another concept or set of concepts of the other data representation, is a complex activity. Moreover, the question of how the specialty engineer will be able to find mappings when one concept is semantically similar to a group of two or more concepts into another ontology needs to be addressed.

In addition, the mappings shown in Figure 2 resemble one to one and complex matching problems that have been studied within the database community (Doan 2002). For instance, consider a one to one semantic match at one of the levels. With the support of an "expert", Concept 7 from O_1 (*Steel Pipe, Black Weld, Screwed*) is matched with Concept 8 from O_2 (*Metal, Pipes & Fittings*). Note that they might have the same referent for the "expert," but they fully syntactically mismatch. The syntax '*Steel Pipe, Black Weld, Screwed*' is not the same or even similar to some to the syntax '*Metal, Pipes & Fittings*'. The input of a domain expert is required to reach the semantic association between the Concept 7 of O_1 and the Concept 8 of O_2.

Consider the case of more detailed queries such as the ones for water distribution pipes of 1¼" diameters in the case example. The specialty engineer needs to map specific instances from one source to another source or from one conceptual structure to another conceptual structure. For example, the user semantically maps Concept 4 (*Plumbing Piping*) in O_1 to Concept 6 (*Pipes and Tubes*) in O_2. However, the mappings needs to further be developed to reach the queried element, regarding the availability and costs of specific items from different material suppliers such as pipes for internal water distribution in buildings. The specialty engineer should follow the subsumption relations of the concepts. This approach is similar to following down the hierarchy of the taxonomy. A taxonomy is a central component of an ontology (Noy & McGuinness 2001), it is very narrow form of specification for agreeing on a conceptualization - centrally controlled categorization (5). Assume the specialty engineer, as expert, asserts that a Polymer Pipe between 1" and 11/2" diameter is suitable for internal water distribution, e.g. PVC (Polyvinyl Chloride) pipe. Hence, mappings of Concepts 9 (*PVC 1¼"*) from O_1 to Concepts 10 (*PVC*) and Concept 13 (*1¼" Diameter*) from O_2 are made. Observe that Concept 10 subsumes Concept 13 to perform the mapping. Concept 10 is a more general concept than Concept 13. The example indicates a complex type of mapping that includes a joint of two concepts from one source to another concept of another source.

O_1 and O_2 show how the relationships between concepts of two representations could map at a *more general or specific* form, or they could *overlap* or they could *mismatch*. These types of intuitively semantic relationships have what is called a level of *similarity* (Doan 2002, Giunchiglia & Shvaiko 2003). Thus we can say that Concept 4 (*Plumbing Piping*) in O_1 is *similar* to Concept 4 (*Building Service Piping*) in O_2, at least intuitively due to specialization relation from Concept 2 (*Mechanical*) in O_1 and Concept 2 (*Mechanical*) in O_2, and due to similar syntax description of Concept 4 (*Plumbing Piping*) in O_1 is *similar* to Concept 4 (*Building Service Piping*) in O_2.

In addition, it is important to note that the relationship between concepts such as *Isa*(*HVAC, Mechanical*) is also a possible map to other concepts of the ontology. These mappings between different types of elements make the semantic reconciliation more complex. In this line of the analysis, some concepts from O_1 and O_2 have *similar syntax* and *overlap* within lower specification of the concepts. In these cases, in order to perform semantic reconciliations an expert, who understands the *referents* in the domain, executes the reasoning process. For example, in an attempt to perform reconciliation between node 7 in O_1 and node 8 in O_2, an understanding of what is meant by '*steel pipes types'* is required.

Formally, the comparison of the concepts between $O_1(a_1,\ldots,a_n)$ and $O_2\ (b_1,\ldots,b_m)$ can be performed through a set of criteria $C=(c_0,c_1,\ldots,c_n)$, for which the result can be measured using the following three properties (Gehlert & Esswein 2007):

- Equivalence: Two concepts a_i and b_j can be considered to be equivalent (equivalent (a_i and b_j)) if both concepts cannot be distinguished by all criteria C used for the comparison. As such, the equivalence relation is reflexive, symmetric, and transitive.
  For example, the nodes O_1(a9), O_2(b13), and O_2(b14) have the following properties as shown in Figure 2, O_1 (a9, (*Unit/MH, Units, Labor, Material, Total, Total O&P*)), O_2 (b13, (*Crew, Daily-Output, Labor-Hours, Units, Materials, Labor, Total, Total Incl O&P*)), and O_2 (b14, (*Crew, Daily-Output, Labor-Hours, Units, Materials, Labor, Total, Total Including O&P*)). To find the semantic equivalence of the node O_1(*PVC, ¼''*), and O_2(*Acid Waste Polypropylene, ¼", Diameter*), or O_1(a9) and O_2(b13), a set of the criteria C is used. In this case, the criterion is C = (*Units*). Then, the equivalence relation for the nodes through criterion C can be expressed as *equivalent* (a9, b13, (*Unit*)). Therefore in this case, the equivalence relation holds for these three concepts as it is reflexive (equivalent (a9, a9 (*Units*)); symmetric (equivalent (a9, b13,(*Units*))⇔(b13, a9,(*Units*)), and transitive (a9, b13,(*Units*) ∧ (b13, b14,(*Units*) ⇔(a9, b14,(*Units*)). As it is observed from the example, O_2(b14) is used to demonstrate the transitive property.
- Similarity: Two concepts can be considered to be similar, (*similar*(a_i and b_j)), if both concepts cannot be distinguished by the set of criteria, $\check{C}=(c_0,c_1,\ldots,c_{n-1})$. However they differ in the criteria $\hat{C}=(c_n,c_{n+1},\ldots,c_{m+n})$, where ($n,m \in$ N; n,m >0;$C=\check{C}\cup\hat{C}$; $\check{C}\cap\hat{C}=0$). The similarity relation is symmetric, not reflexive and not transitive with few special cases as exceptions (Gehlert & Esswein, 2007).

As discussed in the previous example, consider the nodes O_1(a9) and O_2(b13), as shown in Figure 2. To find the semantic similarity of the node O_1(*PVC, ¼''*), and O_2(*Acid Waste Polypropylene, ¼", Diameter*), or O_1(a9) and O_2(b13), a set of the criteria C is used. In this case, if the criteria C is C=(*Units, Labor, Unit/MH, Daily Output*). Č=(*Units, Labor*), and Ĉ = (*Unit/MH, Daily Output*). Then, the semantic *similarity* relation for the nodes through criterion C can be expressed as *similar*(a9, b13 (*Units, Labor, Unit/MH, Daily Output*)). Therefore in this case, the equivalence relation holds for these two concepts as it is symmetric (*similar* (a9, b13,(*Unit/MH, daily output*), b13, a9, (*Units, Labor*)), and not reflexive (*similar*(a9, a9 (*Units, Labor, Unit/MH, Daily Output)).*

- Difference: When two or more concepts are not equivalent, transitive and reflexive, they are said to be different.

  For instance, consider the concepts O_1(a9), O2(b13) and O_2(b14) with criteria C = (*Unit/Mh, Crew, Labor*). To find if the semantic difference holds for these concepts between O_1 and O_2, the test to the relation with the equivalence, symmetric, and transitive property is required. If any of the properties does not hold, the concepts are said to be different. The symmetric and transitive properties do not hold, then in finding the semantic equivalence relation is found that (equivalence (a9,b13), C) $\Leftrightarrow$ (equivalence (b13,a9),C) and (equivalence (a9,b13,C)) $\wedge$ (b13, b14,C) $\Leftrightarrow$ (equivalence (a9,b14,C). Therefore, comparing the semantics of the O_1(a9), O_2(b13) and O_2(b14) with criteria C = (*Unit/Mh, Crew, Labor*), the concepts are determined to be different.

In summary, the example using O_1 and O_2 illustrates the complexity of semantically reconciling concepts from two sources. The sources used were ontologies representing examples of models of AEC domain concepts. The differences in their terminologies and their structure induce a complexity in aligning mappings between represented concepts. This complexity is a semantic heterogeneity case, which is categorized as an ambiguous reference (Ding et al. 2004), because the same term has a different meaning in different ontologies. In addition, the example shows: how one concept from one ontology has similar but not exactly the same syntax as that of another ontology, which can be assessed as having similar semantics by an expert; how two concepts with a similar meaning can be structured differently in different ontologies; and how concepts can be formally analyzed with a set of criteria to establish similarity, equivalence, and difference relations between them. In the previous engineering example, therefore, the complexity of equating meanings to semantically reconcile a concept or set of concepts of one representation to another is demonstrated. This complexity suggests the need for intervention by a domain expert in performing such reconciliations.

5. SEMANTIC RECONCILIATION THROUGH CONCEPTUAL ROLE SEMANTICS

In this section, an approach to semantically reconcile representations is proposed through the study of the internal role of the representations. The approach relates (1) the inferential commitment of the source to the representations, and (2) the semantic import by the interpreter. Inferential commitment (Brandom 2008, Scharp 2005) is a deontic status where an actor undertakes, acknowledges, and attributes. Semantic import is an endorsement of a commitment and a semantic position by an actor who participates as interpreter of a particular representation. The assumption is that if the internal role of a representation is recognized, the treatment of the conveyed semantics can be facilitated, revealing important aspects of the meanings to provide proper understanding during the transition from the source to the interpreter. Therefore, it is expected that an internal role of the representation reveal the obscurities in semantically reconciling sources of information.

Although inferential commitment can be understood as one single concept, this research takes a further distinction between the source and the interpreter for the analysis of semantic reconciliation, by proposing (1) inferential commitment from the source and (2) semantic import by the interpreter. Therefore, in order to set a framework for the fundamentals for this approach, this research borrows the conceptual role semantics notion that studies semantics through the use of forms of representation and its implication for reasoning. The approach recognizes the importance of role of the social component shown and explained within the second tier of the framework of communication (see Figure 1). A contribution is expected to the understanding in reconciling information to communicate the content of representations of concepts in the construction domain.

5.1 Actor's Interpretation

An actor's interpretation of a representation has to be conclusive on its *semantics* in order to assert an understanding of such representation. For example, an interpretation of a visual representation of one detail of a typical spread footing has to be conclusive; however, its interpretation is subject to the actor's cognitive levels of understanding. The actor's semantic import from such representation is asserted when the representation is recognized. Based on the preceding consider a designer who is the information source or the actor who originated the representation. The designer originated a typical spread footing representation. When the representation is originated, the inferential commitments to that particular representation are made. In this case, the designer performs inferential commitments to the visual representation that pictures a detail of typical spread footings. The representation then conveys meanings to another actor, who is the interpreter such as a contractor, and that actor is the one who performs the semantic imports.

5.2 Conceptual Role Semantics

Concepts are abstract, mental structures of an entity, events, or relations of a domain. The internal *role* of these abstract, mental structures for conclusive semantics is called *conceptual role semantics*. Recognizing this notion is a step forward to investigate the semantic reconciliation of the representations that are shared, exchanged, and integrated. Conceptual role semantics articulates the representation to the actor either as an information source or interpreter. This articulation contributes to the study of the actors-representation-relationship.

Conceptual role semantics is a framework rather than a theory concerning the roles of representations. This framework involves the concepts' reasoning or caused inferences and the concepts' contribution of cognitive abstractions to meanings (Block 2006). Cognitive science, computer sciences, and other sciences broaden the framework of *conceptual role semantics* in seeking the semantics of the forms of representations through the role they play in the actor's cognition, and in seeking to *use* the actor's input on such representations.

Theories of truth and reference can be seen as contenders to *conceptual role semantics* in defining the source of meanings for any symbols, signs, or syntactic systems. Referents are supposed to indicate truth in the *correspondence* between the symbol and the world. The theory of reference stems from the work of Gottlob Fregean (Appiah 2003). Fregean's theory considers *senses* as referents that link a symbol in the proposition to the world correctly. *Correspondence* is a metaphysical notion that claims that the description of the world is truth by the existence of some observation with corresponding elements and a similar structure; metaphysics is concerned with the explanation of the nature of the world (Appiah 2003). However, *conceptual role semantics* put the cognitive role as central to define meaning instead of a specific reference to the external world. Understanding a meaning consists of having symbols with relevant conceptual roles and not having an understanding of truth conditions. *Conceptual role semantics* holds that meaning are imported and inferred by the *role* of the syntactic representations (Greenberg & Harman 2006).

Conceptual role semantic theories explain how the roles of the representations determine the meaning and content in thinking or internal thought. The *use* of forms of representation is the means for reasoning. The use of these forms includes: perceptual representation; recognition of implications; labeling; categorization; theorizing; planning; and control of action (Greenberg & Harman 2006). For example, an '*aluminum window*' is a syntactic expression or a term for distinguishing it in later operations for a variety of purposes. The actual feature '*made of aluminum*' might have served to label it and further classify it as a metal window element. *Conceptual role semantics* suggest the way in which the label is semantically distinguished from other labeled elements such as the element named '*metal-aluminum windows*'. This suggestion consists of the way they were assigned to be used within the external world. The content of the element '*aluminum window*' enables the actor to treat it as in the *openings* category and as in the *metals* category, when this actor imports the semantic of '*aluminum window*'.
The uses of the syntactic forms determine the meanings and the element's functional aspects. Although not essential or unique, the functional aspects are relevant to the use of the '*aluminum window*' syntactic form.

Harman (2005) brought forward the account of whether an external, referential or truth-conditional theory plays a role in inferring commitments to the representations. Harman's *conceptual role semantic* framework embraces a theory that is internally based for recognizing semantics. Thus, meanings of natural language expressions are determined by thoughts, with which the expression is correlated, and not by truth conditions. The contents of the expressions are determined by their functional role in the actor's psychology. Within the *conceptual role seman-*

tic framework, the meaning of syntactic expressions is determined by the role of the conceptual scheme of the thoughts. The functional role is internal and it has inferential aspects for the actor's reasoning. In other words, the symbolic expressions play a functional role in thoughts for meaning or content. An expression is perceived, internally processed, and revealed through actions. According to conceptual role semantics, the interpreters' semantic import from the symbolic expression consists of their knowledge of how to *use* the expression.

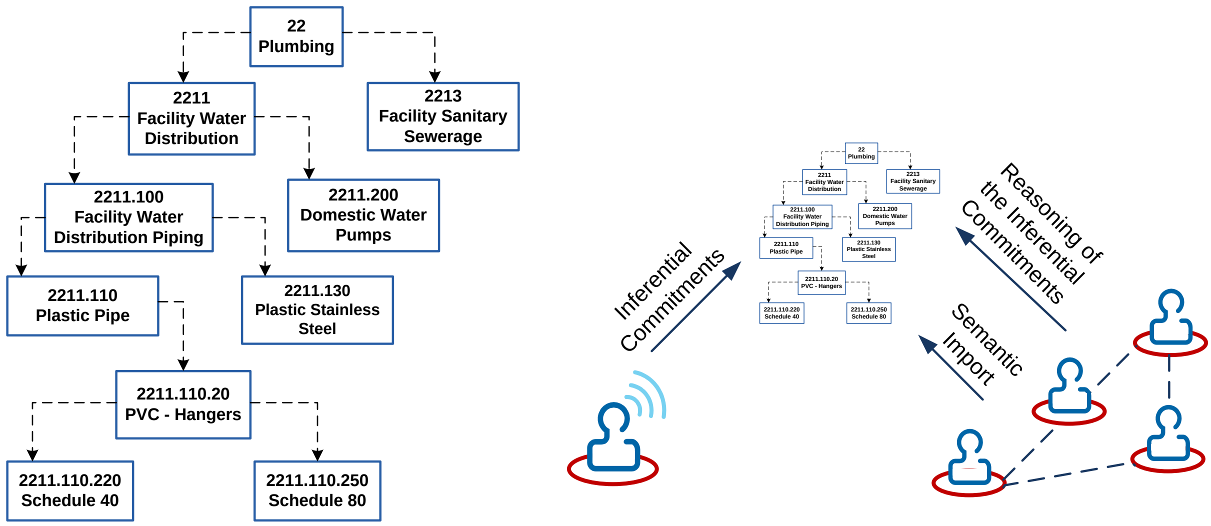
5.2.1 Formal Form Example Taxonomy

Consider the *ad-hoc* taxonomical form to represent construction products in the plumbing category based on the Masterformat standard (CSI 2004) shown in Figure 3(a). These types of taxonomies are typically employed for activities such as estimating or planning. A taxonomical form of representation is a set of syntactic forms organized within categories based on a particular area of knowledge. As in shown in Figure 3(a), the taxonomy represents a hierarchy of plumbing products. This taxonomical form has relationships, properties, and objects, which organize knowledge for activities. In the example and from Figure 3(a), these activities are the estimating and planning of the plumbing in a facility.

Under the *conceptual role semantic* view, in building or in conceptualizing the representation, the assumption is that the actors make inferential commitments to representations that correspond to certain construction concepts. The organization of properties, relationships, and objects in a representation such as the taxonomical hierarchies correspond to the conceptualization of the representations. These conceptualizations are the inferential commitments of the source. The actor who generates the taxonomy, such as the estimator, makes inferential commitments to the representations so that the taxonomy conveys semantics to be imported by the interpreter. An illustration of the generation of inferential commitments and interpretation of the semantic import is shown in Figure 3(b).

The representation is tantamount to "languages of actors' thoughts." In this example, these thoughts are *formally* represented through a taxonomical form that organizes knowledge, so that the representations convey semantics to be imported by the interpreter. The natural language terms shown in the taxonomical representations are syntactic forms *per se*. The relationships between the terms have automatic *inheritance* features, which can be interpreted as free path for *inferences.* The resulting terms from the breakdown are the actors' inferential commitment to the representations. According to the selected features of the knowledge domain, the source evaluates the multiple sorts of properties, functional aspects, and other features. The purpose of that is to make inferential commitments to the terms and the relationships to the taxonomy. In Figure 3(a), the actor-source made an inferential commitment in contrasting different *PVC* types based on their different pressure classification, *Schedule 40* and *Schedule 80*. Thus, this taxonomical form mediates to enable reasoning on inferential commitments by representing products into classifications through properties and other functional aspects.

The resulting form of representation must bear some relationship to properties, objects, or situations in the external world by virtue of that domain nature, in this case, construction-plumbing products. These relationships do not imply correspondences of the concept to the physical world as true conditions. The '*PVC-Hangers*' label in the taxonomy of Figure 3(a), does not imply that the interpreter will physically find *PVC* pipes and *hangers*.
The *hangers*, for example, can be made from copper, plastic material, or stainless steel. The relationships are *common* set of properties, objects, or situations that are shared and, in turn, perceived by a group of actors, such as construction project participants. The representation serves as a vehicle for reasoning regarding the inferential commitments that the source made. The representation conveys meaning from the source. The set of properties, objects, or situations that are contained in the taxonomical representation serve as common domain vocabulary for project participants. However, the resulting representation is not grounded to the external world; instead, the resulting representations contain the inferential commitment made by the source, or in order words, the translation to a taxonomical form from the author's thoughts.



(a) Taxonomy of piping concepts based on Masterformat 2004.

(b) Inferential commitments to the representation, reasoning, and semantic imports

FIG. 3: Formal form taxonomy example.

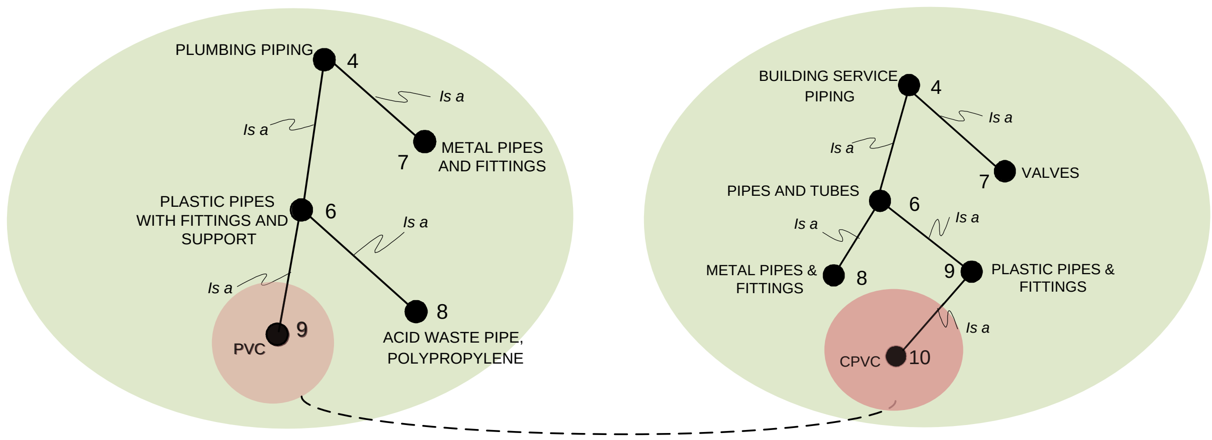
Since the representation serves as a vehicle for reasoning regarding the inferential commitments the source made, the interpreter, a human actor, reasons on such commitments through common sets of relationships and vocabulary contained in the representation. The reasoning on the taxonomical form will result in the semantic import of the set of objects, properties, or situations from such representations. The question is how the representation should be formalized in a way that the reasoning to perform semantics imports is facilitated, and what is required to convey the expected meaning from the source. Introducing the *conceptual role semantic framework* contributes to the understanding of what is required to facilitate these inferences and the elements for reasoning on semantic imports from the symbolic expressions.

A close observation of the syntactic expression *PVC-Hangers* of the taxonomy suggests that the expression conveys limited meaning if the role of inheritance is not taken into consideration for reasoning. In other words, the interpreter attempts to perform semantic imports of the syntactic expression *PVC-Hangers* only in isolation from the whole taxonomy. The *aggregation* role of the *PVC-Hangers* expression is also missing. A further explanation of the *aggregation* role that is expressed in the label *PVC-Hangers* of the individual type of material PVC and of hangers as object will facilitate the semantic import of the expression. The relationships between the object-properties of *PVC* and of *Hanger* as object are missing. A further explanation in natural language of the *PVC-Hanger* aggregation role will facilitate the semantic import of this expression from the taxonomy. After inferring the semantic import from the expressions, the interpreter should know how to *use* the expression. As such, the interpreter perceives internal processes, and reveals through their actions the symbolic expression. Syntax expressions contained within representations lack of mechanisms to semantically describe the inferential commitments. This problem is exhibited with the different pragmatic uses of syntactic expressions.

5.2.2 Semantic Reconciliation Example

Symbolic expressions play a functional role in thoughts for meaning or content within the conceptual role semantic framework. Therefore, this example illustrates the semantic reconciliation of representations through its role. The approach relates (1) the inferential commitment of the source to the representations, and (2) the semantic import by the interpreter. The assumption is that if the internal role of a representation is recognized, the treatment of inferential commitments can be facilitated, revealing important aspects of the meanings in order to provide proper understanding during the transition from the source to the interpreter.

Figure 4 shows two sections from two different taxonomies, T_1 and T_2, as representations of classifications of construction products. The classification of Figure 4(a) is the one that is generated by the source, and the classification of Figure 4(b) is the one of the interpreter. These classifications are two organized lists of natural language terms originated by different sources.



(a) Source's representation *(b) Interpreter's representation*

FIG. 4: Mapping of two sources of information.

The sections shown are parts of two taxonomies that characterize elements of piping components used in buildings. As the taxonomies correspond to different sources, each one of the sources classifies the terms through their own inferential commitments. The inferential commitments take into account the *role* played by item's semantics that are defined in the classification. The role enables these items to build a relationship between them, which in turns facilitates the reasoning of the inferential commitments. The semantic inference that was committed in the taxonomy is present in the representation as part of the role of the taxonomy items. In other words, the source and the interpreter classify the piping components into representations according to their own perspective. Under the *conceptual role semantics'* view, however, the inferential commitment should take into account the *role* that serves the item's semantics to be defined into the classification. The role enables these items to build a relationship between them.

The interpreter in the example, such as a specialty engineer, wants to relate two concepts of the taxonomies shown in Figure 4 to find semantic reconciliations. The elements of T_1 and T_2 represent the concepts of piping components used in buildings. The concept from the source is syntactically represented as '*PVC*' in node 9 of T_1, denoted as (9,T_1). '*CPVC*' in (10,T_2) is the concept from the interpreters' representation. In general, this is the case when the specialty engineer integrates information concerning building components from other sources. As the semantic reconciliation is required between these two taxonomies, mappings from one source, T_1, to the other source, $T_{2,}$ need to be executed. For this purpose, the specialty engineer analyses the semantic inferences of the taxonomy from the source, T_1, and imports their semantics. The actor, as the main form of reasoning to find semantics, bases his or her reasoning on contrasting the *similarities* of the syntactic expression from their own representation and from the source.

As shown in Figure 4, finding *similarities* is possible through contrasting syntactic expressions with the purpose of establishing syntactic relations among the compared items. The actor contrasts the form of representations, expressed as a 'syntactic' form, through a *similarity* relation. Contrasts are performed between the nodes. Node 9 of T_1 has a syntactic content of 'PVC' and node 10 of T_2 whose syntactic content is 'CPVC'. There is no syntax equality between 'PVC' and 'CPVC'. However, if a syntactic relation of similarity is established, it does not give *consistent* results on equating the semantics of the compared items.

For clarity, *similarity* and not *equality* relationships between nodes and their syntactic expressions are the ones that are attempted to be found. In importing the semantics of the represented concepts from the taxonomies, they cannot be equated but they can be associated. As the roles of each one of the structures of the taxonomies differ, the question is what needs to be taken into consideration to perform such associations. The core answer to this challenge is to find the semantic inferences represented in source. The semantic inference that was committed in the taxonomy is given by the role of the taxonomy items. Asserting a correspondence implies the identification that the 'PVC' concept has a semantic role in T_2. The content of (9, T_1) has a conceptual role in T_2. Note that if the correspondence between these two taxonomies is established, this relationship does not consist of mapping 'PVC' of (9, T_1), and the content 'CPVC' of (10, T_2). It consists of importing semantics of the 'PVC' to the system of T_2, which must describe the semantic role of that system.

There is no implication that two nodes similarly marked by the same syntactic forms have the same semantics. The syntactic forms are not used to name them as similar. Under *conceptual role semantics*, 'semantic similarity' is given by the role played by the distinct markers or syntactic forms. In the example, if a correspondence is made from the content 'PVC' of (9, T_1), and the content 'CPVC' of (10, T_2) the correspondence conveys information about the semantic role of node 10, but the semantics has to be given in terms of the role it plays within the concept represented in the taxonomy of node 9.

For further illustration of the plausibility of *conceptual role semantics*, consider other highlighted components or nodes in Figure 5. Under *conceptual role semantics*, a consistent result on the semantic of a representation is definable if the *set* of terms that has inferential roles from inheritance properties is taken into consideration. There is not a consistent semantic definition if the terms or components of the representation are considered in *isolation*. The role of using the components of the representation is not clearly defined if the set is not considered.

In Figure 5, the semantic definition of (9, T_1), 'PVC', and that of (10, T_2), 'CPVC, is not consistent if their roles, applied from T_1 into T_2, are not identified. The set for T1 and T2 is shown with the highlighted color in Figure 5. Finding the role that (6, T_1) and (9, T_1) plays, involves the set of syntactic contents of 'Pipes and Tubes' (6, T_2), 'Plastic Piping & Fitting' (9, T_2), and 'CPVC' (10, T_2). Therefore, the interpreter contrasts the role of aggregation of 'PVC 'of (9, T_1) into 'CPVC' of (10, T_2). The aggregation role implies: "inclusion of all pipes and accessories of *polyvinyl chloride resins* (see Figure 5)."

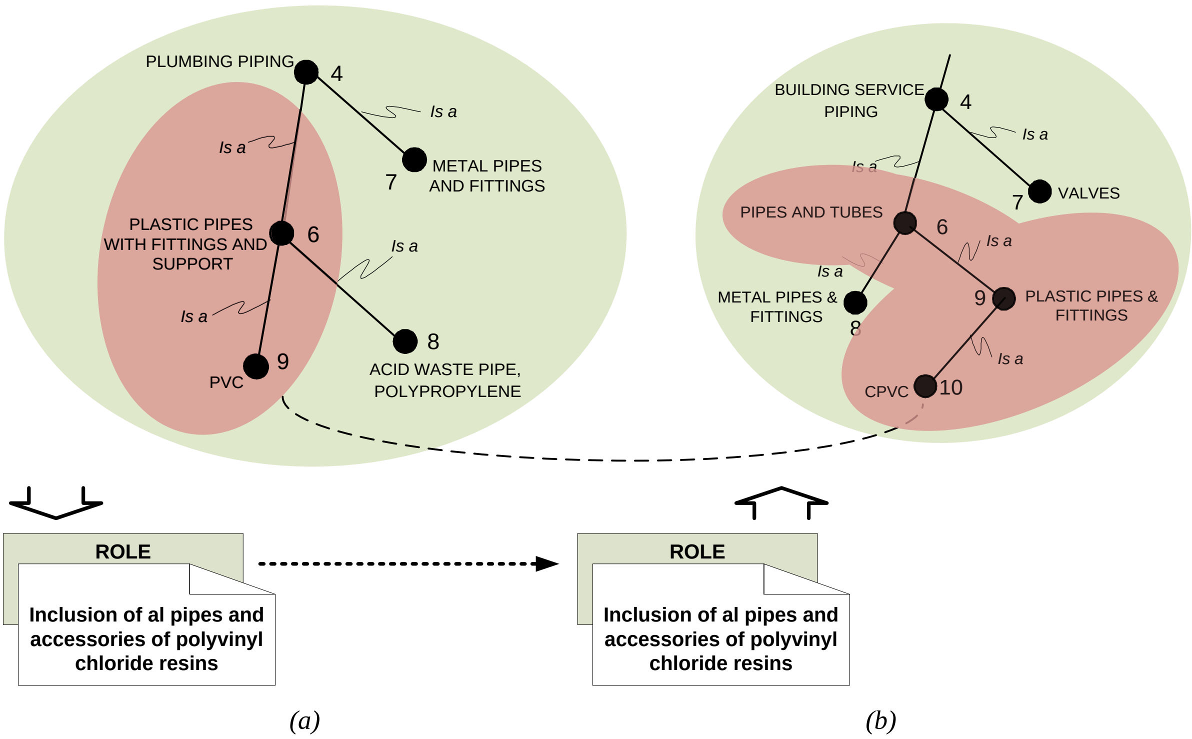


FIG. 5: Semantic reconciliation through the role of representations.

The interpreter asserts similarities between (9, T_1) and (10, T_2) when the inferences provided from the aggregation roles from T1 play a similar role in T2. The inclusion of all pipes and accessories of *polyvinyl chloride resins"* can be considered the same for both taxonomies. It can be observed that the role of aggregation cannot simply be defined by a mathematical function as a subset of the taxonomies, denoted as ($9 \supset 6, T_1$) and as (($10 \supset 9$) $\supset 6, T_2$). Further interpretation of natural language such as the interpretation of the expressions '*fitness and support*' as accessories is required. The identification of the role to semantically reconcile two representations, therefore, can reduce inconsistencies to the harmonization.

In summary, the understanding of the functional roles should provide the interpreter elements for reasoning on the representation to import its semantics. The social role is essential to perform semantic imports. As was discussed previously, finding similarities between one or two nodes through syntax does not result into consistent semantic imports. With conceptual role semantics, the importance of role of the social component, shown and explained within the second tier of the framework of communication (see Figure 1) is recognized. Solving reconciliation of sources of information to communicate the content of representations of concepts through their functional uses is an approach that contributes to communicate the intended semantics as a medium or vehicle of meanings among social actors.

6. CONCLUSION

The current investigation suggests that there is no exact classification, axioms, models or rules that define concepts for the construction community. The description of concepts into some form of representation does not guarantee the understanding by other members of the community of what is described, since the members have different backgrounds, theories and views, including vocabulary used. The developers' and actors' construction of the representation of concepts may be based on different choices in categorizing concepts and different forms to name the same concepts. Semantic reconciliation problems will be encountered in interrelating sources of information through sharing, exchanging and integrating information.

We argue that the meaning of a fixed set of axioms, which defines classification, models and rules, cannot be "fixed" true. The creation of categories from the physical world assigns "fixed" conceptualizations. Therefore, the conceptualization of construction concepts should follow the same evolutionary line. Models are expressions that embrace symbols that characterize an objective reality in the world. However, models cannot hold truth characterizations; they state axiomatic relations under a set of assumptions.

The fragmentation of the AEC domain hinders its characterization within one single model of reference, as the construction industry is also dominated by concepts that overlap with other industries. In addition, the ability of developers and domain actors to reach consensus is hindered by the actors' heterogeneity and the project's fragmentation conditions. Within this perspective, there is a significant problem for communicating meanings of concepts in the construction domain, as well as the modus operandi for the representation of these concepts.

At the same time, meanings depend on the level of understanding of the interpreter. The meanings of what is represented are adjusted by subsequent interpretations within the actors' mind. This research suggests studying the actor-representation relationship to supplement approaches of models, schemas, or conceptual models. As a result, this research shows the need for human intervention for activities that involve sharing, exchanging and integrating information. As was presented in the paper, the study of reasoning for reconciliation implies the inclusion of the relationship between the construction project actor as a cognitive agent and the explicit forms of representation. Once an examination of the complexity of reconciling two forms of representations has been performed, human intervention from a domain expert is needed for reasoning with the objective of finding semantic associations. Deciphering and reasoning for associating each one of the structures is a complex task even for experts in the field. In addition, associating semantically two or more nodes from one to the other structure does not imply an accurate association if they are syntactically expressed as similar. The actors' semantic positions and the representations' vagueness are other aspects to consider for identifying closer and similar, semantic associations between two data structures, schemas, or models.

We do not deny the usefulness of models, such as parametric models and other BIM standards (IFC), but we contend the defectiveness of them to fully express semantics. Evidence of this problem was presented based on semantic reconciliations. By incorporating theories and strategies from other sciences, this study introduced Conceptual Role Semantics and presented a case example to illustrate a methodology that addresses the complexity of the semantic reconciliation process. Conceptual role semantics is a strategy that focuses on the actor or interpreter and the representations. There should be further research that addresses the challenges on understanding the cases of failure to adopt the actors' semantic positions and of the vagueness of the representations when they fail to characterize what they refer to. It is anticipated that in focusing on strategies that investigate the existing relationships between the representation and the interpreter significant contributions will be made in activities involving exchanging, sharing, integrating information, and communication assisted by contemporary information technologies.

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