FRAMEWORK FOR INTERPRETATION OF CONSTRUCTION CONCEPT REPRESENTATIONS

By

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To my family,

Roberto, Lucia, Aura, Adriana, and Hernan Mutis

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Construction actors have the ability to operate regularly and concurrently on ongoing activities with other actors, or to interoperate, during the project life cycle. They socially interoperate according to particular situations and project needs, once they have identified their needs for interacting with others by manipulating or computing the information. The elements or products of the interoperations have the quality of *information*. Actors interoperate through the exchanging, sharing, transferring, or integrating of information. However, actors on construction projects experience interoperability problems that increase the use of resources, raise projects costs, and intensify the complexity of the project.

As a consequence of these interoperability problems, the construction industry has concentrated its efforts on finding new methods for exchanging, sharing, transferring, and integrating information. These efforts advocate that interoperability is possible through the use of logical models to share common domain concepts in a conceptual model. Logical models have an advantage based on the efficiency in accessing the model. These efforts fail to derive a common model due to the significant fragmentation of the domain, the multiple views of the

participant's, and the combinatorial explosion that is achieved when one attempts to define the relationships among construction concepts.

Our research develops a systematic approach that aids construction participants in identifying the potential inconsistencies of the information within the interoperation. This strategy facilitates the construction project actors in the acknowledgement of their misconceptions concerning the observed information. The strategy establishes a framework for reducing errors produced from the assertions or conclusions about the observed pieces of information. This framework addresses the need of a mediation mechanism in interoperability. The framework brings the necessary elements to interpret the information supplied from other participants in a project. The mediation mechanism reacts as a source of verification of the construction concepts employed in the interoperability activities.

Our strategy focuses on a semantic interoperability step, which is the *understanding* of the information representations generated from different parties. The research scrutinizes the *interpretation* of the representations performed by an actor as a cognitive agent, by searching for the understanding of the *fundamental elements* involved within the *actions of interpretation.* The purpose is to bring into existence a strategy that aids the actors in reducing the time, the resources, and the errors generated during their interpretation operations.

CHAPTER 1
INTRODUCTION

Interoperability in a Construction Project

Many specialized and professional teams concurrently perform tasks in capital intensive and complex construction projects. These dynamic relationships demand more cost-effective interactions in the manipulation of the information used in projects and it has pushed actors to find strategies for the faster manipulation of the information they share with others and at lower costs. The manipulation of information with others takes place through the actions of exchanging, sharing, transferring, or integrating of information. The information they manipulate is a set of information packed in forms of representation. The *process* of exchanging, sharing, transferring, and integrating of information from multiple sources is called interoperability.

In the construction industry, project actors also have the ability to interact with other actors, or to interoperate. They regularly and concurrently intervene within activities, or interoperate, during the project life cycle. This interoperation takes place at any time on demand during any construction activity.

Construction participants have long attempted the development and deployment of information technologies as mechanism to deliver productivity and efficiency to interoperate throughout the life cycle of their projects. Actors interoperate through any role played in a construction project. These roles are not only dynamically played within the organization but also dynamically played with external agents.

However, within the process of exchanging, sharing, transferring, or integrating information, project actors experience significant problems that increase the use of resources, raise the costs, and intensify the complexity of a project. Roughly, the practical problems are lack of coordination, inconsistencies, errors, delays, or misunderstandings. As a consequence,

efforts in the construction industry have been focused on finding efficiency as well as economy for exchanging, sharing, transferring, and integrating information. The efforts have been exerted in finding new techniques or methods for these operations. The purpose is the reduction of time, resources, and errors within the interoperability activities with the objective of overcoming the lack of effectiveness as well as their costs.

An assumption of the construction industry is that the adoption of strategies that employ existing technologies will significantly reduce interoperability problems. The adopted strategies are various and include (1) designing standards, models, and conceptual models in a consensus approach --e.g. Industry Foundation Classes IFC and aecXML (IAI 2005)--for exchanging, sharing, and transferring, (2) designing mappings for integrating information from different sources (Amor 1997; Amor 2004) (3) and semi-automatically mapping disparate sources (Katranuschkov 2001).

However, multiple problems have pervaded the efforts within the strategies adopted by the community. They range from the impossibility of reaching consensus on evolving standards, the differences on the levels of systematization or sophistication of the construction participants' systems, to the methods of representing information (Partridge 2002). In addition, another significant problem is the existing differences in the representations of information generated by dissimilar, independent sources in spite of their use of the same conceptual model for generating the representations. These differences, for example, are evident in the levels of detail among representations that were generated from different actors.

As our research recognizes the multiple problems that pervade the community efforts, it also *identifies* failures in addressing the inherent paradigm that hinders interoperability. The paradigm that needs to be addressed is semantics within interoperability or semantic

interoperability, which is based on the understanding of what is represented within the information generated by other domain agents. Thus, the agents' abilities in exchanging, sharing, transferring, and integrating the *meanings* of information are the goals of semantic interoperability. This research explores this paradigm and proposes new insights for the construction domain.

Limitations of Current Information Representations in Supporting Interoperability

The information supplied by external project sources such as regulations or legal standards or by internal project sources such as budgets, contracts, and schedules is conveyed in dissimilar documents. These documents are sets of information packed in a different form of representation. The focus of interoperability is to address the information about construction projects that is generated by different sources. The forms of representation of the information consist of construction documents. Construction participants convey the information concerning their activities though the life cycle of the project. The content of these documents are characterized by employing either human readable, paper-based forms or by employing human readable, computerized forms.

A common misconception concerning the documents represented in computerized forms is that they can be exchanged, shared, transferred, or integrated without any human intervention or manipulation in the process. The description of information through representations in computational systems does not guarantee continuous, workflow scenarios among construction project participants. The information described by computers is "displayed" in human readable forms in the actors' systems. Within the semantic interoperability paradigm terms, computers *mediate* for *representing a concept*. Computers serve as *mediation* mechanisms by transforming and computing a representation of construction concepts from computer readable forms to human readable form. Information is taken as representation of the concepts of a domain in the

semantic interoperability arena. A concept is an abstract, universal notion, of an entity of a domain that serves to designate a category of entities, events, or relations.

The fact that concepts are represented through the employment of computational systems does not indicate that the information could *automatically* be processed within other actors' systems, or in other words, automatically be exchanged, shared, transferred or integrated within other project participants. The representations of construction concepts are transformed and computed through the actors' systems. An automatically interoperability activity such as exchanging or integrating of information requires a priori, complex, agreements among the agents, concerning the syntactic forms, agents' physical and social environments, and agents' context related to their intentions and purposes.

In the simplest interoperability case, by employing human, readable, computerized systems, the representations generated from one actor's sources are "displayed" when they are mediated in another actor's computational systems. The operations over the representations are limited to storage, reproduction, sharing, distribution or exchanging with the objective of being "displayed" in each of the construction participants' own systems.

This investigation recognizes that the role of actors within the interoperability activities cannot fully be eliminated by performing computations on the forms of representations. The technologies that the actors employ serve to assist them in computing and transforming machine to human readable forms in these interoperability activities. In the actors' systems, some computations can be performed for completing an interoperability activity. However, the technological *assistance* in the actors' systems does not indicate that there is a full replacement of the need for the actor's intervention in the manipulation of the representations. The benefits of employing the technologies for computations are the facilitation of elaboration of the

representations in construction participants' systems, fewer inconsistencies and errors, and easy manipulation for storage, reproduction, sharing, distribution or exchanging.

The Case of Integrating Information for Interoperability

Construction projects are common, physical environments where actors socially interact for *integrating* their information, according to particular situations and based on particular project needs. Once project actors have identified their needs for interacting with other actors' information, they process the information by manipulating or computing it in their own system, or, in other words, by integrating the information. The requested information from other actors is related to the purposes and to the intentions within the agent's context for interacting with them. One aspect concerning the integration activity is that the actors' manipulations of the representations of information cannot *fully* be replaced by computation. For example, one construction participant cannot integrate his/her schedule into another actor's schedule for the purposes of optimization of time or of resources. They need to *interpret* and re-elaborate the other party's schedule, even if they follow the same conceptual model for structuring the schedules. The actor that performs the integration needs to interpret the schedule that can be expressed in a form of representation such as tables, structured database schemas, or electronic files. The representation of the schedule is displayed in human readable forms through the computer systems in order to be manipulated.

The *integration* of information as an interoperability activity is known as the processing of the information into other actors' systems. In construction project scenarios, the *integration* is a process where one or more documents or forms of representation from other actors are requested in order to be employed in different actors' systems. This information can be represented through tables that follow structured conceptual models, documents assembled in markup languages (e.g.

XML), and through documents in natural language built in CSI standards (e.g. Masterformat), among others.

It is important to note that the construction research community has recently exerted major efforts in attempting to solve the information integration problem. Their efforts are targeted at supporting many modes of communication and collaboration on all projects with the purpose of aiding processes involved with computerized systems, or Information Technology (IT) (Amor 2000). The objective is to work on methodologies on achieving automation in processing one actor's information within another actor's systems.

Since fully automatic interoperability with the representation is not feasible, human manipulations on any form of representation are part of the process. There is an explicit relationship between the actor and the representation that is further analyzed in this study. As was mentioned concerning the manipulation of representations within the schedule example, one of the actions is the *interpretation* of what is represented in the paper-based or computer-readable forms by one or more actors during the interoperability activity. Although interpretations are mostly cognitive operations, there are fundamental aspects addressed in this research for advancing the understanding of the semantic interoperability paradigm. The following section of this chapter presents a further explanation of this point.

The Interpretation Step

The study of '*understanding*' the information generated by other agents involves the *interpretation* step of the meanings of the manipulated information. What has been named as information is taken as representation of the concepts of a domain in the semantic interoperability arena. The *interpretation* step moves our analysis to inquiries concerning how a construction participant sees the real world or how he/she maps the views of the world into representations that reflect these views. For this purpose, this research takes into account aspects

concerning the nature of knowledge representation *per se*, the method for characterizing domain concepts into representations, and the act or step of interpreting concepts from other representations generated by other domain agents, among others.

An Analogy of the Interpretation Step

For clarity on the *interpretation* step, a parallel in the process can be illustrated within a speech act theory (Searle 1969). The speech act characterizes what the speaker communicates to the listener by relying on the mutually shared background of the information or contexts and the intention of the utterance. In the simplest case, two actors, a speaker and a listener, participate in a speech act. Thus, when there is an utterance within a communicative act, an understanding of the facts and relevance of the conversation, a setting up of the background information pertinent to the conversation, and assumptions and inferences are needed to capture the intended meaning within the expressed utterance.

In the case of the *interpretation* step as part of an interoperability activity, what is shared among the actors is not an utterance but a representation of concepts. Some actors are the ones that generate the information and others are the interpreters. In the speech act, there is the listener and the speaker. Actors are participants in a construction project, and the project is the environment where the motivated interactions of the actors take place. The actors who share the representations with other peers within the project have a predefined role. The concepts are translated into different forms of representation in order to semantically communicate them and suggest some actions to the interpreter. These actions are the result of the inferences and assumptions made by the interpreter. It is not a requirement for the actors to share the same space or synchronically and deliberately be arranged for performing the interpretation within the interoperability activity, as they are within speech acts. The interpreters identify the intention

based on the representation generated by the sources and assert their meanings. The result of these assertions is the interpreters' commitment to actions based on a particular activity. If it was not possible for the assertion to be executed in order to capture the representations' meanings, additional requisitions of information from the sources will be needed. Within the speech act, the listener asserts and commits him or herself to an action or rejects the utterance when its intention was not captured.

In the interpretation step within the context of a construction project, additional aspects can be taken into consideration for a full commitment to the actions that follow the interpretation. Figure 1-1 is an illustration of this step. When a need emerges for information from other project participants during a construction activity, there is a course of action for requesting the information from these sources.

As shown in Figure 1-1, the actors request information through previously defined and identified channels of information flow. The channel defines the method for requesting and providing information which can be specified contractually between contractors and subcontractors. The form of representation of the requested information can also previously be defined between the interpreter and the source. Alternatively, the interpreter relies on the forms, syntax, and vocabulary of the sources for representing concepts as a viable, readable form for performing the interpretation. Once the actor or interpreter has received the information from the sources, an identification activity of the concepts that has been represented is performed. The identification consists of an analysis of the observed representation in order to perform reasoning for identifying meanings. The analysis is defined by the interpreter's intentional nature that motivates the requisition of information. In other words, the interpreter focuses on the representation sections which motivated the request for information and that are useful for his or

her activity. The interpreter can also further articulate the sections or parts of the representation to complete the interpretation. The reasoning for identifying meanings consists of finding semantic associations from the observed representation within the interpreter's own body of knowledge.

As illustrated in Figure 1-1 if the semantic associations cannot be found by the interpreter for performing an interpretation, the sufficiency of 'details' that describe the representation of the concepts are not satisfactory for the observer. The interpreter or observer searches for additional sources of information in order to find associations for identifying the concepts in the representation. The additional information can be provided by the interpreters' databases, knowledge bases, or even by experts. If the supplied information for finding semantic associations is not sufficient to help the interpreter identify the concept, the interpreter has to request additional information from the sources in order to have a better level of sufficiency for performing the interpretation. This flow of information is shown in Figure 1-1.

When the semantics' associations satisfy the required conditions for the interpretation, the interpreter performs an action as a result of the interpretation. The conditions are satisfied when the intentionality with the observed representations is accomplished or, in other words, when an action can be committed by satisfying the purpose of interpreting the representation. This action is generally recorded in the actors systems, or it is a part of a more complex, subsequent reasoning process by the interpreter, which can be manipulated and calculated.

This research claims that it is not possible to develop fully automatic and integrated technologies for the construction industry in general to provide productivity and efficiency. Human intervention is necessary in some component of the interoperability case. In consequence, strategies that enhance productivity and efficiency for the human intervention component of the interoperability process need to be derived. This research explores and advances the strategies of '*understanding*' the information generated by other sources.

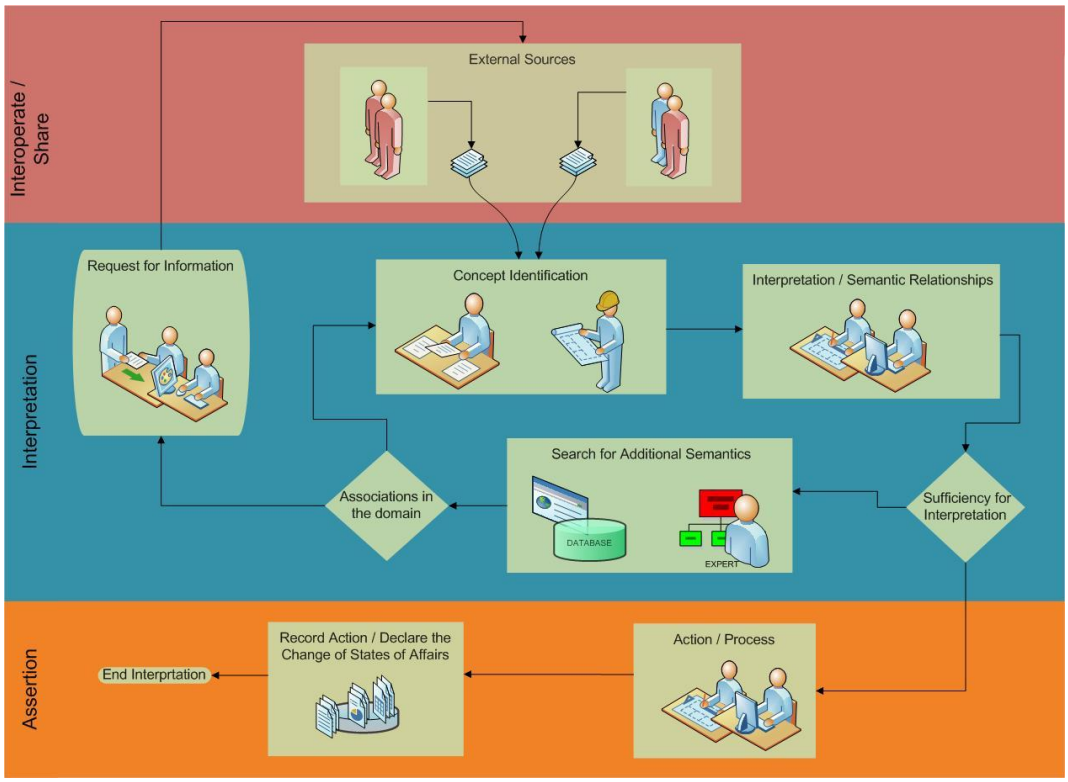


Figure 1-1. Interpretation process.

Practical Problems in the Interoperability Process

As mentioned earlier, the frequent problems encountered in interoperability are lack of coordination, inconsistencies, errors, delays, or misinformation. The exchanging, sharing, transferring, or integrating of information among construction participants is burdensome with their high costs and need for human intervention. The consequence is a reduction in the productivity and efficiency of current interoperability activity.

When actors find these problems in a construction project, they are forced to either partially solve coordination errors, or to totally rework the construction documents. This additional step produces project delays and requires the use of additional resources, as well as producing disruptions in the construction workflow.

In consequence, rework due to inconsistencies, misinformation, or other problems that cause a lack of interoperation can result in project delays. The delays can be propagated throughout the whole set of activities that result in the escalation of the complexity and cost of the whole project.

The following are *motivating examples* that illustrates the dynamic of the problem of interoperability within the construction domain.

Interoperability

Suppose a general contractor (GC) is responsible for completing a large project with tight scheduling constraints. The GC uses cost control to track the schedule progress of the work, to control material costs, and to monitor subcontractor costs. This activity anticipates the intervention of multiple participants, for instance: the GC, a Project Manager, and Subcontractors. Thus, the GC constantly needs to know whether the Project Manager (PM) has enough time according to the GC's schedule to complete a task, say Task A and/or whether there is enough time for subcontractors to complete Task B. Then the GC has to *request* some

information from other construction participants. When the GC receives the information sent or *transferred* from other project parties, he or she *interprets* such information and then *integrates* it into his or her system. With the new information, the GC controls the costs, tracks the schedule progress of the work, controls material costs, monitors subcontractor costs, and is able to perform additional operations as well. For instance, the GC will be able to predict the anticipated costs and the scheduled completion dates, since the cash flow for a particular work package depends upon the corresponding activity's progress.

The GC performs an interoperability activity at a certain time of the project in response to some of his or her needs. The GC's next step is to rely on project control applications that examine tracking of costs, quantities, and resource performances, and that *update* his or her project schedules. This process is *manually* performed. The tracking and updating operation are the result of the GC's interpretation of the information supplied by others actors. The GC interprets the required sections of construction documents that were supplied by these other actors. The GC intervenes in the interoperability process by requesting and integrating the information generated by the PM or Subcontractors. The PM and Subcontractors *share* their information with GC.

There is a disruption in the workflow of the information when the GC intervenes for interpreting and processing this information in the GC's system. The process cannot automatically be performed and the PM's and Subcontractors' systems cannot inexpensively be integrated. The use of human intervention results in project cost escalation and in the reduction of productivity and efficiency. For example, when the tracking and updating operation in the GC system takes place, a re-elaboration of the other actors information is performed, in order to adapt and integrate others actors' information into the GC systems. Other, additional problems

and delays occur when the GC is not able to interpret elements of the other actor's documents for the GC needs. In this case, additional delays may occur in solving the inconsistencies of the other actor's documents which results in a reduction of the GC's productivity and efficiency.

Semantic Interoperability

Semantic interoperability stands for the understanding of what is represented within the information generated by other domain agents. In the previous example, the explained situation is that any subcontractor's resources change as the construction project progresses. The change produces a modification in certain activity durations as well. Subsequently, the GC must manually update his or her schedule and other project control tools associated with the change.

The GC and the Subcontractors are performing interoperability by requesting and sharing information contained in the documents. Figure 1-2 illustrates a flow of the construction documentation of project actors within an interoperability activity. Sharing information, for example, indicates that the documentation is distributed to the actors involved in the interoperation.

The GC needs to fully understand the meaning of description of the resources. It is assumed that the Subcontractor sends the information in readable representation to the GC. In the previous example, the resources are the ones that the subcontractor intends to share and the ones that the GC searches for within the subcontractor's documents. The GC should understand how the subcontractors describe their resources in the construction documents. The understanding of the description implies the comprehension of the meaning of the description of the resources. For example, the GC should understand that a '*compressor, air, dry pipe system*' is a standpipe equipment employed for fire protection in the subcontractor's documents. The GC's understanding of this resource implies that its description within the subcontractor's documents can be associated with the GC's resources description with the purpose of updating any change

of the resource in the project. In other words, the GC observes the resource in the subcontractor's documentation, say Z. Then the GC finds associations to a concept, say Y, which corresponds to the resources that the GC works within his or her system or documents. If the GC is capable of performing these associations, then the GC understands what the subcontractors described as resources in their construction documents.

The GC manually finds these associations. As a further illustration, the reasoning process on finding these associations consists of breaking down the Subcontractor's document and looking for the selected resources that should have represented in these documents. The search is a matching operation of what the GC understands about the selected resource that needs to be updated from its description in the GC's own system and its description within the subcontractor's documents. The matches are found through similarities of syntax of description of the source. If a match is not found, the search process is repeated. In this case, an analysis of the context of the documents can also be included. This analysis consists of observing additional pieces of information within the Subcontractor's documents on a case-to-case basis.

If during the search of the matches the GC finds inconsistencies, errors or lack of syntax details for defining the required resources, the GC is forced to request additional sources of information either from other sources or from the agent who generated the documentation. For example, when the GC needs clarification about the definition of a resource used in the Subcontractor's document, the GC contacts the Subcontractor by fax or telephone.

One aspect to take into account with the example is that the distribution and the representation of the information elaborated with computer do not imply that the interoperation is executed automatically. This interoperation consists of request and sharing the documentation from other sources for updating the GC's resources. The GC should manually perform these

updates and, if inconsistencies or lack of details are found, finding other information sources or contacting the Subcontractors is required.

In summary, the GC needs to manually formalize semantic associations between their information and their Subcontractor's documents in order to keep track of the changes to support good time management and cost-effective activities. The GC should be able to reuse these associations for future updates with the Subcontractor's information.

In construction projects, any significant change of resources, times, or activities should be propagated through multiple construction participants. This type of operation requires coordination efforts among the parties involved. It is easy to observe from this scenario that any sharing, exchanging, distribution, and integration of data among parties should be done in a collaborative fashion and in an efficient way.

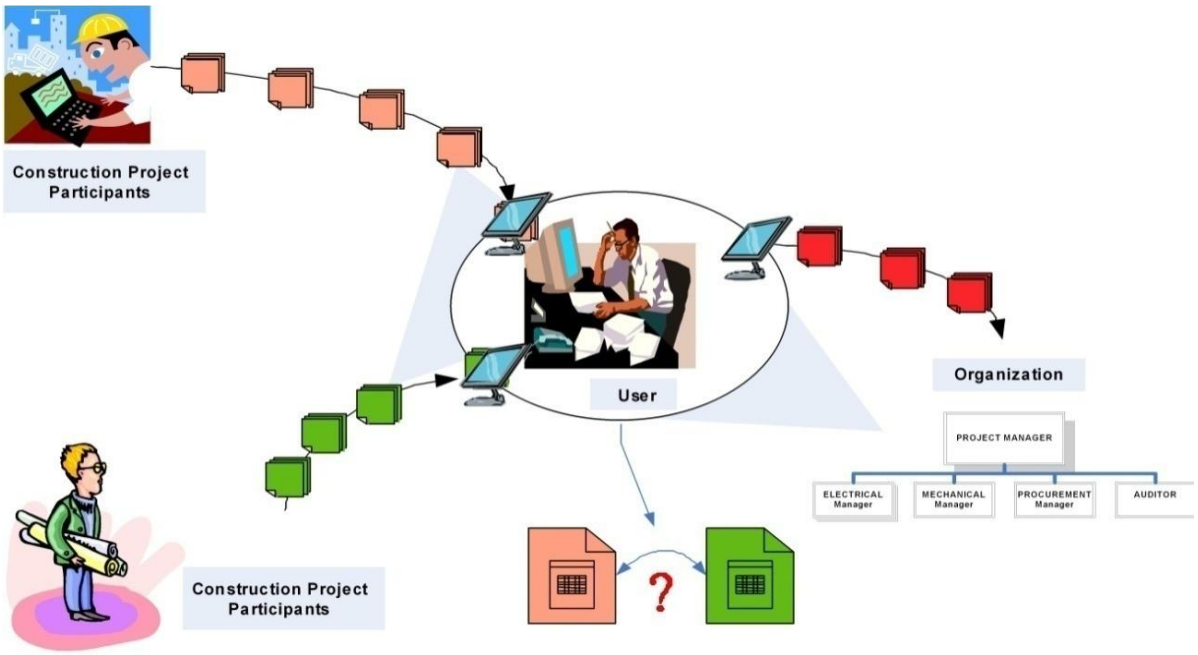


Figure 1-2. Interoperability and information analysis to find correspondences.

A Semantic Syntax Matching Example

The following example involves an actor or a construction participant who is faced with the task of manually resolving a discrepancy between two sources of information. As the reader can notice, this example involves three actors: two subcontractors and the PM. The example illustrates a higher complexity in an information sharing case. The *situation* of the case is a cost estimation process for a construction project which is performed by a project manager (PM). In this activity, the PM requested two estimates from two subcontractors; Subcontractor A and Subcontractor B (see Figure 1-2 and Figure 1-3). The request for information from other sources is a sharing of information operation. As an example, the objective of the PM can be stated as the selection of the most inexpensive Subcontractor based on the cost of the installed linear feet (L.F.) of PVC. Figure 1-4 shows the Subcontractors documents. The purpose of the PM accessing the subcontractors' information is to find the difference between the cost of the two items in each subcontractor's estimate, in order to performing a cost optimization activity.

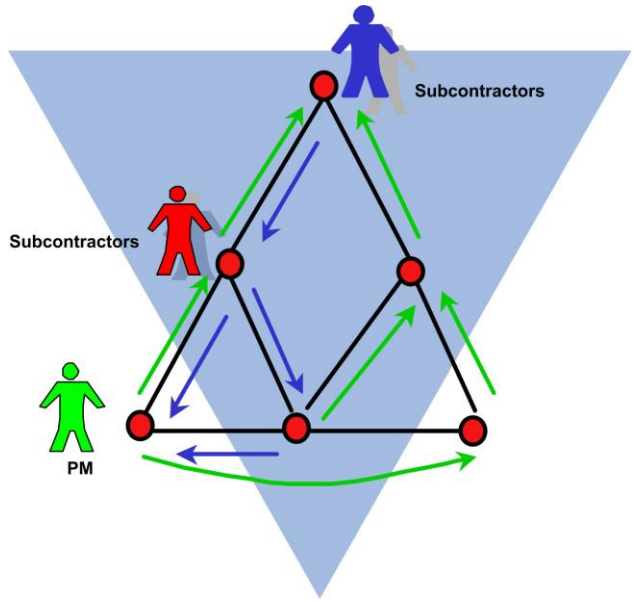


Figure 1-3. Request for information from other construction participants.

Briefly, the reasoning process involved in this interoperability activity can be enumerated as: searching and selecting the item or concept to be estimated in the subcontractors documents, interpreting the concept described in the sources, finding the potential or similar descriptions of the concept by comparing their syntax, finding mappings by comparing syntax or by finding semantic associations between the description of the concepts through the context, evaluating the equivalence of the concepts for the intended cost estimated activity, and, if the evaluation is satisfactory, proceeding with the cost optimization activity.

As the reader can notice in Figure 1-4, the PM should perform a manual comparison of the PVC items for these two sources. The activity starts by identifying the mechanical division Construction Estimating Institute (CSI) Division 15 in the piping section (CSI 2004). The PM identifies the sections within the documents of the sources represented by two tables in Figure 1-4. The reader must take into account the fact that the optimization encompasses tasks concerning comparisons of costs from the two sources.

Tables A and B in the Figure 1-4 consist of a set of tuples (rows), where each tuple has one value that corresponds to each column in the relation. Thus, Table A has the tuple (15.41504, Pipe PVC, SCH 40, 1¼" & Fittings, 16.43, L.F., 7.76, 1.10, 8.88), which allocates the value "15.41504" to the column "CSI No.", the value "Pipe PVC, SCH 40, 1¼" & Fittings" to the column "Item", the value "16.43" to the column "Unit / H", etc.

In the example, the PM's objective is to find the difference between the PVC pipes costs from each estimate in order to perform a cost optimization activity. Once the PM has identified the syntax 'PVC' pipes by locating them within the document, semantic associations are performed by mapping between these two sources.

Therefore, for achieving a valid comparison in the cost optimization of L.F. of PVC, the PM searches for a set of semantic associations that satisfy consistent similarities between the two tables or sources. The natural question is how the PM interprets that “Units” from Table A corresponds to or matches “Unit” from Table B or how “Item” from Table A correspond to “Description” from Table B, etc. The PM must find the semantic associations between these two data sources. This is less feasible to execute if the PM does not associate the actual values that correspond to each column. The PM can only map the syntax that corresponds to the ‘PVC’ in each table. The PM finds additional semantic relations within the context of these sources such as the units to characterize the PVC in each table. The PM semantically maps instances or values for the columns “Unit” and “Units”, and the instances “L.F.” in Table A which corresponds to “L.F.” in Table B.

The semantic association of the two sources allows the values to be related (“L.F.” from Table A = “L.F.” from Table B. It is important to observe that additional information in the semantic mapping process is needed. The reader, who already has some knowledge of the domain, known as “expert knowledge”, would know that the value “L.F.” means “Linear Feet” and does not have any other interpretation. Thus, the PM only used the syntax such as “L.F.” for semantically mapping the “Units” and “Unit” columns.

In addition, the PM can identify other correspondences of the PVC from the two sources. The PM must find relations between the values of the columns “Item” and “Description” for PVC. Thus, the PM relates “PVC, SCH 40, 1¼" & Fittings” with a possible match “Plastic 1-¼" diameter & Fittings”, and “PVC, SCH 40, 2" & Fittings” with a possible match “Plastic Pipe PVC 2" diameter & Fittings”. If the PM evaluates the consistency of the semantic associations, and finds semantic associations that are not reliable, the PM must verify the descriptions of each

item with the actor that generated the tables by contacting each source by phone or fax. Clearly, this mapping activity together with the interpretation step is a time consuming and inefficient activity especially when verification or clarification of the documents is needed. Interoperability could become an overwhelming activity if the PM needs to find semantic associations from more than two construction participants.

SUBCONTRACTOR A						
CSI No.	Item	Unit / H	Units	Labor	Material	Total
15.41504	PVC, SCH 40, 1¼" & Fittings	16.43	L.F.	7.76	1.10	8.88
15.41506	PVC, SCH 40, 2" & Fittings	6.40	L.F.	11.52	1.53	13.07
15.41542	Pipe Pyrex 1½"	4.44	L.F.	16.60	14.30	30.90

SUBCONTRACTOR B								
Code	Description	Crew	Output	Labor H	Unit	Material	Labor	Total
15108 - 520.4410	Plastic 1-¼" diameter & Fittings	Q-1	42	0.190	L.F.	2.45	7.10	9.55
15108 - 520.4460	Plastic Pipe PVC 2" diameter & Fittings	1 Plum	59	0.271	L.F.	2.65	9.10	11.75
15108 - 520.50	Plastic Pipe CPVC ½" diameter & Fittings & Supports	Q-1	54	0.148	L.F.	2.88	5.55	8.43
15108 - 520.7310	Plastic Pipe SDR 15 100 psi 1½" diameter	Q-1	N/A	15%	L.F.	0.64	N/A	0.64

Figure 1-4. One-to-one matching.

Summary

The common practice concerning the generation of information for construction projects is that the construction participants create their information independently rather than in a collaborative environment. There are no a priori agreements or coordination on the automation of the interoperability activities. These agreements are complex and expensive to achieve. Agreements for automation on interoperability activities should address characteristics of the construction participants' network on their social and physical contexts, which require the

understanding of the forms of representations, such as syntactical forms and domain vocabulary, the conceptual model, the intentional conditions, and additional properties of the employed construction concepts. Therefore, strategies of *consensus* such as *a priori* agreements or as standards over the content of what is described within the information will not guarantee an effective and productive interoperation.

The construction industry seems to be focusing on finding other strategies for *integration*, for *mapping* or for *consensus* rather than strategies for '*understanding'* the information generated by other construction participants. This research claim that strategies for an *understanding* of what is going to be added, processed, or manipulated should primarily be addressed.

In this research view, the strategies undertaken by the community will not provide solution for fully automatic and integrated information workflows. Since these strategies, including others for integration and for mapping, for achieving consensus are not feasible, actors in construction projects are forced to *manipulate* the information. As the fully automatic interoperability with the representation is not feasible, the manipulations on any form of representation are part of the interoperability process. The manipulations involve an *interpretation* step performed by the actor or construction participant, One or more components of the interoperability process demand *human* intervention.

A strategy for improving the efficiency and productivity of the human intervention is needed. The research identifies the interpretation step of observed representations as the paradigm for defining a framework with the objective of achieving efficiency and productivity within interoperability. In this framework, this research addresses fundamental aspects of the *interpretation* step of what is represented in the paper-based or computer-readable forms that significantly advances the understanding of the semantic interoperability paradigm.

CHAPTER 2
RESEARCH INQUIRY

This chapter outlines the line of inquiry explored by this research. It also describes the spectrum of the undertaken paradigm within the construction domain, the specific assumptions that bound the problem, the contributions and implications to the construction community, as well as the research questions that further define the context and the objectives of this investigation. For an illustration of our research inquiry, Figure 2-1 shows a roadmap of the main research steps as well as the proposed strategies taken for solving our research questions.

From the Problem to the Research Initiatives

Construction project actors have the ability to operate regularly and concurrently on ongoing activities with other actors, or to interoperate, during the project life cycle. The elements or products of the interoperations have the quality of *information*. They interoperate through the exchanging, sharing, transferring, or integrating of information. However, within these activities, agents of the construction projects experience problems that increase the use of resources, raise the costs, and intensify the complexity of the project.

From the two examples cited in Chapter 1, one notes that interoperability embraces multiple steps and requirements in order to be made possible. As a consequence, the research community has centered its efforts on finding new techniques or methods for exchanging, sharing, transferring, and integrating information. The trends of these approaches have been that construction concepts are represented by symbolic representations for their implementation on database systems or knowledge-base catalogues. This form of construction representation of the concept facilitates data storage and retrieval, and results in better system efficiency. However, the classification method used to categorize the representation fails to define the concept at an

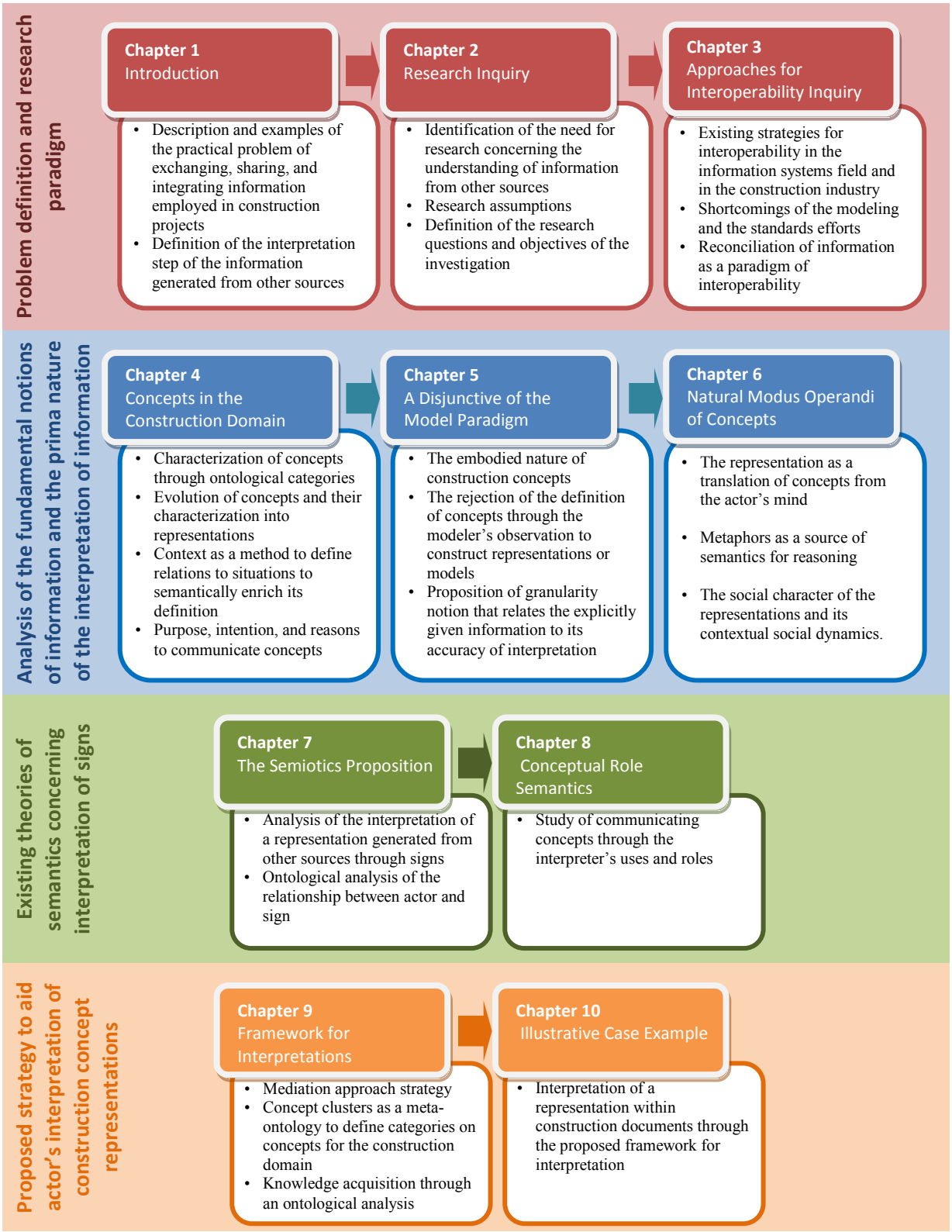


Figure 2-1. Research roadmap.

accurate level of detail. This fact raises questions about consensus obsolesce or the usefulness of the method to represent the construction concept representations. Other efforts advocate the use of logical models to share common domain concepts in a conceptual model. The use of a logical model gives an efficiency advantage in accessing the model. However, these efforts fail to derive a common model due to the significant fragmentation of the domain, the possible multiple views of the participant's, and the combinatorial explosion that is achieved when one attempts to define the relations of concepts.

Our research focuses on a semantic interoperability step, which is the *understanding* of the information representations generated from different parties. The research scrutinizes the *interpretation* of the representations performed by an actor as cognitive agent. This research also quests for the understanding of the *fundamental elements* involved within the *actions of interpretation.* The purpose is to bring into existence and to assemble a strategy that aids the actors in reducing time, resources, and errors within their interpretation operations. The quest for *efficiency* as well as for *economy* of these operations is the motivation of our present research efforts. The purposes of these efforts are the reduction of time, resources, and errors within the interoperability activities.

There is a need to develop a systematic approach that aids construction participants in identifying the potential inconsistencies of the observed information. The systematic approach guides the actor to interpret the information in the construction documents. This need is a motivation to design a strategy that allows construction project actors to recognize that they are missing elements concerning the observed information contained in the construction documents. The strategy is an incentive for establishing a framework for reducing errors produced from the assertions or conclusions of the observed pieces of information. This strategy has to respond to

the need for a mediation mechanism in interoperability that aggregates the necessary elements to interpret the information supplied from other construction participants in a project. The mediation mechanism has to react as a source of verification of the construction concepts employed in the interoperability activities.

Fundamental Inquiry Assumptions

It is clear that the interpretations are executed from previously elaborated representations by other construction participants. These representations are described in the construction documents as well as characterized by employing either human readable, paper-based forms or by employing human readable, computerized forms. The description of these representations in computational systems does not guarantee continuous, workflow scenarios among construction project participants. The information described by computers is "displayed" in human readable forms in the actors' systems.

An important assumption to outline is that information is taken as representation of concepts of a domain. The domain is defined by the areas or disciplines involved within a construction project and whose agents participate in interoperability activities within the project life cycle.

Outline of the Theoretical Propositions

Our investigation searches for explanations of the limitations of current representations of information used for interoperability. The purpose is to illustrate the spectrum of the representation problem and to suggest an additional overlooked step. This step is based on a novel way to see the problem supported by semantic associations of a representation. The objective is to acquire an understanding of the role of semantics through representations, and to conduct an analysis to visualize the semantic representations for ambitious challenges like integration or collaboration

This investigation aims at understanding the fundamentals of the problem for sharing, exchanging, or integrating of information. As was explained, the focus of the fundamentals of the problem is on the interpretation step of the observed representation.

Information is a broader term used for naming representations, in either human or computable forms, of concepts. Our research proposes the understanding of the nature of these representations through the Pierce triadic relations of (1) quality material or existence of things, (2) reaction to the signs or the conception of being relative to the things which determine the way the sign is related to its object, and (3) representation of the things or the interpreter's mediation through some formal rule that associates the observed sign to an object (Peirce 1991).

Also, this investigation advocates the employment of construction concepts as a main form for semantic operations within sharing, exchanging, and integrating information. Therefore, our study suggests as a postulate that the employment of concepts defines the *modus operandi* through interoperability.

Objects and Research Questions

As was mentioned in chapter 1, the search for efficiency and for economy in interoperability with construction documents is the *motive* of this research. The need for actor intervention in interpreting the construction concepts as an essential piece for creating interoperability is recognized. The action of interpreting is a process that involves the relationship between thee construction project actors as cognitive agents and the explicit information represented within the construction documents. The objective is the exploration of this relationship as the onset of our research efforts. However for achieving efficiency and economy within the identified action of interpretation, a conceptual framework that provides a theoretical proposition for interpreting construction concepts has been constructed. It provides guidance for understanding the phenomenon immersed in the semantic interoperability activity.

Therefore, strategies that search for efficiency and for economy can be designed from this framework.

The conceptual framework is the result of the *analysis of* the fundamentals of information represented within construction documents and *of* the relationship between actors as cognitive agents and explicit symbols or representations. The purpose is to explore *why* and *how* this paradigm represents a challenge to the construction industry community. The objective is to find the conclusions and the discussions as a result of this research. From the resulting conclusions and discussions, the line of reasoning logically follows theoretical propositions that will be stated in our research.

Therefore, the theoretical propositions grouped in the conceptual framework are the pillar of inquiries concerning the motivating aspects of the effectiveness and the economy this research. The conceptual framework provides a scheme for understanding the theoretical proposition within the studied paradigm.

The framework furnishes new insights and a revolutionary contribution to the understating of interoperating with information used in construction projects. The objective is to facilitate to the reader the logic or the theoretical propositions for designing strategies or mechanism for interoperation with the purpose of acquiring the effectiveness and the economy of the interoperability actions. Experiments and behavioral studies can be easily designed for testing the assembled logic by addressing particular relationships from this conceptual framework. These studies can be done through controlling variables or through the direct, precise and systematic manipulation of cognitive agent behavior, such as the reduction on the interpretation time in an interoperation activity. The framework facilitates where to look for relevant evidence in a construction project situation as well as reflecting important theoretical issues.

The reader should notice that searching for efficiency and for economy is the *motivation* but not the *object* of our research. Therefore, our research primarily addresses the understanding of the semantic interoperation action of interpretation which the cognitive agent and the representation of information are involved with. The objective is the construction of the conceptual framework for interpretation of the construction concepts. Therefore, the central idea of this research is to explore the fundamentals concerning why and how the interoperation with construction documents represents a paradigm and how the articulation of the resulting conclusions is possible through a conceptual framework.

A set of case studies are presented as a validation strategy. The case studies are focused on the theoretical propositions exposed in the conceptual framework. The logic relationships of the framework are included within the context of construction project situations. The case studies give the reader the ability to associate the phenomenon of interpreting construction concepts in a semantic interoperation within the context of construction project activities. The reader, then, will be able to identify real life situations when they perceived the logic of the relationships exposed in the conceptual framework for interpreting construction concepts. The case study benefits the reader in understanding the theoretical proposition constructed within the conceptual framework.

The research questions that capture what this research is interested in answering are the following:

- How can an actor effectively interpret what is represented within the information generated by other construction project actors with the purpose of sharing or integrating the representation during a construction project activity?
- Having identified and analyzed the relationship between an actor as construction participant and the construction concepts represented in human readable paper based or computer forms, how can an actor semantically interoperate with an observed representation of the concepts as described in the construction documents?

CHAPTER 3
APPROACHES FOR INTEROPERABILITY IN CONSTRUCTION

Introduction

The *effective* exchange, sharing, transfer, and integration of information are studied within the *semantic interoperability* arena. *Semantic interoperability* can be defined as the *understanding* of the information concept representations by the domain's agents. This paradigm can be approached from two different angles or perspectives: *information systems* and *problem domain*. The former is addressed within the sphere of the *computer science* domain, and the latter is addressed by a particular domain where interoperability takes place (i.e. heavy construction, building construction). The approaches have different input to find semantics.

A solution from the particular domain perspective embraces "informal" methods such as surveys to find semantic definitions. Other mechanisms to find semantic definitions are the prescription of models that structure manageable pieces of work and that are aimed at agents that have the same view of the models (e.g. framework models that propose the breakdown of construction products). Solutions from the information systems attempt to find axiomatizations and models of information (Zúñiga 2001). These solutions use complex algorithms and other tools from fields such as artificial intelligence. These solutions from each perspective have been driven independently by specialists from the domain and from the scientific community. For example, a project participant is interested in how to make other participants *understand* the information furnished by each agent in any interoperability activity, while computer scientists and knowledge engineers are interested in how to model a domain.

This chapter contains a review and an analysis of recent efforts in the construction and information systems domains. It will briefly explain current approaches and strategies from information systems and refer to them with illustrations of the construction domain problem. At

the end of this chapter, this research focuses on the reconciliation problem within semantic interoperability. The reconciliation process deals with finding common semantics about sources of information from different agents. The purpose of focusing on this problem is to enhance the understanding for reconciling sources of information by addressing the reconciliation process for integrating, mapping or merging information. The resulting conclusions define aspects of the fundamentals of information and the knowledge representation paradigms for determining semantic associations between two sources generated by different agents. These aspects will be further explained in the next sections of this chapter. The finding of semantic associations is an action of interoperability with semantics, i.e. semantic interoperability.

Approaches for Information Systems

The term *information systems* is commonly used in the sphere of interoperability literature under several areas of specialization such as knowledge representation, databases, computational linguistics, knowledge sharing, and artificial intelligence among others. This research refers to *information systems* as a non-specific area of specialization. This section presents an analysis of the strategies used within the semantic interoperability paradigm. Two issues to remember from chapter one are the following: First, semantic interoperability addresses the '*understanding*' of information from different actors, and second, information that is used for interoperation is symbolized by *representations* such as visual and textual representations.

As the reader may notice, the interoperability arena examines areas of specialization under information systems that cover different problems. For example, paradigms such as computational performance of the system's actors, communication exchange protocols among agents' systems, and networking and systems distribution are under the interoperability umbrella. This research focuses on the representation of the information rather than on the technologies used to connect agents in interoperability.

In order to represent the 'real world' in the agent's systems, engineers map it into data representations that the computer systems are able to manipulate and process. In other words, data representations are logical, coherent structures of information that are manipulated by computer applications and humans. These data representations could 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 raw representation that does not have any kind of logic arrangement (e.g. an image).

When the structured data representations are organized in a *logical model* that defines data contents and relation, they form a schema. This model defines a pattern of the represented elements of the 'real world' and their relations. A good example is the entity relation method that describes procedures to model a schema in a database arena and which describes entities, data types, relations, user operations, and constraints (Elmasri and Navathe 2000; Garcia-Molina et al. 2002). When schemas are addressed to model a particular domain, they are called conceptual schemas. Conceptual schemas attempt to outline a particular domain in terms of modeling elements, by creating a general characterization of the environment of the domain.

Therefore, from the information system standpoint, engineers or computer scientists endeavor to exchange, transfer, share, and integrate information within a domain by using schemas or conceptual schemas. However, this characterization of the domain by conceptual schemas is challenged with significant problems when an interoperability solution is implemented. These problems appear when a relation needs to be established between two conceptual model schemas elaborated by different agents. For an example refer to Figure 1-3

which shows the efforts within an interoperability process to map two information systems schemas, represented by two tables from two different participants.

In the information system standpoint, it is clear that the main problem to interoperate is to find relations between two conceptual schemas. The problem can be divided into four categories (Spaccapietra et al. 1992):

- *Semantic Conflicts*, which are the conflicts that appear when independent developed data representations do not represent the same abstraction of the concepts of the real world, or when the abstractions overlap;
- *Descriptive Concepts*, which occur when concepts defined in different data representations represent identical concepts of the real world but are described by different properties or attributes;
- *Structural Conflicts*, which appear when the same real world concept is defined by using different modeling concepts in different data representations (e.g. one type of attributes and value attributes);
- *Heterogeneity Conflicts*, which appear when the integration of two types of data representations is attempted (e.g. object oriented and STEP).

The scientific community has no solution for the aforementioned conflicts. The conflicts are derived from the fundamental problem of representing the 'world' using representations. The fundamental problem is built upon philosophical questions concerning the method to represent the 'real world' and on inquiries such as "What exists?", an ontological question; "What should be represented?", for performing interpretations, which is addresses in phenomenology; or "How should be represented?", from the area of epistemology. New sciences like cognitive sciences are aimed at contributing with insights together with philosophy, psychology, knowledge representation, and computer science disciplines.

From the information system standpoint, computer scientists have worked on developing strategies toward semantic interoperability. Although they might not be complete solutions, they are methods that aid in interoperability by integrating, mapping, and harmonizing conceptual

schemas. These strategies can be grouped according to methodologies to harmonize, to integrate, or to map conceptual models (Katranuschkov 2001). The following analysis of current strategies is made in order to understand interoperability approaches. For a better illustration, examples that are found in the construction domain are presented in each strategy. Several of these aforementioned concepts of the construction domain in this strategy are fully detailed in the following section that describes the approaches for interoperability in the construction domain.

A Priori Consensus

This strategy embraces all the standards where the main models of conceptualization are first created and subsequent data models are developed by referring to that created *conceptualization model*. 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.

In other words, this strategy establishes *a priori* how conceptual models represent the information and how it is dictated syntactically and semantically in a logical perspective. A conceptual model indicates the framework of reference where the domain community has formulated their particular definition of concepts and, from this reference a data model. Interoperability participants, information system developers, computer application developers, and others, refer to that conceptual model in order to help structure any concept in the data model. Examples of conceptual models in the construction industry classification are Master Format Standard (CSI 2004) and the IFC models (CSI 2004; IAI 2005).

Data models created under the conceptual models are expected to facilitate the interoperation of information from different actors' systems. Within this logic, data models and

the data representations that fit the data models will assure that the concepts of the domain are represented at least in the same way. The *conceptual models* work as higher layer models from which consistent specific data representation are derived. This consistency builds a framework that diminishes the disagreement over the meaning, interpretation, or intended use of the same concept. Examples of conceptual models in the construction industry are standards and catalogs (ISO 13584), CIS/2 (Crowley et al. 2000), and IFC (IAI 2005).

However, the consistency of this strategy has significant limitations. The fragmentation of the domains makes it difficult to elaborate complete modules of reference and modules of interpretation. The construction industry not only is a fragmented domain but it is also dominated by concepts that overlap with other industries.

A Posteriori Integration

This strategy aims at obtaining integration consistency for previously elaborated data models. The integration is intended to contain one coherent data model. This strategy is particularly driven by the database arena. The strategy consists of finding relations between concepts from the data models or schemas. The criterion to find the relations 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 of concepts' compositions. After these analyses are made, this strategy addresses an examination of the schemas to generate an integrating model by resolving the conflicts of relating concepts from two different sources. In summary, this strategy detects differences, defines correspondences, and creates new schema or merges the existing ones.

In databases, the technique used to determine correspondences between data representations is called a matching operation (Rahm and Bernstein 2001). These operations

tackle integration from different sources – applications, data warehouses, web-oriented data integrations, e-commerce, etc. Matching works on an operation called mapping. Matching is a schema manipulation operation that takes two schemas as input and creates a mapping that identifies corresponding elements in the two schemas (Madhavan et al. 2001). The strategy pursues consistency of the final integrated schema, involving more use of manual operations than semi-automatic or automatic operations. This strategy has significant limitations derived from its own nature. The strategy intends to find semantic correspondences based on relating concepts through similarities in the syntax and in the structure of the data representations. However, 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. For a better illustration consider the examples illustrated in Figure 3-1 and Figure 3-2. Figure 3-1 shows that despite the identification of data representation in simple schemas, which in Figure 3-1 are the two tables, mapping or finding a relation among the correspondences is extremely cumbersome: schemas may possess structural and naming differences; they may have similar but not identical content; they may dissimilarly express data representation; they may use similar syntax but have different semantics, etc.

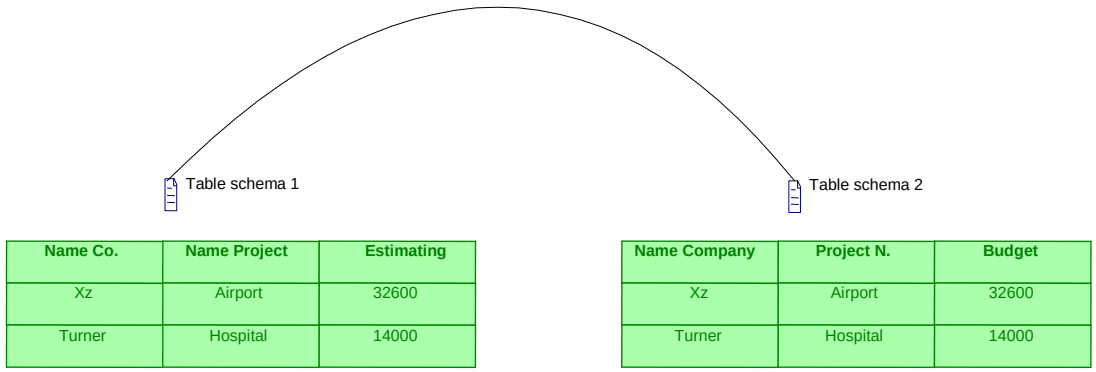


Figure 3-1. Mapping complexity: Different syntax, same semantics.

Most of the solutions through this strategy are targeted for Entity Relation type data representations where 1:1 mapping relations are more suitable to handle. However, when complex or aggregate relations exist, the mapping process is difficult to support. In Figure 3-2,

TABLE A						
CSI No	Item	Unit/H	Units	Labor	Material	Total
15.41504	Pipe PVC SCH40, 1¼" & Fittings	16.43	L.F.	7.76	1.10	8.88
15.41506	Pipe PVC SCH40, 2 " & Fittings	6.40	L.F.	11.52	1.53	13.07
15.41542	Pipe Pyrex 1½"	4.44	L.F.	16.60	14.30	30.90

TABLE B								
Code	Description	Crew	Output	Labor H	Unit	Material	Labor	Total
15108-520.4410	Plastic Pipe PVC 1¼" diameter & Fittings	Q-1	42	0.190	L.F.	2.45	7.10	9.55
15108-520.4460	Plastic Pipe PVC 2" diameter & Fittings	1 Plum	59	0.271	L.F.	2.65	9.10	11.75
15108-520.50	Plastic Pipe CPVC ½ diameter & Fittings & Supports	Q-1	54	0.148	L.F.	2.88	5.55	8.43
15108-520.7310	Plastic Pipe SDR 15 100psi 1½" diameter	Q-1	N/A	15%	L.F.	0.64	N/A	0.64

(a) One-to-One Mapping

TABLE A							
CSI No	Item	Unit/H	Units	Labor	Materia	Total	Total Incl O&P
15.4150	Pipe PVC SCH40, 1¼" & Fitting	16.43	L.F.	7.76	1.10	8.88	9.77
15.4150	Pipe PVC SCH40, 2 " & Fittings	6.40	L.F.	11.52	1.53	13.07	14.37
15.4154	Pipe Pyrex 1½"	4.44	L.F.	16.60	14.30	30.90	33.09

TABLE B									
Code	Description	Crew	Outpu	Labor	Unit	Materia	Labor	Total	Overhead & Profit
15108-520.441	Plastic Pipe PVC 1¼" diameter & Fittings	Q-1	42	0.190	L.F.	2.45	7.10	9.55	15%
15108-520.446	Plastic Pipe PVC 2" diameter & Fittings	1 Plum	59	0.271	L.F.	2.65	9.10	11.75	13%
15108-520.50	Plastic Pipe CPVC ½ diameter & Fittings & Supports	Q-1	54	0.148	L.F.	2.88	5.55	8.43	15%
15108-520.731	Plastic Pipe SDR 15 100psi 1½" diameter	Q-1	N/A	15%	L.F.	0.64	N/A	0.64	20%

(b) Complex Mapping

Figure 3-2. Mapping problem cases in relational data representations.

there is a comparative example of one to one and complex relation cases. As was mentioned previously, the *mapping* component of the *a posteriori integration* strategy is one of the most challenging and demanding processes.

Mapping Strategy

This strategy analyzes data representation sources and finds their relations through a set of formalized mappings. These mappings are derived from the knowledge domain or from conceptual models using mapping languages. Although mappings could be considered as part of the integration process of the a *posteriori integration* strategy, they are different because the *mapping strategy* employs conceptual models, which are derived from *a priori* consensus, to aid the mapping process. The *Mapping strategy* use concept models in order to find appropriate relations on conceptual levels. This strategy embraces the methods to finding mapping formalisms. It takes into account the type of data representations, the possible conflicts among them, and the correspondences of the mapped concepts. Furthermore, the mapping on more sophisticated types of data representation, such as ontology is a more ambitious process (Partridge 2002).

For an illustration of this complexity in the construction domain, consider the following example. Take two ontology representations, named A and B. Each one of them has the concept: {spread footing}. Assume concepts A and B take the form of assemblies. Thus, concept A includes other elements such as {reinforcement, concrete, dowel bolts, bulk excavation} and concept B includes {reinforcement, concrete, dowel bolts, compacted backfill}. The relation between the concept and the elements are denoted as A as *partof* {reinforcement, concrete, dowel bolts, bulk excavation} and as B as *partof* {reinforcement, concrete, dowel bolts, compacted backfill}. The problem is determining how an actor can semantically map one node from one representation to the "most semantically *similar*" node of the other representation? To

illustrate this problem in a simple way, observe that the nodes A and B partially match; they semantically match although they are *not equal*. In fact, the nodes are *similar* and *overlap* into *more specific* elements of the concepts of the nodes.

Then we say concept A{spread footing} and B{spread footing} are similar; they overlap in the more specific elements {reinforcement, concrete, dowel bolts}, and they mismatch in the elements{bulk excavation} from A and {compacted backfill} from B. In order to execute a match at the element level between concept A{spread footing} and concept B{spread footing}, we map only concept A{spread footing} with only concept B{spread footing}. Note that A and B are mapped at the {spread footing} level, not on the A and B elements.

However, element {concrete} from A, denoted as *part of*{concrete, A}, mapped with element {concrete} of B, denoted as *part of*{concrete, B}, can be matched at a simpler level. In this case, we have the mapping of these two elements at the element level. The element level performs mappings between individual concepts, and the structural level maps the semantics of two concepts, where each one holds other concepts (Giunchiglia and Shvaiko 2003b).

In addition, we can have a structure level case such as whole concept A holds whole concept B. In this case, this matching is not fully matched because concept A semantically differs from concept B. Element A is a A{spread footing} and element B is a B{spread footing}, but on a more specific or simpler level {reinforcement, concrete, dowel bolts, bulk excavation} is part of A and {reinforcement, concrete, dowel bolts, compacted backfill} is part of B. They differ in the elements {bulk excavation} and {compacted backfill}. This result is called a partial match.

The *mapping strategy* involves the roles of two components: the mapping language and mapping patterns. The mapping language is used to express the concepts of the data

representation, such as entities and attributes, in a formal representation of the language in order to perform mappings between two sets of concepts of two data representations by means of language specifications. Examples of these languages are Express X (Hardwick and Denno 2000), Agent Communication Languages such a KQML (Knowledge Query and Manipulation Language proposed by DARPA), and VML View Mapping Language (Amor 1997), among others. Mapping types are the common mapping cases, which can take place between two elements, such as attribute-to-attribute, entity-attribute, etc.

Approaches in the Construction Domain

Most of the efforts to develop approaches for the interoperability problem in the construction domain have been made on models. The sense (meaning) of the term 'model' corresponds to a description, an emulation of some 'original' or aspects of the 'real world'. The trend on modeling in the industry is based on construction processes or construction products. Products are manifestations of physical objects (i.e. windows) and processes are the transformation of these objects from one state to another (i.e. installing windows). In order to understand the modeling trend and to have a better picture of the use of information in the construction industry, an analysis of its composition is discussed in the next section.

Use and Composition of Information

The information used in the construction industry, which in the broad sense includes architecture, engineering, and construction, can approximately be broken down by specialization, by life cycle, and by the type of source where the information is generated. The analysis of the composition is presented in Figure 3-3. Other groups that are used in other fields of the domain could be added to the composition (i.e. facility managers).

Figure 3-3 shows a top-down view that is an abstraction and a simplification of the information that it is used by a construction project. For example, 'sliding window' is a product

that is used in the first stages of a project in estimating and planning tools and, in latter stages, is analyzed in processes, which in turn takes the name 'installing sliding window', and in contractual documents (e.g. subcontractor's contract for the installation of windows). A product is the result of mapping an intended artifact and a representation. In the same way, a process is the map of an intended activity into a representation, and documentation is the description with high levels of details of products and activities in a construction project. The construction participant's function is to manipulate information and complete an activity that is part of a stage of a life cycle within a project.

If the composition is broken down, the resulting parts are formalized into components that are mapped and modeled into computational representations. For example, a request for information (RFI) is an internal document from a construction organization, which contains a certain level of detail of information and conserves a level of abstraction of the group, and the structure of which is mapped and elaborated into computational representations. A door is a physical object that is modeled as a construction product and which it supposed to contain levels

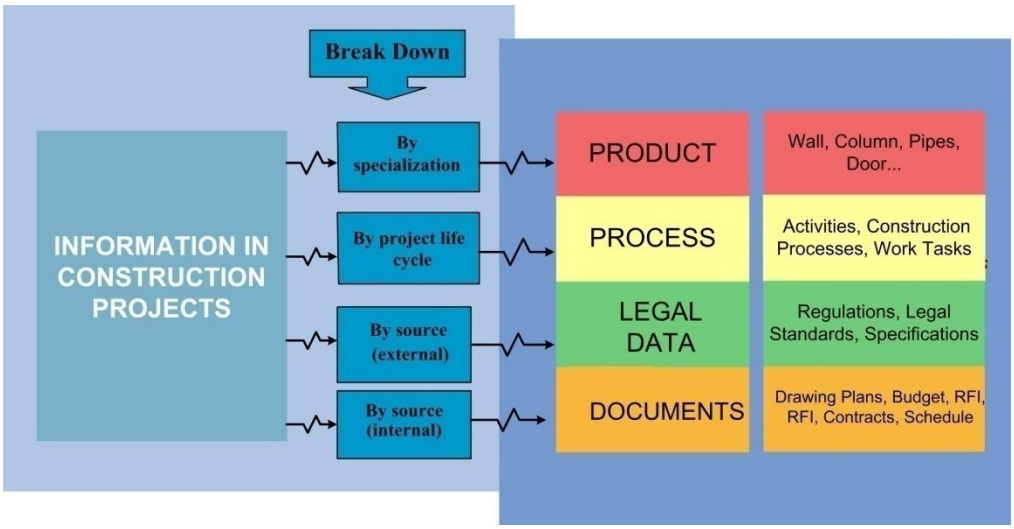


Figure 3-3. Components of the information in the architecture, engineering, and construction domain.

of details of properties and attributes that a construction participant would find in the 'real world'. At some point, the level of details of the information is left to the individual construction participants who perform the interoperability tasks.

Although, this way of addressing the information is a natural way to perform abstractions of construction projects and map them into computational representations, this level of generality contrasts with the '*uniqueness*' feature that characterizes projects in the construction domain. For example, *specifications* are construction documents which conserve a structure organized by standards but the content is exclusively used for a particular project. Then, the levels of details of the *specifications* contrast with the goal of the standards to find generalities. This is an additional fact that will affect the effectiveness and adoption of solutions for interoperability.

Modeling the information for interoperability

Most of the efforts for interoperability in the construction domain have been made regarding modeling. These initiatives attempt to structure schemas that contain logic relations and concepts of the information found in the construction domain. These schemas are abstractions of possible instances that the construction participant finds in a particular area of the domain that is being modeled. The reader may notice that the definition of the schemas is similar to that of the *conceptual models*. *Conceptual models* indicate the framework of reference where the domain community formulates particular definitions of the concepts, while a *schema* is a map of concepts and their relations. In other words, *conceptual models* provide formal definitions of the basic concepts and their relations, but the schemas serve as templates to map the concepts and relations. In the same way, c*onceptual models* have an affinity with *conceptual schemas* in which both define concepts for a particular domain by reflecting the developer's abstractions or understanding of that domain. The difference lies in the fact that the *conceptual schema* is not coupled with any modeling language.

When the concepts are mapped from the 'real world' to computational representation, they are built in data representations. The reader should be reminded that these data representations can be structured or non-structured. In the construction domain, the structured data representations are called data models, which could take the form of 'product data models' or 'process data models' when representing products or processes respectively. In any case, these 'data models' will fit a predefined conceptual model.

For clarity, developers use formalizations that describe the modeling principles. An example of these formalizations is Integrated Definition Methods (IDEF), which is used for modeling processes. IDEF is a group of modeling methods that can be used to describe operations. IDEF was created by the United States Air Force and is now being further developed by Knowledge Based Systems, Inc. Originally developed for the manufacturing environment, IDEF methods have been adapted for wider use and for software development in general. These methods are used to create graphical representations of various systems, to analyze the model, create a model of a desired version of the system, and to aid in the transition from one to the other (KBSI 2004).

The possible proliferation of conceptual models motivated developers to come up with strategies in order to manage how they 'see the world' or how they interpret the construction concepts. An example that clearly justifies this need is when developers suggest 'pieces' of *conceptual models* to be integrated into conceptual models. The common optic to manage these pieces of models was proposed through the use of a *high layer model. High layer* models are also labeled *reference models.* These models explicitly define a kernel type structure from which the concepts can be derived. For example, Björk (1999) proposed the reference model shown in Figure 3-4 for construction information processes and Industry Foundation Classes (IFC)

defines constructs of processes and products through the use of the kernel model (IAI 2005) (see Figure 3-5).

The IFC model, for instance, is a shared project model to capture the 'lowest common denominator' definitions across several construction industry disciplines. It has two types of specification documents: the first define concepts of different disciplines (e.g. HVAC, architecture), and the second serve as a guide where software engineers implement any computer application with structured data by mapping them into IFC data files, (see Figure 3-5). In this way, "IFC data files provide a neutral file format" that enables computer applications to efficiently share and exchange information (Froese 2003).

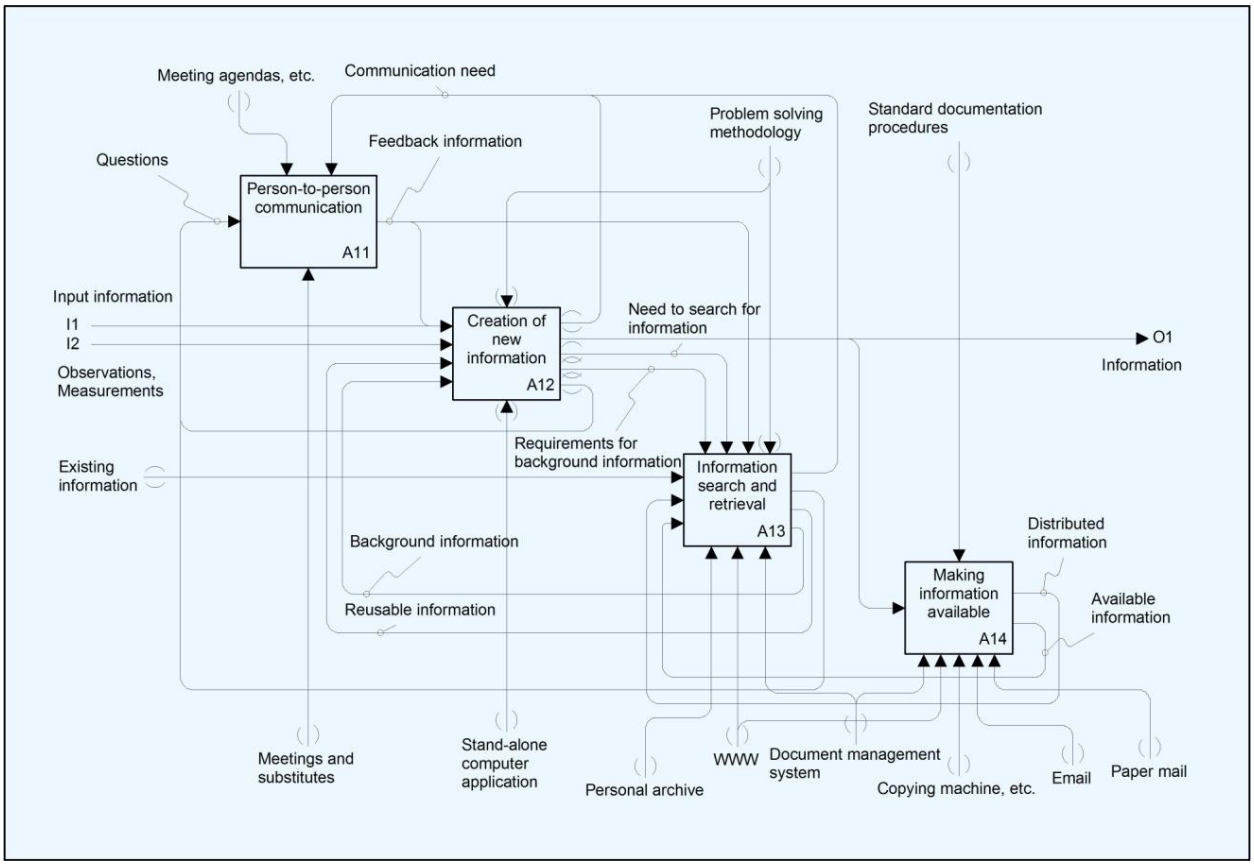


Figure 3-4. Process model. Four generic information process activities and their interactions (Björk 1999).

Figure 3-5. Industry foundation classes (IFC). Architecture diagram with kernel model components.

The efforts for establishing interoperability on models are more advanced on *product* modeling than *process* modeling (Eastman 1999; Froese 1996). An example of the *product modeling* initiative is RATAS, which is a *building product model* that breaks down products in a network decomposition scheme into five levels: building, system, sub-system, part, and details (Björk 1992). Other efforts on *product modeling* are aimed at sharing information by using protocols. The Building Construction Core Model (BCCM) provides a common framework for data exchange through a set of application protocols and facilitates the implementation of the

coherent Application Reference Models (ARMs). The BCCM was identified as ISO-10303 Part 106 of a STEP activity. The BCCM model addresses products, as tangible items; processes, as the logistics and activities; resources, human, plant and constructed items; and controls, which are constraints applied to products, processes, and resources.

There are also other initiatives that capture functional and behavioral information about building components. One example is the Semantic Model Extensions (SME) (Clayton et al. 1996), which interprets a design by assigning meaning to graphic forms.

The role of the documentation component

As was illustrated in the composition of information in Figure 3-3, documents and legal data are fundamental pieces of information that construction participants use to interoperate. Documents contain the necessary information at a certain level of abstraction for describing construction concepts. This description is packaged in various levels of details until a formal document is created and the rest of the description relies on the level of knowledge of the construction participant. For example, the understanding of the construction product 'CPVC pipe' in a request for information document (RFI) is dependent upon the understanding of what this product means to a construction participant.

Therefore, documents in the construction industry, in order to describe a product or process during the building life cycle, have been expanded with further details within more specialized functional fields. The trend is that construction project operations have been broken down into more specialized areas according to the division of labor. The tendency of having more detailed documents contributes to less misinterpretations of the document's content, and therefore, creates an effective exchanging, sharing, and transferring of information and an *understanding* of the information concepts by construction participants.

There is no significant advancement from the construction domain community for interoperability by using these components. The initiatives have relied on the software community to develop interoperable document management tools based on 'de-facto' standards (Zamanian and Pittman 1999) or on exchanging information syntaxes such as XML format. For example, aecXML provides XML schemas that describe information that is specific for data exchanges among participants involved in the design, construction, and operation of buildings, plants, infrastructures, and facilities. The aecXML schemas that are currently under development include: Structural, Infra-structural, FM, Procurement, Project Management, Plant, and Building Performance.

Part of the *documentation* component traditionally has used classifications in taxonomical order to find ways to make partners understand the division of labor. The taxonomy is a method that helps construction participants conceptualize a construction project, and, therefore, perform interoperability activities. These classifications are simple conceptual models for representing the division of labor, which is a way of conceptualization that helps perform clear communication among all construction participants. Most of the classifications have been developed by practitioners and industry committees. For example, the Construction Specifications Institute, CSI, which is an association of architects, engineers, contractors, suppliers, owners, and facility managers, which boast of more than 16,000 members involved in commercial and institutional construction, has developed the MASTERFORMAT classification (CSI 2004). This joint effort consists of a list of numbers and titles classified by work results or construction practices, primarily used to organize project manuals and detailed cost information and to relate drawing notations to specifications. There are other efforts that have been made by other associations such as the new Overall Construction Classification System, OCCS, a

classification system that organizes data in a common language from the conception to the whole life cycle of the construction project (OCCS 2006).

Construction participants employ these classifications as higher layer models from which more *consistent,* specific data models are derived and used in custom construction applications i.e. *ad hoc* construction estimating databases based on CSI. The consistency maintained in the higher layer models or conceptual models diminishes the disagreement over the meaning, interpretation, or intended use of the same concept among construction participants.

Other Efforts at Ontological Engineering in Construction

In this section, a brief description of the main features of other ontological efforts is explained as well as an explanation of how the cited approaches differ from the current research. At the end of this section, a matrix is presented that aids the illustration for comparison purposes.

The ontology model developed at Stanford (Bicharra et al. 2003; Staub-French et al. 2002) is an exercise of applying ontologies for case studies. Case studies are used to identify relationships and 'features' (they named concepts as 'features' and as 'properties'). The exercises do not attempt to create a formalization of the ontologies; they are simple exercises of finding meanings of 'features' and 'properties' of particular construction products, and particular construction processes. The conceptualization does not achieve the axiomatic level and is committed to the domain knowledge of the ontology developer.

The work at Loughborough University related to ontological engineering is focused on intelligent computing (Aziz et al. 2004). Their work is oriented in creating technologies on mobile construction for collaboration. In the main architecture, they proposed an ontology layer that handles the relation between concept description and logic. They now have gone further and have advanced this work towards the semantic web architectures. They proposed an intelligent agent base system that is capable of controlling its own decision-making and action based on its

perception of the environment. This effort proposes a series of methods for intelligent remote collaboration and one of the layers for conceptualization is an ontological one, which they call semantic tier. This tier enables knowledge description and knowledge access by supporting information retrieval, extraction and processing. The ontology is accessed to support inter-agent information transfer and it is used as a neutral source to access and exchange information.

El Diraby (2006; 2005; 2003) has worked on the development environment for interoperability in the construction domain. He envisions an architecture that integrates engineering, economic, and social aspects. His efforts have started in infrastructure projects (El-Diraby 2003) and optimization of construction projects by using decision models. Perhaps his joint effort with the Lima et al. (2005) in developing e-COGNOS is the most important contribution. e-COGNOS is an ontology that conceptualizes knowledge management scenarios of construction projects. It was built to address the support of consistent and extendable representation of construction knowledge. The interesting part of this project is the methodology used to induct knowledge. It benchmarks other construction projects and validates the results with domain experts. The first step to build e-COGNOS ontologies is the recognition of IFC and British Standards BS6100 (BSI 1992) taxonomies as well as the Unified Classification for the Construction Industry UNICLASS (UNICLASS 1997) taxonomy in order to reflect mainly the IFC structure and International Organization for Standardization (ISO) 12006-3 (ISO 2007). In this sense, e-COGNOS recognizes and resembles taxonomies found in the IFC model such as Products, Processes, Actors, Projects, and Resources.

El Diraby (2006) has continued his work in ontology engineering through the definition of the distributed architecture for knowledge management in highway construction. This work consists of the extension of the e-COGNOS ontology model to the taxonomies of domain

concepts in highway construction. This new taxonomy is called HiOnto. The extension to this domain pertains to highway construction. It includes a full ontological description of the main entities of highway construction. In this ontology, a set of sub domain levels of abstraction was developed: domain, application, and users. Each level inherits the concept, relations, or axioms of the preceding level(s). This architecture resembles a set of taxonomies linked: e-COGNOS ontology, application ontology, and user ontology.

In his latest work, El Diraby (2005) proposed a framework for a formalization through ontologies of the construction domain. The claim is that a micro-theory for construction can be formalized in order to capture the main entities in construction as well as their attributes and interrelationships. Again, this work is based on e-COGNOS and its extension to general construction concepts of the domain through formalizations.

There are additional works in the industry based on ontologically engineering. Basically, they are attempts to find a neutral common model to share information for particular construction processes. These researchers employ an ontological approach as the back bone of their architectures to exchange and share information. For example, Kitamura et al. (2004) designed extended device ontology to define the 'behavior' of devices in functional design industrial cases. Other efforts have been aimed at resolving conflict resolution in documents for collaborations by finding semantic consistency through syntactic patterns (Gu et al. 2005). This approach is termed 'Conflict resolution of design documents'. Other efforts have been aimed at finding inter-domain interoperability such as the case of Geographical Information Systems and the construction industry. Peachavanish et al. (2006) explored a new methodology for CAD-GIS integration at the semantic level. Again, these works differ from concept cluster due to their goal of defining a common denominator between two different conceptualization models.

The matrix in Figure 3-6 illustrates the aforementioned differences between the various mechanisms for knowledge organization. Our approach named concept cluster will be further explained in Chapter 9 In the matrix, e-Cognos is the work of Lima and El-Diraby and functional design knowledge is the work performed in Stanford (Bicharra et al. 2003; Staub-French et al. 2002). The others are the ontology engineering approaches (Gu et al. 2005; Kitamura et al. 2004; Peachavanish et al. 2006) as discussed previously.

	Representation	Actor	Context	Pragmatics	Intentionality	Additional Form of Representation	Part-Whole Relationship
Concept Clusters (Mutis et al. 2006)	Ontologies / Taxonomies	Social Role	Context	Pragmatics	Cognitive agent in construction organization	Natural language / Visual symbols / Documents	Part Whole Relationship
E-Cognos (El-Diraby 2003; 2005 et al.)	Ontology	Actor	No	No	No	Altenative Taxonomies	Part Whole Relationship
Functional Design Knowledge (Kitamura et al. 2004)	Ontology	Specific Area (Designers)	Functions	No	Function Decom-position	Alternative Taxonomies	Between relations of functions
Building Project Ontology (Bicharra et al. 2003; Staub-French et al. 2002)	Ontology	Organizational Functions	No	No	No	Natural Language	Yes / Product
Conflict Resolution of Design Documents (Gu et al. 2005)	Ontology	Organizational Functions	No	Through Wordnet	User profile	Natural language / Documents	No
CAD-GIS Integration (Peachavanish et al. 2006)	Ontology	Actors / Role Definitions	No	No	No	Objects / Metadata	No

Figure 3-6. Comparison of ontology engineering approaches with concept clusters.

Shortcomings of the Current Modeling Efforts

The current modeling approach that is used in the construction industry is inadequate and plagued with several shortcomings. This section addresses these shortcomings of current

modeling practices and presents a clearer illustration concerning the conditions that should be achieved for an effective approach, harmonized with current interoperability practices. In Chapter 4 an exploration on the fundamentals of the limitation of the modeling paradigms are discussed.

The reader should take into account that the aforementioned models were defined to contribute to creating interoperability in the construction domain by functioning as high layer models from which more consistent, specific models are derived. In other words, the abstraction made by the models predicts the reality that a construction participant will find during the life cycle of a project by prescribing that situation. This is a good starting point to analyze the shortcomings of the current efforts.

The first shortcoming of the current models is due to the fact that the models themselves force a view and create preconceived interpretations of the user's real world. Models are not created from a successive abstraction method. Models are not built through methods that analyze domain concepts according to their nature and then initiate a description of such concepts by generalization. In addition, models are only elaborated within a designer's perspective or with a limited consensus among some modelers.

One consequence of this preconceived view is that users struggle when defining construction concepts in their applications when they attempt to adopt the models' or others' understandings of what a construction project is. The models reflect the real worldview of their developer, but not a reality that guarantees a common interpretation of the construction participants. Models are subjective and they are typically imposed on the users' implementations.

Other shortcomings encountered are due to the incompleteness of the models. The models are incomplete in their specifications and they lack comprehensive information (Amor 2000;

Zamanian and Pittman 1999). This incompleteness makes it impossible to use them in practice in the industry. For example, the absence of any concept in the conceptual model would force a merging or a reconciliation of the concepts into others, diminishing the reliability of the real semantics.

Other problems with the current modeling efforts are related to the heterogeneity of information and to the various levels of systematization or sophistication of the construction participants' systems.

- Considering the aforementioned shortcomings, interoperability initiatives should address: the sufficiency of the concept descriptions, which addresses the ability of the concept representation to provide construction participants the necessary information for performing interpretations;
- flexibility, which allows the concept representation to add additional semantics in order to define a concept;
- adaptability, which is the ability to recognize other particular types of representations of the domain; and
- efficiency, which is the capability to perform interoperation with economical factors.

The sufficiency involves the specifications of the level of details of concept representations and the methods of generalization and abstraction for performing interpretations. The flexibility is concerned with the ability to avoid the rigidity of concepts' definitions by avoiding uniquely predefined concept descriptions. The adaptability recognizes the inclusion of other types of representations such as visual representations for practical purposes. The efficiency involves the ability of the model to elicit agents and agents' systems to perform their designated functions with minimum consumption of time and resources.

The next section shows the complexity that would take place when the conceptual models are elaborated and a further step needs to be taken. This step corresponds to the semantic reconciliation of concepts of models from different sources. The complexity in further steps of

semantic interoperability will be discussed in the next section in order to contrast it with the simplification adopted by the modeling strategy.

The Reconciliation: A Case Example of the Semantic Interoperability Paradigm

With the purpose of finding strategies within the reconciliation paradigm, part of our research is aimed at *finding insights* into the problem of reconciling representations of concepts within the construction domain. The reconciliation problem deals with finding common semantics about sources of information from different agents. The database community describes the reconciliation as one of the obstacles on the road toward solving the heterogeneity of information problem (Garcia-Molina et al. 2002).

Reconciliation is a fundamental step of, sharing, and integrating information. To illustrate the complexity of the reconciliation problem an example will be shown in this section. This example employs ontologies, which are structures of knowledge representation that contains explicit information from the construction domain. The example is narrowed to the step of performing a mapping on the ontologies. As the examples show, further efforts should be spent on step, the reconciliation of two or more sources of information.

Ad *hoc* ontologies of certain construction businesses are shown in Figure 3-7 and Figure 3-8, (a) and (b). The ontologies represent the construction business model.

The reader is reminded that ontologies are often associated with taxonomic hierarchies of classes and the subsumption relations, but they are not limited to this structure, which could be easily confused with the rigid inheritance structures from object oriented representations. Ontologies acquire knowledge about the world and frame them into categories and add terminology and constrain them with axioms from traditional logic. An ontology is based on the formalization process of the knowledge of a domain. The knowledge contains domain concepts that are explicitly described in common vocabulary in order to be formalized. A domain expert

extracts and translates the concepts into a common vocabulary and formalizes the resulting translation through a formal language, and axiomatic rules. This operation is called a conceptualization. The nodes in Figure 3-7 represent the Concepts in a graphical representation of an ontology.

Figure 3-7 shows some specializations of the root, represented by Concept 1, such as {Functional Areas, Administration and Buildings}, which in turn are represented by Concepts 2, 3, and 4 respectively. The concept Project Manager, Concept 7, has instances like {Bill O'Connell, General Manager, New Hall UF} with fixed attributes like {Name, Hierarchy, Project In Charge}. Thus, the instance Project Manager O'Connell has the values Name=Bill O'Connell, Hierarchy = General Manager, Project in Charge=New Hall UF. Additionally, there is a set of relations among concepts like {is a, part of, has}. The relations are generally denoted as PartOf(Project Manager, Administration). These relations describe associated defined relations within classes, inheritance relations, and instances of properties.

If the analysis is reduced to finding mappings that express semantic equivalence between the two ontologies, then the reconciliation problem can be expressed in terms of how an actor can semantically map one concept from one ontology to the "most semantically similar" concept of another ontology. It is clear, then, that the mappings for this example are semantic associations between two or more concepts.

Graphically, it is possible to bring up a clear picture of the complexity in finding a reconciliation of two ad hoc ontologies. Consider the two ontologies which are shown in Figure 3-8 (a) and (b). 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, as shown in Figure 3-8 (b).

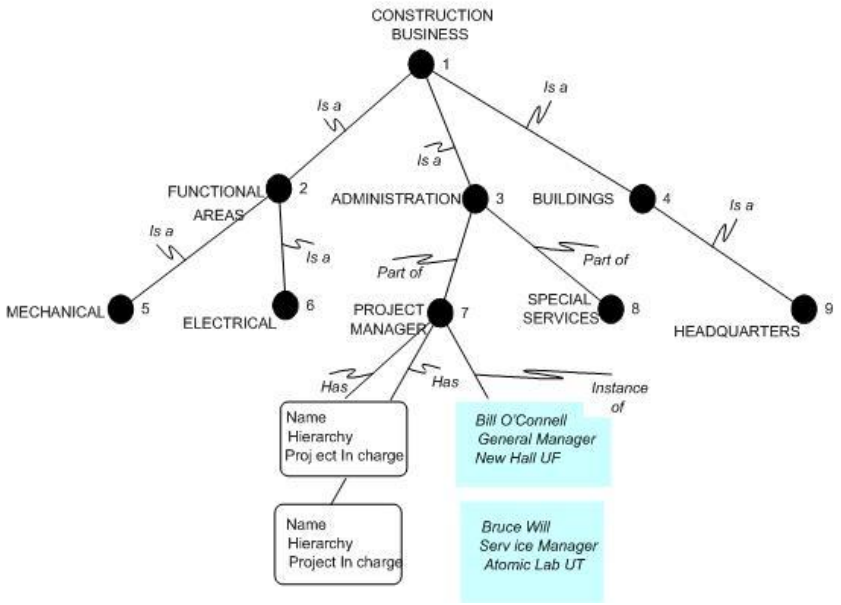


Figure 3-7. Structure of an ad-hoc construction business.

The 'is a' relation corresponds to a semantic link between two concepts that have a subsumption relation. The 'part of' relation corresponds to the association of a concept x to another concept y that represents part of the concept y, or in other words, a component of x. The 'part of' relation and the 'has' relation correspond to a semantic link that constrains the subsumption relation to a directional relation of containment (Brachman 1979; Woods 1975).

How and when is reconciliation needed in the semantic interoperability process? With Figure 3-8 as an example, suppose that the construction participant queries information about the

availability and costs of specific items from different material suppliers, say pipes for internal water distribution in a building. Specifically, the construction participant or actor need to perform a semantic association between the most similar concepts of the two ontologies that contain the information sought. The problem is in how a construction participant can semantically associate a concept or concepts of one data representation to another concept of the other data representation. Moreover, as can be intuitively noticed in Figure 3-8 (a) and (b), the question of how a construction participant will be able to semantically associate more complex matchings when one concept is semantically similar to a group of two or more concepts into another ontology needs to be addressed.

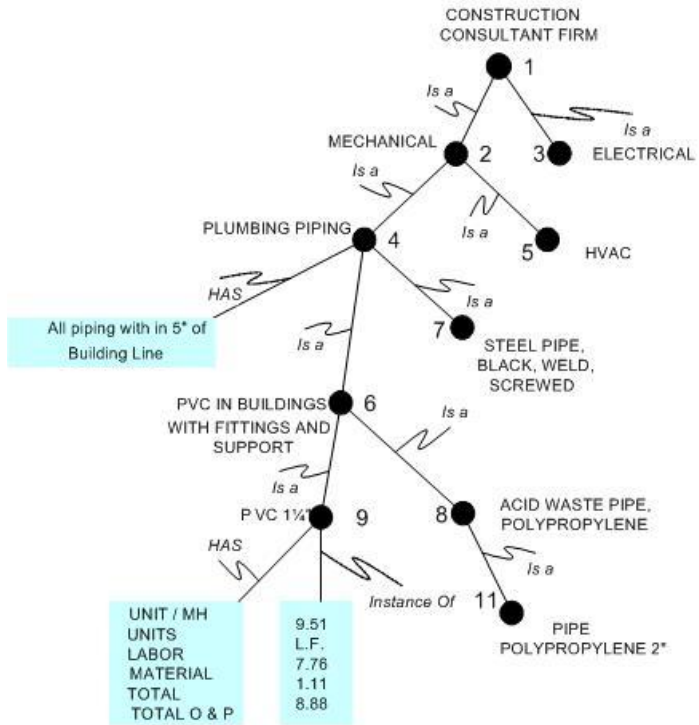
In addition, the mappings shown in Figure 3-8 resemble one-to-one and complex matching problems that have been studied extensively within the database community (Doan 2002) . For instance, consider a one-to-one semantic match at one of the levels. With the aid of auxiliary information such an "expert knowledge", Concept 7 from Figure 3-8 (a) (*Steel Pipe, Black Weld, Screwed*) is matched with Concept 8 from Figure 3-8 (b) (*Metal, Pipes & Fittings*). Note that although they semantically match, they fully syntactically mismatch. The syntax '*Steel Pipe, Black Weld, Screwed*' is neither the same nor even similar to the syntax '*Metal, Pipes & Fittings*'. The input of a domain expert is needed to reach the semantic association between Concept 7 of Figure 3-8 (a) and Concept 8 of Figure 3-8 (b).

Consider the case where the construction participant queries more detailed information from two construction firms concerning the cost of water distribution pipes of 1¼" diameter. In other words, the participant 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 Figure 3-8 (a) to Concept 6 (*Pipes and*

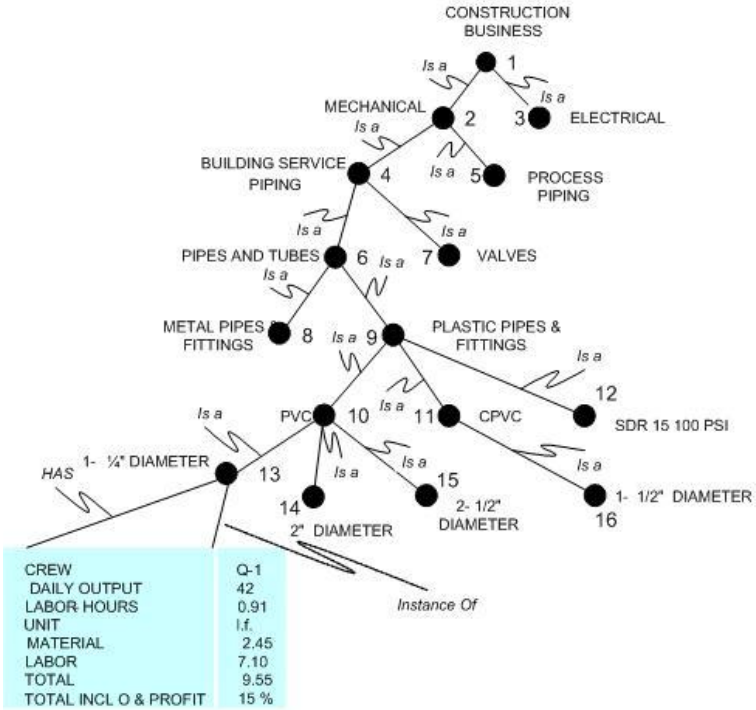
Tubes) in Figure 3-8 (b). But this mapping does not resolve the aforementioned query concerning the availability and costs of specific items from different material suppliers such as pipes for internal water distribution in buildings. The user should follow the subsumption relations of the concepts. This approach is similar to following down the hierarchy of a taxonomy.

A taxonomy is a central component of an ontology (Noy and McGuinness 2001). Assume the expert's information asserts that a Polymer Pipe between 1" and 11/2" diameter is suitable for internal water distribution, e.g. PVC (Polyvinyl Chloride) pipe. Hence, the user matches Concepts 9 (*PVC 1¼"*) from Figure 3-8 (a) to Concepts 10 (*PVC*) and Concept 13 (*1¼" Diameter*) from Figure 3-8 (b). Observe that Concept 10 is concatenated with Concept 13 to perform the match. Concept 10 is a more general concept than Concept 13 and vice versa, Concept 13 is more specific than Concept 10. This is a complex type of match that includes a joint of two concepts from one source to another concept of another source.

Figure 3-8 (a) and (b), shows how the relationships between concepts of two representations could match at a *more general or specific* forms, 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 and Shvaiko 2003a). Thus we can say that Concept 4 (*Plumbing Piping*) in Figure 3-8 (a) is *similar* to Concept 4 (*Building Service Piping*) in Figure 3-8 (b), at least intuitively due to specialization relation from Concept 2 (*Mechanical*) in Figure 3-8 (a) and Concept 2 (*Mechanical*) in Figure 3-8 (b), and due to similar syntax description of Concept 4 (*Plumbing Piping*) in Figure 3-8 (a) is *similar* to Concept 4 (*Building Service Piping*) in Figure 3-8 (b).



(a) Ontology of a construction consulting firm.



(b) Ontology of a construction business

Figure 3-8. Ad hoc construction ontologies.

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 process more complex. For further analysis, note that some concepts from Figure 3-8 (a) and (b), are similar and overlapped into more specific elements of the concepts. In these cases, in order to perform reconciliation an expert with sufficient level of knowledge about certain concepts in the domain would be needed for executing the reasoning process. For example, in an attempt to perform reconciliation among node 7 in Figure 3-8 (a) and node 8 in Figure 3-8 (b), an understanding of what is meant by 'steel pipes types' is needed

There is no possibility of asserting truth when actors observe explicitly represented information, such as the ontologies of Figure 3-8 (a) and (b), even in the scenario where an observer is able to perform plausible interpretations on the *boundary of sufficiency*. An agent that endeavors to interpret Concept 9 in Figure 3-8 (a), which is explicitly defined as *PVC 1¼"*, can identify the concept as Polyvinyl chloride produced from the monomer, vinyl chloride (chemical formula CH2=CHCl). The actor, however, ignores the *PVC* level of flexibility that is described by the ontology's modeler in Concept 9 as *PVC 1¼"*. Concepts cannot be taken for granted as derivations from properties of entities, of events, or of relationships inherited from the physical world. The meaning or semantics of a concept is established a priori and the complexities of a phenomenon cannot be accommodated in the limited resources of symbols and propositions. The modeler assumed an objective relation between the symbolic representation and a phenomenon. The modeler disregarded the level of phthalates (plasticizers) in the description of *PVC 1¼",* Concept 9, in their description of the flexibility of the *PVC*.

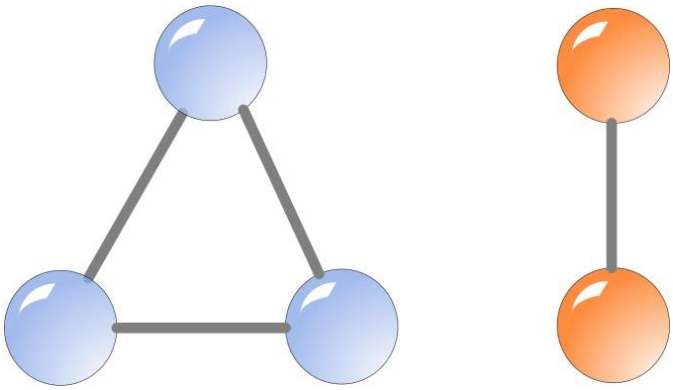
For example, when an actor attempts to reconcile two or more explicitly represented structures of information, generated from different sources, the resulting complexity is a major paradigm. The actor can reconcile Concepts 9 (*PVC 1¼"*) from Figure 3-8 (a) to Concepts 10 (*PVC*) and Concept 13 (1¼" Diameter) from Figure 3-8 (b). However, observe that Concept 10 is concatenated with Concept 13 to perform the match. Concept 10 is more general than Concept 13, and vice versa, Concept 13 is more specific than Concept 10.

In summary, the examples of Figure 3-8 (a) and (b) illustrate the reconciliation problem of two ontology representations that are from the same domain, but have different terminologies. This semantic heterogeneity is a conflict that 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 of one ontology has similar but not exactly the same semantics as that of another ontology and how two concepts with a similar meaning can be structured differently in different ontologies.

Complexity for Reasoning

The previous examples showed the complexity of the reconciliation problem in attempting to relate two or more concepts from two different sources. The process of identifying *similarities*, in which an expert or actor intuitively finds semantic relationships according to the expert's level of knowledge, and of identifying *affinities*, in which the expert intends to find the degree to which the concepts fit in the context of usage, is an expert's *reasoning* step. Experts read the concept structure and perform an abstraction of the structures to identify relationships in order to find semantics and assert interpretations. However, this *reasoning* is a complex problem that, in turn, makes difficult to reconcile concepts from two or more different sources. For clarity, consider the following example. Two concept structures from two different sources need to be reconciled by an expert. Figure 3-9 (a) and (b), shows these structures in which the nodes

represent concepts and the links between the nodes represent an explicit relationship between the concepts. The structure shown in Figure 3-9 (a) has three nodes and three relationships and the structure shown in Figure 3-9 (b) has two nodes and one relationship. The two structures are dissimilar for the purpose of illustrating the nature of the reconciliation problem. The components and forms of conceptual structures cannot possibly be found to be exactly similar when they come from different sources.



(a) 3 Nodes (b) 2 Nodes

Figure 3-9. Concept structures from different sources.

Figure 3-10 shows the association that the expert performs in order to reconcile the previous concept structures. The shadows on the structures illustrate what portion of the concept structures are selected to find semantic similarities and to fit concepts in the context of usage within the expert's knowledge. The complexity of the reasoning process is illustrated in finding the most accurate associations among the multiple set of possible mappings. In addition, is important to take into account that the associations of the two conceptual structures presented in Figure 3-10 are not mapping patterns. The reasoning process for reconciliation does not find mapping patterns. It finds the closest meaning through mappings between two concepts from different concept structures.

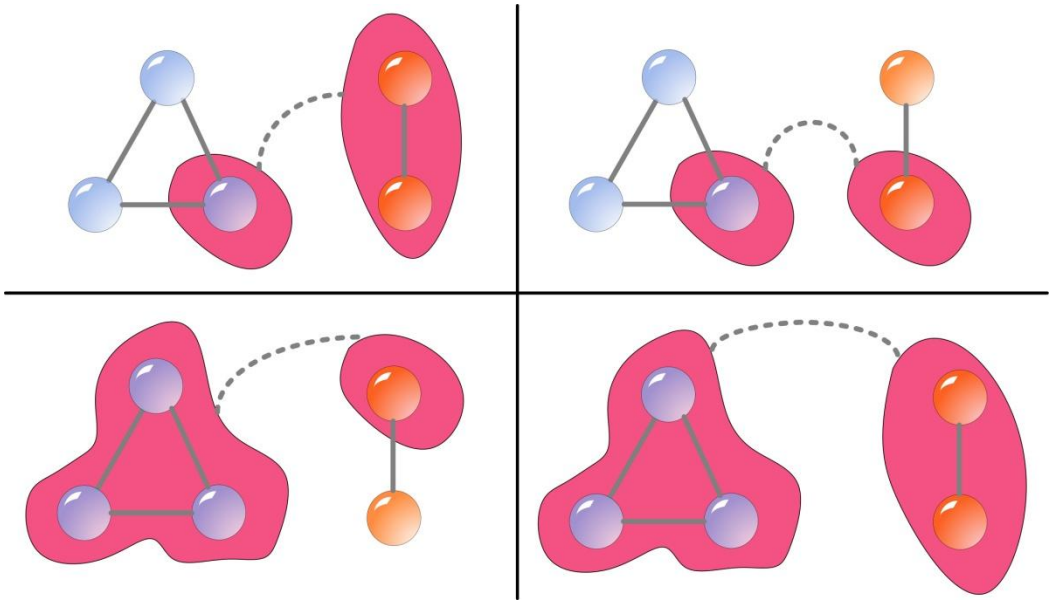


Figure 3-10**.** Complexity of reasoning for the reconciliation of two concept structures.

Summary

As shown by the example from Figure 3-10 human intervention by 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 each structure to the other structure does not result in an accurate association even though they are syntactically, similarly expressed. There are other aspects to consider for identifying closer and similar, semantic associations between two structures. Next Chapter 4 will explore the fundamentals of the model paradigm in order to acquire other insights from other disciplines to bring and to discuss answers about the complexity of reconciliation.

CHAPTER 4
CONCEPTS IN THE CONSTRUCTION DOMAIN: DEFINITIONS AND PARADIGMS

Interoperability in the construction industry implies the interpretation of syntactically defined symbolic notations and of other forms such as visual representations. These notations are deliberately organized to define concepts. The understanding and characterization of concepts into symbols and other forms of representations are also addressed in this Chapter.

Forms of Representations in the Construction Domain

The agents of a community generate descriptions of hypothetical objects and states of affairs of their domain through forms of representations with the purpose of communicating them. These descriptions are abstract and are grounded in the possibility of their existence, although they can be imaginary. An architect, as an agent of the construction-project network, can generate the description of a clay tile roof though a set of symbols, which can be systematically expressed in natural language. The syntactic set of symbols can be interpreted as an utterance in natural language and those utterances are indeed systematically interpretable as to what they mean (Harnad 1994). This description is a characterization of the clay-tile roof objects. The characterization can be expressed through the advantages of being energy efficient, fireproof, and long lasting compared to asphalt or fiberglass shingles. The clay-tile roof description can also include the state of affairs within the space-time region, such as the suitability of use in hot and dry climates.

The goal of the architect's abstract description is to represent his or her concept in a form of representation to be communicated to other actors in the domain. This concept is represented through a set of symbols in the preceding example. The architect's intention through the description of the abstract object is to make a reference to the possible identifiable physical

object that meets the architect's description in the domain. In the simplest case, the architect describes their abstract creation of the clay-tile roof assembly.

In the construction domain, the represented concept through symbols, models, or visual representations is intended to be related to the physical domain, i.e. be physically realized. The construction participant reifies and finds relationships between the interpreted concept and the physical domain. The agents in that world perform this association and transform physical objects through actions. Some of these actions are prescribed within the representations.

For example, a construction schedule is a document and a representation that contains axiomatic rules, and it is employed for planning activities on a construction project. These activities are actions that are going to be taken in the space-time domain. The space domain corresponds to the physical domain of the construction project and the time domain, to the planned order in which the actions (tasks) are executed by the project participants. The construction schedule is a representation that is interpreted by the actors, and it can also be directly manipulated by other agents such as computers. The actors' interpretations are semantic operations and the manipulations of the actors' representations are "computations" of the symbolic composition of the representations. The operations of some activities performed on the axiomatic hierarchy of the construction schedule are "computational" operations. These operations are based on a systematic symbol manipulation following a set of rules. The "computational" operations are not part of the semantic operations although they are interpretable, but they are manipulations of a systematic set of symbols. The semantic operations are based on the actors' interpretations. The actors link together the components of the representation in order to perform actions in the construction domain. These links, which can be either from the representations to the domain or to other components of other forms of

representations, are semantics. The agents' interpretations of and links with objects in the domain, actions, or relations to other representations are semantic operations.

Capturing the Richness of the Domain

The creation of forms of representations, when actors capture aspects from the domain, is intended to reflect perceived features that were assessed as relevant. This judgment sacrifices other features from the infinite richness of the domain for gaining efficiency over the complexity for the operations of these forms of representations. As was mentioned previously, these operations are from the semantics or the computation domain. The richness is limited to the sacrifice made through the actors' categorization, analysis, and conceptualizations of the features to be represented. The same judgment occurs when the representations are generated in the actors' minds. In this case, the representation is intended to meet common aspects or features of the world shared by the community.

A model, which is a form of representation, conceives the world within this limited description. The judgment of the modeler is the mechanism to explicitly build the representations based on assumptions and commitments. The sacrifice made through these judgments is an essential factor for understanding the failures of the operations of the representations in the construction domain. The agents that manipulate the representations ignore the assumptions and the commitments made by the creator of the representations. This misconception is the cause of misinterpretations and of non-acknowledgment of the captured features which have been explicitly described in the representation.

Grounding the Representations and the Domain

The role of the construction participants as agents is to link poor representations through actions in the domain. The agent's interpretation of the representations and the agents actions in the domain are the connection of the concept which is embedded in a representation, to the

physical domain. The actions can also be performed by other agents without interpretation of representations. These agents, however, follow another prescribed set of actions from the models and they do not perform interpretations. The prescribed set of actions of an elevator, an agent in a construction project, is to vertically transport materials a certain distance, at a given speed, over certain time segments, etc. The elevator's action responds to a model that enables the performance of the mechanical movements. A model corresponds to the non-guarantee of operating under any circumstance in the project. The model may prescribe the basic actions for transporting materials. However it may not prescribe the necessary speed for transporting hazardous material.

For a better understanding of the relationship among agents, representations, and the domain, consider Figure 4-1. The two activities in a PERT model are representations of a prescribed series of steps, with certain constrains such as early start, early finish, late start, late finish and their corresponding relationships with subsequent activities, which an agent has to follow. Clearly, this form of representation models the execution process of two activities, which represent a specific concept, for example the timing of vertical movements for transporting materials. The agents, a computer and a construction project actor, perform actions that are prescribed by the model in the domain. The computer agent performs the action by computing the model that consists of manipulating symbolic notations. Then, by some mechanism, such as computing the operation of the crane, the model acts upon or interacts with physical elements in the domain. The construction actor, who is an agent as well, performs interpretations on the represented model in order to execute the indicated process with physical components in the domain.

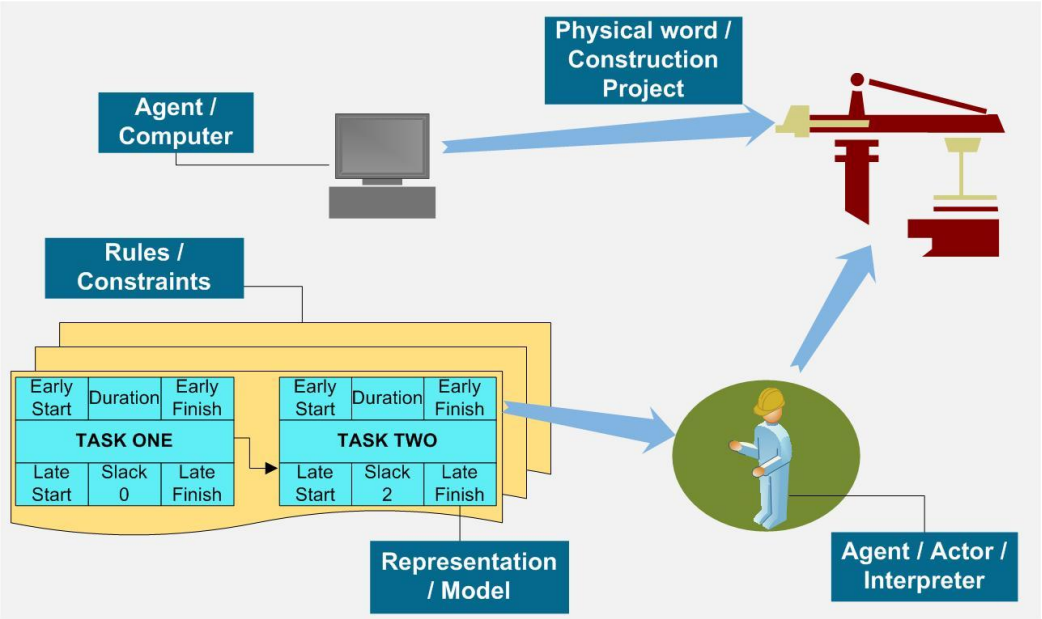


Figure 4-1. Representations, agents, and domain relationships.

When a relationship is set up among a model and an agent or an agent and a domain, an interoperability act takes place. This research recognizes that the automation by computation of the representation is costly and difficult to implement due to the numerous set of operations that constitute construction activities. Hence, it focuses on the relationships between the construction actor and the representation and the construction actor and the domain. The goal is to suggest methods for interpreting representations effectively by developing better methods to represent concepts. A motivating analysis concerning the nature of the representations and these relationships is presented in the following sections of this chapter.

Imperfect Representations

The representations in the construction industry do not fully pick out aspects of features that intervene in an activity on a project. The representations are not complete. The industry has developed other forms for finding the description of the concepts. The partiality or incompleteness of representations in delimiting situations in the construction domain is balanced

with other forms of formal descriptions or conceptualizations, i.e the *specifications*. The objective is to help the construction project actor perform more accurate interpretations by enriching the description of the represented concept.

The *specifications* are formal descriptions of a concept expressed in natural language. They express a *desired* behavior of the concept in particular. If the concept has already been represented in a form such as in a model, the model will describe the series of steps of what is modeled. The *specifications* represent the committed purposes with the concept. The actor's actions, which follow this form of representation, will be complemented with additional information through formal description of the concept by employing the specifications. The model describes the relations, steps, and the order of the actions to be taken by the actor, while the specifications describe the *intended* requirements or conditions that need to be met by the concept in the domain.

The specifications indicate a *declarative* form of describing a concept and model a *procedural* form. 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. This model indicates how the elements should be organized in construction documents. The *specifications* of an element indicate formal characteristics of the element such as the operating temperature range. A brief observation of these forms of representations, the MasterFormat taxonomy and the temperature range expressed in natural language, suggests a description of a concept that captures a particular intention of the modeler. The taxonomy describes a set of elements that are made of plastics and the specification, the intended operating range temperature. The modeler describes through these representations the construction participant's manipulation or use of a plastic element within a temperature range on a project.

Clearly, the taxonomy explains *how* the breakdown of the plastic elements concept is defined, and the *specification* describes an *intended* temperature constraint. Therefore, the *specifications* are sets of descriptions that capture the intention of the actor with the representation, as described in the preceding taxonomy model example. In other words, the *specifications* attempt to describe the *intention* of the modeler or construction participant with constraints or action constraints on the elements in the domains. Furthermore, the modeler *specifies* the conditions of the situation of the element described in the taxonomy through the *specifications* in order to balance poor, explicit descriptions of the concept in the taxonomy.

From the taxonomy model example, two elements have to be outlined. The first element is the construction participant or interpreter, who is the mediator between the domain and the representations or the model. The second element is the representation that prescribes the *behavior* of the agent that manipulates it as well as the *intention* of the modeler or the actor that builds the representation. The actor that builds the representation, or modeler, attempts to make explicit the constraints of the concept in the world. This task cannot be fully satisfied due to the infinite and diversified nature of the world.

The use of the representations on a project by the construction participant is not a guarantee that his or her reasoning for interpreting them is the correct one. The actor's reasoning is based on representations that are incomplete or poor. Small domains can be systematically represented with acceptable and reliable results when the representations are grounded in the domain. However, the unique nature of construction projects makes them a source for infinite richness that has to explicitly be conceptualized in the representations. The actor's reasoning on the poor representations is essential for grounding them in the domain. In other words, the interpreter as a cognitive agent should solve the complexity of applying poor representations in

the real world. Accordingly, there is a need for constructing new forms or representations that facilitate the construction participant's quest in solving this complexity.

Characterization of the Concepts

The assumed characterization notion in this investigation involves the *description* of abstract, mental structures, of entities, of events, or of relationships from a domain performed by an actor as cognitive agent. The *description* is the translation of the concept into syntactic or natural languages, visual representations, or formal structures such as models with the purpose of sharing or communicating the concepts to other actors in the community.

The undertaken course of action of the community for characterizing concepts is through the definition of the *details* and *conditions* of an entity or object. These entities and objects are resources that play a particular the role in a construction project.

Details and Conditions

The *details* and *conditions* are common words used by the construction community for defining the characteristics of any concept used in a project. The use of the terms *details* and *conditions* is a simple form to describe concepts as opposed to complex and formal forms. These complex forms of describing concepts involve ontological distinctions and designations of category of entities, events, or relationships. The description through *details* and *conditions* comprises geometric features, components or parts, additional or assembled items, and functional characteristics.

The *details* are modes of description with features (e.g. geometrical) and other relationships (e.g. dependency relations). For example, the details of a concept which describe the component 'hung' of an entity 'window' are part of the entity 'window' and they have functional characteristics which cannot exists independently; 'hung' needs a 'window' to perform the locking and handling functions that allow an agent to open or close the 'window'.

The *conditions* identify the object or entity as a separate piece in the 'world' in which the construction concept is involved. For any concept, specific situations, which are bounded in a space-time region, are considered and are labeled as *situational conditions*. In the construction domain, situational conditions includes state of affairs, which embrace the entity's location, position, site, place, and settings; status condition, which is the stage of the concept (e.g. completed, installed, delayed) during its life in the time-space region; and the relations with other products or context relations (e.g. set by, part of). In this research, context relations are strictly locative to the object the concept describes. This means that the space or region of analysis is limited to next locative entity.

Situational conditions aids in analyzing the states of affairs and context relations. As an illustration, Figure 4-2 depicts a construction concept 'wood frame window'. It shows the conditions of the visual symbol representation and the possible situational condition (e.g. relative position of the wood window in the wall, and the window settings). As such Figure 4-2 sketches the construction concept context relations and indicates the state of affairs of this particular entity.

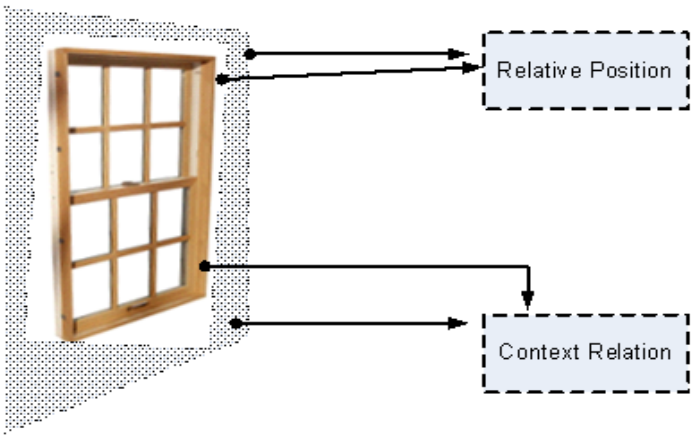


Figure 4-2. Visual representations of *situational conditions* of the 'wood frame window'concept.

For example, in Figure 4-2, ‘place in’ is a context relation of the ‘wood frame window’ to another physical concept; the wood window is vertically placed in the wall. The wood window and wall represent construction concepts, and ‘placed in’ represents the relation between these two concepts.

Implications of Employing Concepts for Interoperability

As was explained in the examples about the reconciliation of two conceptual structures the existence of dissimilar sources of information that generate representations of concepts, is the source of the problems encountered in developing semantic interoperability. Evidence of this problem is found in the difference between the semantics of the conceptual models found in representations such as standards in the construction industry (Mutis et al. 2005).

A compromise is suggested in this study between the cognitive and pragmatic approaches that translates concepts from the actor’s mind to a form of representation that resembles the actor’s mental construct. The translation is a reflection of the agent’s interpretation concerning the concepts *per se*. The central characteristic of the translation is that of the ‘poor *similarities*’ within the results by virtue of the perspectives of the actors who have generated the representations of such concepts. Concepts are furnished *a priori* by the experience of the actors in the learning process. Thus, if the agents attempt to translate them into a representation, they may have different results.

This investigation concludes that the representations that are interpreted and translated from an actor’s mind cannot be *fully* and directly understood by another actor. The existence of a *direct* link between the supplied representation and the interpreters does not guarantee *full* understanding of the translated concept.

The main implication of this conclusion is that the consideration of a set of sufficient conditions to represent a concept in a representation does not guarantee the understanding of the

concept. If formal languages such as logic, which employs symbols, are used as forms of representations, they can represent constraints and, at the same time, are rules of containment. These formal languages express a form of understanding, but do not fully express the characterization of a concept. The representation expressed in these formal languages is a result of assignments of symbols that refer to some entity in the world with the purpose of expressing meaning. For clarity, the assignments represent a set of theoretical structures that include the elements as members of a *category* that satisfies certain conditions.

Consequently, under this assumption, an interpretation that satisfies the set of conditions for symbols is considered true; otherwise it is a false interpretation. This rigid form of assertion of truth for interpreting a set of symbols is further examined within this investigation together with the compromise between cognitive and pragmatic traditions. The purpose is to suggest new strategies for finding levels of knowledge representations that contribute to the understanding of the interoperability paradigm. The *modus operandi* by employing concepts under aforementioned assumptions is fully explained in the following chapter.

Situations and Contexts

A contribution of the understanding for the characterization of concepts is complemented with the notions of *situation* and *contexts*. This examination navigates through the ideas of actors' domain thinking to elaborate the domain's concepts. The tenets for performing the distinctions on these ideas are the *purpose* and *conceptual similarity* principles. Roughly, *purpose* inducts the identification of explicit information to describe concepts and *conceptual similarity* is recognition of the description of a concept in different ways without adopting only one description. The central idea of *conceptual similarity* is to acknowledge the embodied condition of a concept and the possibility to have similar, but not identical, concepts for sharing

among other members of the community. These principles are brought to illuminate the characterization-interpretation cycle in the construction industry scenario.

Situations

A Situation is a widespread notion that attempts to describe "innumerable" continuous processes or an attempt to provide an interpretation for modal assertions. The description implies the interpretation of what the perceived world could be. This investigation does not search for formalization within a modality that addresses concepts like *possibility*, *impossibility*, *contingent*, and *necessity*. It addresses the interpretation and characterization cycle of the situation and contexts. In this analysis, the assumption is that the situation and contexts conserve the same modal status within the cycle. The conservation of a modal *status* puts the situation in a scenario where its characterization and its interpretation, although complex, are viable. If it is considered that the situation is possible to be described, then the interpretation is possible to be performed. If the context is impossible to describe, then the situation is impossible to interpret.

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Situation involves a maximum set of propositions that can be expressed in a representation. *Situations* can be characterized as extracts of conditions or extracts of domains' constraints from *possible worlds*. Situations are captured by actor's stimuli or they can be derived from the imaginary world by a creative, cognitive agent's mind. Situations map perceived conditions of *states of affairs* of the world or map conditions of the imaginary world. The notion of *situation* has created philosophical debates starting from Leibniz's *possible worlds* until Quine's *semantics* (Quine 1981).

The nature of the incommensurability of situations and the number of domains where the situation can be derived from are central for understanding the characterization difficulty of *situations*. In imaginary domains, the characterizations of situations are extremely complex to represent. They are only possible through the use of poor metaphors that are created or assembled on representations. Imaginary *situations* have to be assumed by the interpreters, and they cannot be characterized as *formal* representations by the creative, cognitive agent. This research recognizes the impossibility to define *unique states of affairs* due to the infinite number of situational conditions that can exist. As a consequence, construction industry practitioners struggle to define them by employing the paradigm model.

The description of a *situation* in a representation is intended to accurately translate the perception within a representation. There is not a complete description of what is captured by the senses when the cognitive agent translates what it has perceived from the world into a representation. In the same way, perceptions can indicate 'properties' of concepts erroneously; since they do not carry 'properties' but information about concepts. Yet some incorrect perception and interpretation of a concept are reliable (Margolis 1999), for instance: If an

interpreter, in the dark, at certain angle, considers that a crumpled bag looks like a cat, he or she interprets, under this conditions, the bag as a cat (example from Magolis 1999).

The Translation of Situations into Representations

The organized knowledge, which can be grouped as domains, shapes abstract regions such as the pragmatics domain among other forms of organized knowledge where situations can take place. Actors translate the *situations* within the sphere of this organized knowledge into representations. *Situations*, as well as concepts, can be represented through several forms. Their 'forms' of representations, such as set of markers that stand for natural language, or set of signs that stand for visual *representations*, can be used to describe *situations* and their corresponding explicit information. If an actor attempts to translate a *situation* from the actor's mind to a representation, the translation involves the explicitness of the information. The translation of a situation includes the constraints that explain the conditions of the conceived *situation*.

In the construction industry, the descriptions of concepts are typically developed into representations created within the space-time domain. The situations, then, are commonly described in the space-time region. The construction actors who participate in social activities share these domains. The *situations* need to be characterized through social conventions for being shared and communicated. A construction project is a common, social context that actors share on a physical and a temporal region. In these common domains, multiple *situations* can take place and they must be described through multiple representations within conventional, social forms.

Situations can either require or not require a translation from the actor's mind. The captured image by a lens of a camera is an example of a description of a situation that does not required a translation. It can be easily noticed that the actors who interpret the captured situation share the same space-time dimensions. Consider the *situation* shown in Figure 4-3 of the

installation in progress of a sound isolation layer for a drywall in a construction project. The physical object is placed in a space region, and the temporal description -in progress- is assigned in the time dimension. In Figure 4-3, the space is domain defined at a particular location in the construction project, and the *event* in progress is a time dimension. The construction participants share the same space-time region in a social context, and the photograph is a social form or representation. The actors then can perform interpretation of the situation of the shared social, space-time region in the construction project by employing a common convention form. In Figure 4-3, the image captured through the lens of a camera does not require translation, just interpretation by the construction participants.

Figure 4-3. Image of a situation.

Stability of Situations

The common domain where the *situations* in construction project take place is the space-temporal region that has as components the space and time domain. By virtue of this domain, the described situations continuously change. The remained question is that of what changes can be

considered significant in the situation and how these changes can be instilled in the representation that describes such situation. The space-time region is central for the description of situations on construction industry projects. This notion is aligned with the pragmatisms of James (1897; 1912) in his suggestion that a significant situation cannot be left in an arbitrary, space-time region without bounding it with other events and contexts. Our research addresses the characterization of situations and the necessary assumptions and conditions for the validity of these characterizations.

The first approach that should be taken to address the aforementioned questions is one that explains the concept *'stability'* which is extended and applied to the situations described in the representations. In order to define this notion, the *role of semantics* within the representation must be taken into account. The *role of semantics* within representation was clarified in the previous sections of this chapter. *Stability of situation* determines the permanency of the conditions and constraints that are instilled in the representation by the actors who generate and describe them. The intended *semantics* of a *situation* must be valid when the interpreters perceive the explicit set of conditions and constraints of such representation. The permanency of the conditions and constraints defines the validity of the representation when actors of the community perform the interpretations on this representation.

In other words, the *stability of situations* affirms that the primary set of conditions and constraints, which contain the intended meanings or semantics, is not lost. It can be noticed that describing a *situation* requires a continuing subsequent set of descriptions; its nature implicates the time domain. Then, the primary set of conditions naturally changes. The description of this *situation* should be continuously updated in order to reflect the corresponding changes. The described *semantics'* intent can be lost by virtue of the nature of the temporal domain. If the

explicit *semantics*, through conditions and constraints within the primary description of a situation, is not lost when other actors perform interpretation on that representation, then the situation is considered as *stable*. Furthermore, if the *semantics* contained in the primary set of description is not lost with the added, *subsequent* set of descriptions to the representation, the represented *situation* is also *stable*. The specifications about how to place concrete type K in a particular project, at certain time during a scheduled construction process, are elaborated by natural language. This natural language is a form of representation which describes a *situation*, and it is composed of a collection of signs described by axiomatic propositions, as follows: Concrete temperature at placement must not exceed 90°F; concrete over 60 minutes old must not have a temperature greater than 80°F; no concrete shall be placed that is more the 90 minutes old measured from the time of batching; concrete temperature at placement must not be less than 55°F and concrete shall be protected from freezing temperatures for 7 days after placement, and the ambient conditions must be 40°F and rising at time of placement.

In the preceding example, the description of a situation through natural language representation is *stable* if the primary purpose of the *semantics*, definitions of physical conditions for concrete-placement type K, does not change. It is valid to notice that the *purpose* of the *semantics* is originated from the actor that generates the primary description of the *situation*. Thus, if the conditions are interpreted by other actors as describing concrete-placement situation of concrete *type V*, the indented description is not *stable* anymore.

The fact that other actors misinterpret the *situations* can have multiple causes, which are not further scrutinized within this investigation. Roughly, within the characterization-interpretation cycle, this analysis recognizes the cause of change motivated by the temporal dimension of the *situation*. Concrete type K, for instance, was replaced with concrete type II,

which adds admixtures to high-strength concrete such as fly ash and silica fume, under new regulations.

For the discernment of the characterization of situations, our research does not inquire after the causes of their change, after the truth of their change or after any other inquiry derived from their nature. The focus of this investigation is aimed at understanding the *concepts* in the characterization-interpretation cycle. *Situations* are descriptions of some instances derived from these concepts through representations such as metaphors, sings, or formal methods. As *situations* are complementary to the understanding of the characterization-interpretation cycle of concepts, this research analyzes the influence of *situations* as well as *contexts* within the conceptualizations that take place in the construction domain.

Stable Situations and Evolution of Concepts

The acknowledgment of the temporal region is central in order to make the distinctions of the *situations* continuous evolution of *concepts* within construction projects. These distinctions are necessary to identify the difference between *stable concepts* and stable *situations*. In the same way as *situations, concepts* are *stable* when the primary description, generated by a cognitive agent, retains its meaning to an interpreter. The evolution of a described *concept* consists of the addition of conditions or of constraints to complement an intended description. These are natural additions to the representation of described concept and they are driven by the actors' purposes during a time line. Stable *situations* concern the explicit and detailed description of the *instances* of the concept where the primary purpose of such description is conserved. The *instances* involve propositions, through constraints and relations, with or without other concepts. One characteristic of the *stability* of *situations* is that of these propositions, which contain intended semantics generated by agents concerning concepts described by the representations, do not significantly change over time.

It can be noticed that the nature of *stability* of *concepts* or of *situations* depends of the primary semantics. The actors who generate the description of the concept of situations expect that their description conserves such semantics during their interpretation. The subsequent identification over a period of time of the attempted semantics relations on the representation by interpreters suggests *stability* of *concepts* or of *situations*.

A drawing of a set of squares constrained into two dimensions is placed in an architectural drawing pad as shown in Figure 4-4. The description as a set of squares is a primitive description of a concept that the author translated to the visual representation shown in Figure 4-4. Suppose that the primary semantics of the set of the squares is to describe an architectural 'windows' concept. Thus, the actor that generates the description expects that further interpretation of the set of squares to be the shaped, square windows that describe the architectural 'windows' concept. In this sense, if these further interpretations take place as shaped, squared windows, then the representation holds *stability*.

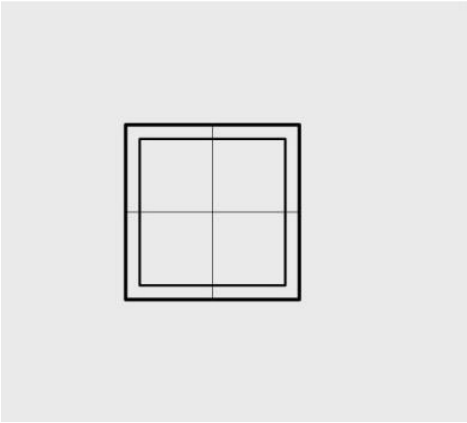


Figure 4-4. Primitive description of a architectural 'windows' concept.

Following the same example, suppose that additional constraints are added to the description of shaped, squared windows, which in turn are additional *semantic* relations to the

concept. As was mentioned, the constraints help describe a concept and give additional meanings. In the case of Figure 4-4, these constraints indicate a situation or an instance of the concept squared, shaped windows. Adding the constraints through adjacent lines and numbers represents this situation of the architectural drawing concept. The constraints include numbers on the set of small squares and distances from one face to the other face to each square on the set of the bigger squares. In the visual representation shown in Figure 4-5, these lines are constraints of *size* and give semantics about the dimension of those representations. The constraints are instantiated with the inclusion of a value shown by the added numbers on the lines. The example of Figure 4-5 illustrates the evolution of a concept and its instantiation. The addition of conditions and of constraints opens the represented concept to generate new *situations*. If the inclusion of this constraint preserves the primary description of the representation, then the represented concept is considered as *stable*.

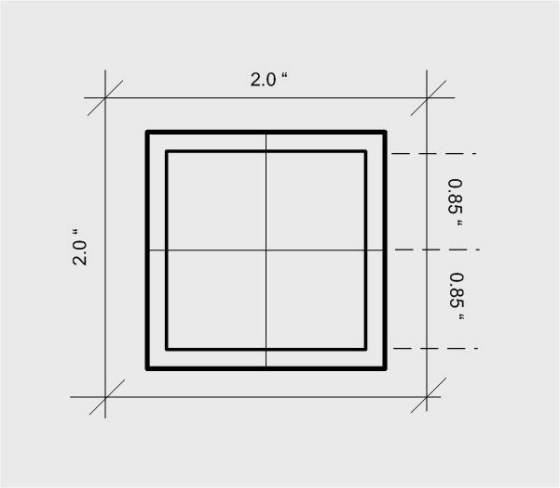


Figure 4-5. Constraints that indicate a situation of the concept squared, shaped windows.

The evolution of concepts corresponds to the natural change of the conceived concepts. The actor that generates the representation translates it from his/her mind to the representation and in turn adds constraints and conditions to simplify or diminish the universe of possible

interpretation by other cognitive agents. The new constraints are mapped and added to the representation through the use of metaphors, signs, or formal representations. The evolution should be perceived through new distinctions. An example that illustrates this point is the addition of another dimension than constraints the representation of Figure 4-6. The assumption of the evolution example is that the actor starts the conception with the most primitive metaphors or signs of the square, shaped window concept. Although these distinctions are shown as obvious in this example, they could be very complex in other cases. The example also shows that the primary, attempted semantics is preserved during the evolution of the concept.

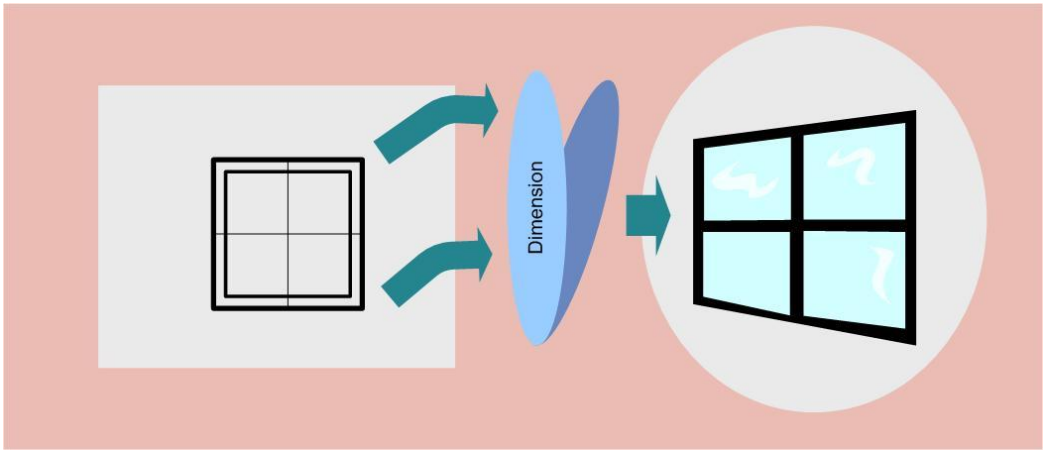


Figure 4-6. Evolution of concept representation which keep initial semantics.

Contexts

Context is a multidimensional notion that is used in diverse disciplines. This notion draws a sense of ambiguity when it is not distinguished from other fields. In the information systems context, it is related to metalevels that separates related, extrinsic information from the intrinsic information, and they are used as a method of reasoning. In *artificial intelligence* the context is used to separate syntax expressions that operates on certain rules elaborated for certain purposes. In *linguistics* the context defines the relevant dimensions of the communicative situation that are

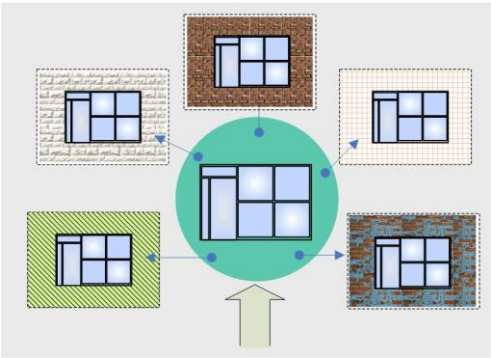
relevant for the generation and interpretation of the discourse by employing additional surrounding natural language from the represented syntax or conversation.

In this investigation, the notion of context is close to the focus of the definition stated in the *semantics* field. Context in *semantics*, which has its roots in linguistics, philosophy, and communications, is related to the method for finding relations to *situations*. In this area of knowledge, *context* is a method in which actors map elements of *situations* to other elements within the same or other domain with the *purpose* of *semantically* enriching the definition or assertion. This enrichment is performed with the intent of communicating a description of a concept or *situation* through a form of *representation* such as texts, oral discourse, images or *visual representations*, among other forms. A visual representation that resembles a *concept* '*doors*' on a computer screen can be further be described by semantically enriching it with other *situations* such as adding other relations to the components of this visual representation. These relations can be of different sort such as the assignment of *size* constraints to the *concept 'doors'* on a computer screen.

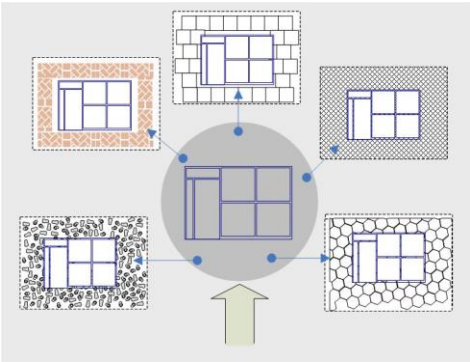
The *purpose* of semantically enriching a concept or a *situation* with additional relations is pivotal to the definition of *context*. *Purpose* can be thought of as a pragmatic function to help communicate a *situation* or a *concept* through representations. Thus, the process of communication by using representations also adopts *intentionality* aspects from the intervening actors. The *situation or concepts* that the actors communicate are embraced within a social context. Thus, any additional relation that is added to describe the context of a concept or *situation* should follow social conventions. The context of a *concept* or of a *situation* translated from the actor's mind is described through representations and signs that follow social

conventions which are interpreted by other social actors. Also, *intentionality* aspects help address the definition of the context relation added to the description of concepts.

An architect attempts to communicate to a contractor a concept 'stainless-steel framed window' as well as the construction brick variations where the 'stainless-steel framed window' can be embedded. In Figure 4-7 (a), the architect's concept of 'stain-steel framed window' and the contractor's concept in Figure 4-7 (b) follow the same type of social convention about the description of the 'stainless-steel framed window. These conventions are the result of some actor's *a priori* experience with the description or the concept, in this case, the 'stainless-steel framed window'. However, a more detailed description of the concept differs due to the aforementioned principle of *conceptual similarity*, even if they have social conventions. In Figure 4-7 (a) and (b), this *situation* is represented through the conservation of the same shape and dimension constraints, but the internal components of the concepts vary. The convention that these actors share can be enough to communicate the *purpose* of the concept or of a *situation*. In this case, the purpose is to make the contractor adopt a variety of bricks in order to consider them as elements for embedding in the concept 'stainless-steel window'. The architect has a purpose for communicating additional context relations so as to describe the *situation* where these brick variations, or context relations, are involved. The architect aids the description of the *situation* with additional context relations. In Figure 4-7 (a) and (b), these context relations are represented by the arrows.



(a) As a glass Window



(b) As a sketch of a window to other wall materials

Figure 4-7. Context relations.

The selection of a context relation that expresses semantics has to be associated with the purposes of communicating the situation. The interpreter actors have to acknowledge the conditions and constraints of the communicated situation. The explicitly expressed purpose through social conventions, which both parties understand, is a catalyst for the interpretation of a situation. Concepts and situations are embodied, and they are constituted a priori by experience. Actors can have countless semantic relations for interpreting the concepts or situations due to the principle of conceptual similarity. The interpreters simplify the possible context relations through the identification of the purpose.

The distinction of purpose, which is a pragmatic function for accompanying the notion of context, is central within this investigation. This pragmatic function includes the definition of intentions, purposes, and reasons of a concept or situation. This function determines a layer of information that should be explicitly communicated to concepts or situations, and its components or characteristic are the actor's intentions, purposes, and reasons. The pragmatics aspects 'conduct' the semantic relations that the actors need to add to this layer or to the description of a situation or concept. In this research, intention indicates one set of possible semantic relations that the cognitive agent has with the object in order to assert an interpretation, e.g. the Project

Manager's intention of defining the type of windows for a construction project is to prepare a consolidated estimate. Purposes connote an interpretation of a cognitive agent of the interaction of some represented entity with other represented entity, e.g. the purpose of the glass in window is to aisle two environments, but keeping the environments visually connected. Reason suggests an interpretation of a cognitive agent concerning the agent's intention behind a represented entity, e.g. the knob of a window would explain that it has the close-open capability, however the architect interprets the knob in its decorative role.

Communicating concepts or situations by using representations embraces the use not only of the semantic relations of such representation but also intentionality aspects from the actors. The intentionally aspects were proposed by Peirce (1991) within the thirdness category. Our research embraces the *embody theory* of concepts and the thirdness category as a form or layer for reasoning is also recognized. It can be noticed that the use of the word category implicates the use of a system for classifying genera or kinds, in the widest sense of this term. Thus if the spirit of the definitions is taken as a system, it will obligate or commit the actors or interpreters to ontologies by answering the metaphysical question: what is there? Thus, the layer of intention should be understood as a layer for reasoning. In the same sense, the expression of concepts or situations with context relations is subject to the cognitive agent's intentions. The perception and interpretation of the representations are the subject matter of the cognitive agent's intention. Thus, the thirdness category or intentionality layer is complementary to the semantic relations defined within the contexts.

Context and Granularity

Concepts and situations are embodied, and they are constituted *a priori* by experience. The identification of the concepts through sings, metaphors, or through formal representations

depends on the interpreters' experience and their capacity for finding similarities. The interpreters observe the expressed context relations, which express semantics and the associated *purposes* of communicating a *concept*, at certain level of granularity according to their capacity and experience. If the interpreters do not find *similarities* of the expressed concept in the body of knowledge for the associated purposes, the granularity representation is deficient for the interpreters. In this case, the interpreters' *a priori* experience does not match any similarity, according to *conceptual similarity*. Thus, the granularity expressed in the representation is deficient to acknowledge the conditions and constraints of the communicated *concept* or *situation*. If the *purpose* of a representation is explicitly expressed through social conventions, it aids the interpretation of the *concept* or *situation* and it complements the granularity of this representation.

In an elemental case example, suppose an interpreter attempts to match a visual representation, shown in the right hand side of Figure 4-7, to a *similar* form in his body of knowledge. The first reaction of the interpreter is to focus on the primary semantic description of the right hand side representation, set of squares printed on the architectural drawings. The adjacent, but separated by blank representation on the same piece of paper, is initially ignored. If the *granularity* of the representation is not *sufficient* to identify the semantics, then the interpreter needs additional context relations to aid the interpretation. This case is represented with the addition of an external visual representation on the left side of the Figure 4-8. This additional representation can be linked as a context relation that complements the granularity of the expressed concept. The interpreter focuses the attention on these two representations and he or she attempts to find semantics through a context relation. If the context relation is identified as

a distinct '*part of*' relation, the interpreter deduces that the left visual representation is an element of the set of squares and that they are metaphors of a 'shaped, square window' concept.

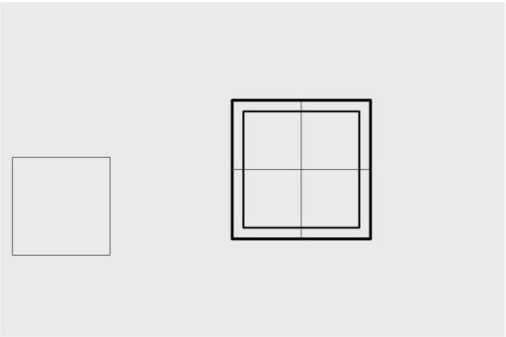


Figure 4-8. Focus on a context relation for complementing the granularity level to interpret a 'shaped, square window' concept.

Characterization of Situations and Contexts

The process to translate a situation or context to a form of representation is complex. These characterizations can be done through metaphors, sings, or any formal form. The characterization implies the assumption that the generators and interpreters recognize the same modal status of the representation. The status indicates the existing state of concept or situation such as possible or as imaginary. An imaginary situation should be assumed as a mind creation for the interpreters, and not a representation that can be mapped to the domains that the agents share. If is considered as possible to be describe a situation into a representation, then it is possible for its interpretation to be performed by another actor. The undertaken assumption is that actors a priori recognize the conditions that define this status. It is not possible to generate representations if the interpreters do not assume a status. A representation whose status has not been defined has the complexity of an infinite reasoning about what it is trying to represent. Safety concepts are represented by possible situations, and they should be recognized by the actors in a construction

project. If the status of possibility is not a priori recognized the reasoning about the representations is infinite or not feasible.

Top Ontological Distinctions

The representations need to be classified into ontological distinctions. The classification aids in the reasoning about the 'world' of the cognitive agent. The distinctions of such classifications are abstractions of conceptual interpretation by perception, and they are combined to generate *categories*. Sowa (1999) remarks that "all perceptions begin with contrasts and they are combined to generate categories of existence". As was defined in Chapter 3, ontology is the study of the existence of entities, events, and their relationships, as well as it is the resource used in formalizing categories, i.e. *'*ontology categories*'*.

This research recognizes top ontological distinctions as the fundamental resource for relating a concept, a representation in the space-time region, and an actor or interpreter. This distinctions are based on the trichotomy of ontological categories proposed by Pierce(1991): Firstness, Secondness and Thirdness. Pierce explained that the first ontological category of any concept is the existence that is *independent* of anything else, the second is the conception of being *relative* to, and the third is the conception of *mediation* where the first or the second are brought to a relation. To illustrate Piece's proposition by using an example from the construction domain, observe Figure 4-9. Each layer of Figure 4-9 represents an ontological category. In the *independent* category, an architectural drawing of the doors concept is specified in the drawings. It exists by itself. The drawings without any interpreter are simply an entity of papers and ink. The *relative* category that the pattern of drawings reflects is a shape of doors. Thus, there is relation between the drawings and the patterns of drawings, which take the shape of doors. The *relative* category is possible under the abstractions of the interpreter who performs the relations. The *mediating* category describes the purpose of the pattern of the shapes, which is to construct a

physical door on a specific building. The interpreter's purpose is to transform the drawings, which contain the construction concept 'doors', into a physical structure. The drawings *mediate*, through the intentions of the interpreter, the abstraction of the patterns 'doors' in order to transform them into the physical entity 'door' of a building. The reader is reminded that representations such as image schemas of *doors* are *metaphors,* which are subject to interpretation by the cognitive agent.

The reader must be intrigued as to why this approach bases the interpretation of concepts on ontology categories. This approach claims that there exists a strong link between cognition and concept, the former represented by a human being (how the world is interpreted) and the latter by the representation of reality or the real world (how the real world is represented). An ontology, which reflects this link, should be elaborated in a way that reflects the generalization of specific concepts of the real world. This approach can take place in the integrationists' paradigm (George Lakoff and Johnson 1999; Gibson 1977), which is a good compromise

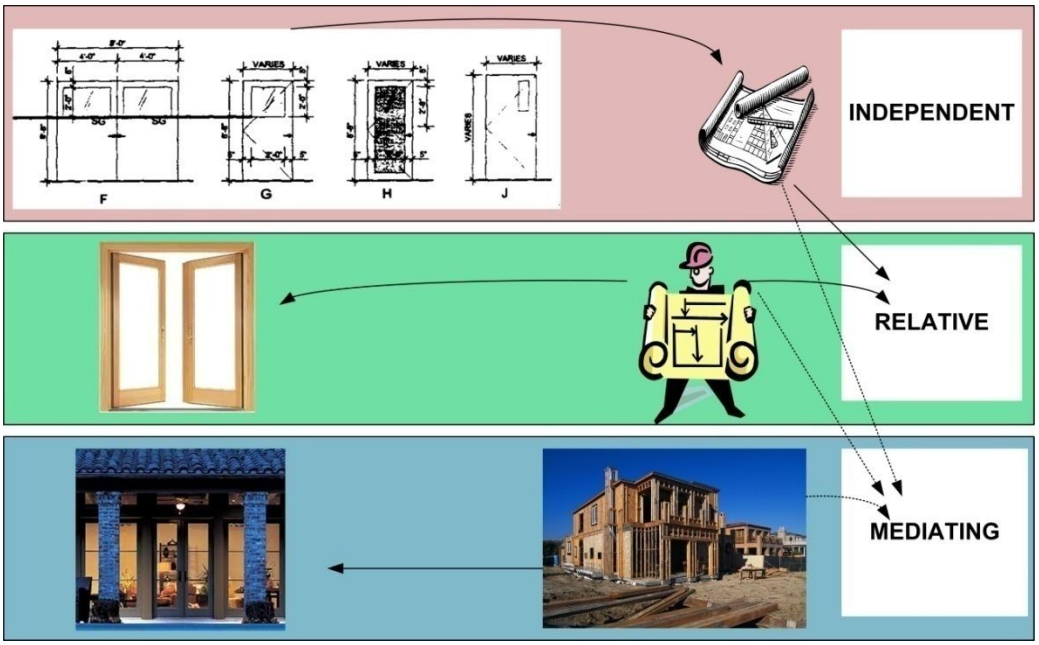


Figure 4-9. Conceptualization on a domain.

between hard ‘referencialist’ and purely context-oriented semiotics (Gangemi et al. 2001). What is most important within the introduction of Pierce categories into an ontology is that this research recognizes the importance of the intentionality of the cognitive agent. The cognitive agent’s purpose or intention is to direct the agent’s attention to an observed concept cognitive agent. The intention guides agent’s attention to what is considered relevant of an observed concept. Pierce’s categories are top ontological categories. Top ontological categories capture the reasoning of a concept and classify it into categories of existence. These categories indicate a common denominator of the concepts of the domain, for a more redefined domain.

The agent must recognize what he or she needs from the representation of the concept and from the context relations, or in Searle’s words, what the speech acts mandate and what the contextual relations included in speech act are (Searle 1995).

CHAPTER 5
A DISJUNCTIVE OF THE MODEL PARADIGM

The description of concepts into some form of representation does not guarantee the understanding by other members of the community of what is described. The choice of representation implicates different kinds of problems primarily influenced by the purposes of the actors in a domain. In a brief examination, consider aspects of representations such as logic and ontology (Sowa 1999). The choice of representing a concept in formal logic involves the lack of a subset of logic expressions to determine meaning of what is intended. The choice of representing a concept through an ontology implicates multiple problems, briefly: different choices to categorize concepts, different forms to name the same concepts, and different approaches for axiomatization, among others. In addition, 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 pipes and water pumps for buildings can be complemented as much as possible with more axiomatization. The result might be more accurate for modeling pipes in buildings for the hydraulic engineering, but might be seen contradictory if the electrical engineer attempts to reconcile his model with the hydraulics ontology on the specifications on electrical, local regulations.

A description of a concept in an ontology rests in the mechanisms of categorizations. The mechanisms are methods for considering only what the significant parts of a concept are from the modeler's perspective. The perspectives of two different modelers are not the same. The ontology of a modeler in Europe about construction materials for sewerage cannot reflect the same categorizations that are made by another ontology developed in Canada or in Texas about construction material for sewerage, because of the differences in the modelers' perspectives.

Ontological distinctions target the structure and the nature of some entities in the domain, but they do not target distinctions that include the role of the entities, which, in fact, is cognitive dependent. That is why we need other approaches that handle the mediation of the cognitive agent, the characterization of concepts through roles, and the characterization of concepts that includes context relations.

Our investigation directs the attention towards the process of *interpreting* a concept from a representation, as opposed to pursuing an approach of searching for the right "choice" for representing concepts. The scrutiny on interpreting concepts results in the study of the conception of truth by cognitive agents on entities, states of affairs, and events in the world. There are differences in the notion of concepts, which rest where the concept was originated and was formed, between the analytical philosophical traditions, and within the cognitive and pragmatic traditions.

This chapter illustrates the assumptions of this research concerning the dependency of the characterization of concepts with its purpose and the influence of a purpose when an actor performs an interpretation of a representation. This assumption is based upon the hypothesis that <u>an entity, event, or relationships that are perceived in the space-time region has no intrinsic meaning</u>. The identification of meaning of entities, events, or relationships in a domain depends upon cognitive factors such as purposes, which is an approach that takes into account the actor's mind to define concepts. The meanings of entities, events, or relationships are not intrinsic *per se* but are dependent on cognitive aspects.

Disjunctive of the Model's Embedded and Embodied Concepts

The notion of concepts as abstract, mental structures of entities, events, or relationships from a domain is a generalization of a more comprehensive notion that goes along with the philosophical approach of this research, which is based more on a compromise between

cognitive and pragmatic approaches rather than on analytical, Western, philosophical traditions. The aim of the analytic tradition is to clarify philosophical problems by examining the language that employs symbols to express it. This tradition privileges the use of sense and reference in the formation of meaning (Gottlob Frege (Appiah 2003), Kurt Gödel (Nagel and Newman 2002), Alfred Tarski's (Tarski 1944), among others). The differences in the notions of concepts between the analytical traditions and the compromise of cognitive and pragmatic traditions rest in the origination and the formation of such concepts. The cognitive notion of concepts is contingent on the human mind, while the analytic tradition notion considers concepts as extractions from the world, as if they were the world itself, which constitutes a characterization of an objective reality.

In the cognitive and pragmatic perspectives, the notion of a concept as an abstract mental structure takes place in the human mind and serves to designate reasoning on categories of entities, events, and relations. Categories are the basic *distinctions* generated by the senses, and they are refined by experience in a learning, cognitive process. The cognitive process serves as a medium for judgments not only about what is captured by the senses but also about what abstract entities are identified by distinctions. *Distinctions* are comparisons to other primary mental structures learned *a priori*. The *distinctions* do not recognize "fixed" *categories* that conform to an ontology of an external reality, with "fixed" categorizations assumed to model what exists. *Distinctions* are based on comparisons that employ contrasts with the purpose of finding relations to a primary, mental structure. Reasoning, a basic mechanism of *inferenc*e that uses these distinctions, is an abstract and mental process that seeks the identification of those primary, mental structures. These structures are constructs that resemble "prototypes" (Lakoff and

Johnson 2003), and they are successively and continuously complemented and modified according to the cognitive agent's experience.

The influence of the pragmatic perspective in the notion of a concept, particularly on the explained definition of *category*, is the addition of a function upon the *distinctions* and the reasoning mechanisms. The function is framed within the role of intentionality. *Intentionality* mediates between the mental structure and the entity. The mediation is aimed to shape the *meaning* or semantics of a concept. The relations that take place in the actor's mind between a mental construct that conserve the notion of a particular concept and the *distinctions*, such as those instilled by stimuli from an entity in the world, constitutes semantics or meanings. The mental constructs are consciously complemented and constitute a continuous learning process during the actor's exposition of situations when the mental constructs are needed. From the pragmatic perspective, an immediate consequence of the notion of concepts is the rejection of the definition of concepts as derivations from properties of entities, of events, and of relationships *inherited* from the physical world.

The result is an additional function upon the *distinctions* and upon the reasoning mechanisms that shape meanings is that the *actor* clarifies what the *de facto* concept represents. The meaning or semantics of a concept is established *a priori*, it is clarified with this *additional function*, and it is framed within one feature: *intentionality*. Although the clarification about 'what the concept represents' might have a sense of relativity, fundamentally as a result of a *de facto* role of a concept, it is indeed the actor's *level of understanding* concerning that concept. The shaping, meaning procedure can be apprehended as a mental process to find additional relations between an entity and a 'view' of a mental structure. An entity is the actor's acknowledgement by stimuli of an object or of a symbol in the external world. The agent

recognizes meanings because of the *distinctions* and of the reasoning mechanisms. This recognition is performed through the reasoning process and it is made possible through the agent's previous experiences with an entity.

The *level of understanding* about a concept involves *dependence* of the agent who finds semantics concerning the concept and, at the same time, concerning an interpretation that is a believed to be shared with other members of a community. These beliefs are considered social facts (Searle 1995) and they are exclusively related to a social understanding of the concepts. This current investigation is aligned with Searle's proposition on the agentive conception of truth about the interpretation of concepts in the world. The alignment is revealed on a common shared structure of knowledge on domains. Agents share a common understanding that implies semantic relations with the purpose of communicating concepts. The so-called '*institutional facts*' in Searle's work are facts that are relative to social understanding. His work seeks to explain collective intentions as a distinct form of *intentionality* from each individual agent's belief. Searle proposes a set of rules that are essential for collective intentionality.

The Limitation of the Modeling Paradigm

As was mentioned earlier, the divergence on the understanding of a concept among actors takes place when actors generate representations of concepts in order to communicate and when actors perceive the representations in the interpretation of those concepts. The generation of concepts from the analytical traditions compromises the understanding by the interpreter of the evidence of some phenomena in the world. The phenomena are syntactically 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 mechanical reasoning process similar to a mathematical manipulation. A group of a community

addresses the understanding and characterization of the world into symbols and other forms of representations; in other words, the representations are aimed to be universally understood.

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 symbol 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 *aluminum* 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*. Models assert truth if the satisfactions of their characterization are met. From this analytical tradition, then, the identification of meanings of each particular symbol in a model can be distinguished in the relations with 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.

Correspondence

For better understanding to the notion of models and their limitations, an analysis of the *correspondence* implications is necessary. *Correspondence* is bonded to the theory of reference that stems from the work of Gottlob Frege (Appiah 2003). Fregean theory considers *senses* as referents that link a symbol in the proposition to the world correctly. The distinction of senses

and reference can be illustrated in Frege's famous statements: "I believe Venus is the Evening Star", and "I believe Venus is the Morning Star", by anticipating the referent as "The Morning Star is the Evening Star" (this account of Frege is based on Appiah's citation. Both of these expressions refer to the entity Venus, but they have different senses. The referent in this expression is the *mode* of presentation, in the case it is "the morning star." In other words, the referent determines how it is picked out or associated from the world in the mind. Frege stated that referents hold truth-value, which is either True or False, in virtue of the conditions that hold each expression: "the morning star" and "the evening star" refer to Venus in virtue of different properties. Senses are abstract objects that exists in mind and that do not interact in the physical world. Frege also used analytic distinctions in proposition to identify the parts that inform about a sense and the parts that are referents within contexts in expressions. The sense of a whole proposition is determined by the senses of the parts, and, in the same way, referents of the whole proposition are determined by the parts. Then, an expression has true value or false value when the *reference* is determined or picked out for the expression. The expression "A saw a professor at the conference" is a sense that has no referent, but the expression "A saw a professor of economics that won the 2007 Noble Prize at the conference", has a referent with "true" value.

Referents are supposed to indicate truth in the *correspondence* between the symbol and the world. *Correspondence* is a metaphysical notion that ss 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. *Correspondence* refers to the form of the 'fitting' of the propositions in the model in the world. Within this definition, propositions in a model become false if the *correspondence* does not adequately fit and they become truth if the opposite case occurs. One of the implications of considering the

correspondence theory, which is an assumption in the modeling paradigm, is that the absence or failure to formulate a proposition in the model, which in turn constrains the model, regards false instances of the world that should be included in the model. A failure in a model is considered a *false fact* in the world that clearly distorts any situation that occurs out of the modeler's mind.

Willard Van Ormand Quine, one of the most influential American philosophers, contradicts the idea of referents and *correspondence* (Quine 2006) . In his famous dictum "*To be is the value of a variable*", he distinguishes a relationship between logic and metaphysics. The choice of a form of logic is the choice to commit to a certain arrangement of the world. From this, Quine accepts the existence of entities of the world when they are described by variables, but neglects the commitments of properties or other abstract entities, by assigning values to variables. Commitment is what an actor or agent considers real in a situation in the world. A commitment is an assertion of truth, which is termed *ontological commitment*. Quine recognizes an ontological commitment created by variables that describe objects or entities, but does not recognize other commitments such as properties of the objects. In other words, Quine expresses explicitly a commitment to the relation of the entity and symbols as variables. The choices of variables that any actor relates to an entity of the world are the actor's commitments to the existence of those entities. Variables are symbols employed in logic, and entities are the conjunction of properties of things in the world. For example, if an actor selects the variable, in this case, a word in natural language, '*aluminum_window'*, for all *aluminum_windows*, the entities that can vary over *aluminum_window* are the entities whose existence is assumed.

The important point of Quine's analysis within this investigation that is to be emphasized is that an actor does not embrace truth when the actor assigns an interpretation of the world to a variable. An actor bounds the interpretation to a variable, but that variable does not contain any

implicit contents of properties or abstract entities. The properties and other entities might be implicit in the first description of the entity or object, but they cannot be described explicitly by employing variables. In this research view, this point underlines the failures of modelers of domains in attempting to communicate their interpretation to a model of the description of the phenomena, which is expressed axiomatically through models. Our investigation claims that commitments are *interpretations* by the modeler of the observed entity. Our investigation also rejects the notion that these interpretations are tantamount to truth.

As models are based on propositions, they suffer the limitations that logic and the symbolic notations convey. Models cannot capture the richness of the phenomena of the world in their syntactic notation. Furthermore, the continuous change of the physical world makes it impossible to set stable propositions. These particular propositions are mappings from the instances of the world and the modeler's experience to elaborate concepts. Thus, the assumption that establishes an objective relation between any symbol and the world is not possible. The modeler's assumption is that the propositions are a set of necessary and sufficient conditions that describe the phenomena. The complexities of the world cannot be accommodated in the limited resources of symbols and propositions.

Embodied Concepts

The inclusion of the word *embody* within the notion of *concept* implies that the sensory-motor systems are main characters in the definition. Concepts are created and shaped by employing inferences that take place in brain as a result of the way the brain and body are structured and in the way they function with other cognitive agents and in the physical world (Lakoff and Johnson 2003). Under this perspective, the actors depend strongly on the concepts and on the form of reasoning.

The claim of this line of thought is that concepts are created through the sensory-motor systems independently from the categories of reality. Concepts are products of a continuous adjustment through a learning process of the cognitive agent, but the mechanisms for perception and object manipulation are responsible for conceptualization and reasoning. Concepts are represented as mental structures that are continuously adjusted by learning experience. The mental structures can be encountered in basic levels, and they are used for reasoning. These basic structures can be used as metaphors for inference and reasoning.

The *actor* takes the understanding of the phenomena by perceiving it as truth. This is embodied truth, not objective or absolute. However, it is not subjective (Lakoff and Johnson 1999). The sense of 'shared truth' comes with the aide of a common set of spatial relations. Cognitive scientists had proposed a spatial relation as a common domain from which to derive truth, and, from this domain subsequent relations to derive semantics are determined (Gärdenfors 2000). From a cognitive science perspective, truth is gradually adjusted with the interaction of the agents in the world, while within phenomenology, truth is perceived and discovered from experience in the world. The embodied concepts are further explored through our survey on semiotics in Chapter 7 as well as through the characterization of concepts in the following sections.

Semantic Holism

The mapping of symbols to entities in the world through referents is not objective. The mappings are products of an interpretation made through the senses, and therefore cannot support a determinative truth. The understanding from the cognitive line of thought concerning the foundations of meanings of representations and, from the analytic perspective, its contrast to symbols and language assigned in logic and their connections to entities in the world, is a central component to enlighten the problem of interpretation in interoperability.

Within the analytic tradition, all forms of representations that are used for communication, such as natural language, formal languages, and models, can be framed by expressing them as symbols in a form of logical language. The examination of the relations of symbols to the world for identifying meaning started with Quine (1952), who scrutinized symbols from logic, axioms, and their connection to the entities in the world. Quine stated that symbols could not have meaning by themselves without being linked to a set of symbols or to the abstract structure of a model. In other words, the meanings of symbols cannot be derived until all of symbols in the set or in the model are interpreted. An interpretation, under this tradition, means the association made with symbols within a *set* of symbols or within a model. According to Quine, one symbol is not enough to guarantee the intended interpretation. This doctrine is known as semantic holism. Semantic holism or meaning holism is the idea that the meaning of an expression, which is composed by symbols or set of symbols, depends on its relations to many or all other expressions within the same totality (Pagin 2006). For clarity, *holism* entails the view that no complex entity can be considered to be only the sum of its parts.

Semantic holism claims that arbitrary formal symbols can only have consistent meaning if they are interpreted all at once, as the whole set of symbols. Meaning holism was formulated for linguistic expressions, but Quine extended it to formal syntactic expressions. Meaning holism articulates the idea that expressions or symbols can be interpreted all at once, not in a separate, isolated way. The isolation of one of a complex entity's part causes the loss of the meaning that was attempted by the sum of its parts. The meaning of an expression depends on the totality of the whole set of expressions. The meaning holism theory contrasts with atomistic theories that state that each simple expression can have a meaning independent of all other expressions. It also contrasts with molecular theories, where the meaning dependencies in an expression are

restricted to smaller parts or subsets of expressions, and with compositionality principles that state that the meaning of a complex expression depends on the meaning of its parts and on its mode of composition. This analytic distinction is not a matter of problem solving strategies. In fact, it is a paradigm that has intrigued philosophers for centuries.

The importance of the meaning holism approach is that it rejects Frege's idea of a fixed truth when one, unique expression refers to one entity in the world via objective senses. Frege stated that the logical axioms are true because they express true thoughts through references to entities in the real world. For clarity, sense is the mode of presentation of the reference. Therefore, a unique expression cannot hold truths about an entity in the world through references. The expressions that embrace symbols cannot claim truth that characterizes an objective reality in the world. Ontologies that assign variables in order to describe some phenomena in a domain cannot hold truth characterizations. In the same way, models cannot hold truth characterizations; they state axiomatic relations under a set of assumptions. Within the perspective of this investigation, this is a significant problem for communicating meanings of concepts in any domain, such as in the case of the construction industry.

Since members of the construction industry share space-time regions, commonalities about entities, events, and relations arise. There are no unique classifications of categories of the entities in the world that pervade for all members of a community. The only general acceptance of classifications, rules, and axioms, is done by '*enforcing'* them by *legalization*. The enforcement does not indicate an objective characterization nor a universal truth for the members of community. Accordingly, if members of the community recognize that one person has the authority to enforce a classification, then the members of a community should exclusively understand the classification, axioms, and rules as assumed truth about the characterizations.

These enforced rules, classifications, and axioms, which are supposed to describe concepts, are known as ‘standards’. Approaches that employ taxonomical classifications experience an analytical problem when the modeler restricts the categories to what has been inherited.

The current investigation proposes that there is no single correct classification, axioms, or rules that define concepts for the construction community. The meaning of a fixed set of axioms cannot be “fixed” as true. Meanings can be adjusted by subsequent interpretations. At the same time, meanings depend on the level of understanding of the interpreter. The creation of categories from the physical world assigns “fixed” conceptualizations contrarily to the dynamic nature of the observed physical world.

Granularity

Our research proposes the use of a concept of granularity to manage the problem of semantic holism within interoperability practices. We propose here that the way to overcome the problem of semantic holism is through *granularity* and the way to acquire concepts. This investigation focuses on new levels of representations such as *intentionality*. The purpose is to address in a different way the characterization of concepts by considering the notion of granularity of the concept representations. The introduction of the granularity notion is explained through the recognition of the role of the cognitive agent’s intention for the interpretation of concepts. This intention makes the agent contrast the intended semantics of the representation with the observed concept representation. This contrasting is a simple cognitive process that makes the agent select the relevant details and situational conditions of the representation of the concept and then perform an abstraction. An actor perceives observational factors that are noticeable. Gibson (1977) stated that what the agents perceive are *affordances*, not qualities of the object. *Affordances* are invariant combinations of variables of what the cognitive agents notice. In this fashion, if a cognitive agent perceives *affordances* and performs a reasoning

process with them, the agent can perform plausible interpretations by using non- observational factors such as experience.

Granularity refers to what the agent notices. The cognitive agent looks at the world through 'grain' sizes, abstracts the things that serve the agent's purpose, and translates different granularities as needs dictate (Hobbs 2002). As mentioned before, the relation one agent has with a concept is the agent's cognitive thought of such a concept. There is a strong relation between semantics and the 'grain' size for interpretations. The reasoning behind 'grain' size shaping is powered by the intention of the actor. Thus, interpretations are cognitively associated with a certain level of granularity by the agent.

As was stated before, representations themselves do not have intrinsic meaning. The semantics of the representation are motivated by the agent's purpose. This purpose makes the agent select *relevant* details and situational conditions in order to perform the interpretations. This agent's '*relevance*' makes reference to the grain sizes, which are sufficient or deficient in articulating interpretations. It is clear that *details* and *situational conditions* are the *descriptions* of a concept into a representation. Conspicuously, *granularity* states that the *sufficiency* of *details* and *situational conditions* contributes to performing accurate interpretations.

An important definition proposed by our research is that of *granularity level*. The *granularity level* of a construction concept is a 'boundary' of significant *details* and *situational conditions* or irrelevant *details* and *situational conditions* used to perform 'correct' interpretations. For example, in a text-based representation of a concept the correct level of the *details* and *situational conditions* will be reached when the observer can find the set of descriptions of the details and *situational conditions* with which to interpret the construction concept.

The actor that generates the representation adopts this boundary in order to describe the representation of the concept with sufficient levels of *details* from which the observer could elaborate an accurate interpretation. Then, the right level of *details* and *situational conditions* occurs when the observer finds all significant *details* and *situational conditions* in the representation. The right level of *details* and *situational conditions* are the right level of *descriptions* of a concept into a representation. Thus, when an actor in a construction project performs an accurate interpretation of a representation, a *boundary of sufficiency* is reached, and when it is asserted incorrectly, a ‘boundary of deficiency’ is revealed.

From the above analysis, there are two cases concerning the *boundary of sufficiency*. First, the actor does not have the *a-priori* relation (e.g. experience) with the representation. In this case, the actor is not able to notice any significant semantic relation between the *details* and *situational conditions*. Second, the actor is not able to map any semantic association or notice any significant *details* and *situational conditions* because the representation has poor descriptions. This is the case when the explicit information consigned as the description of a representation of a concept is not enough for performing an interpretation. Then the representation is semantically poor and the description of its representation is deficient and accurate interpretations cannot be performed. Thus the representation is not a recreation of the original purpose that was intended by the representation’s author.

Our investigation proposes the recognition of a triadic relation: representation, relation, and purpose. Granularity levels express and support this triadic relation: the signs, which are representations, are independent from other factors; the relation indicates the relationship between the cognitive agent and the representation; and the purpose is the agent’s intention with the representation. If the cognitive agent performs an accurate interpretation, the *boundary of*

sufficiency indicates that the agent selected relevant or discarded irrelevant *details* or *situational conditions*, according to the agent's purpose. The *boundary of sufficiency* also indicates that the *details* and *situation conditions* that were used, also called explicit information, were enough to perform the interpretation.

The information that is explicit is that which has been articulated in a representation. The *boundary of sufficiency* indicates a right level of granularity for the actor's intention for performing an interpretation of the articulated information of the representation. For clarity, articulated information refers to the associations of the symbols or signs made by the actor that were perceived with the purposed of finding semantics.

Figure 5-1 articulates the *granularity* of the representation and the response of the cognitive agent in a qualitative graph. The *boundary of sufficiency* is the peak of details and *situational conditions* where the observer can derive an interpretation. The observer discards other details that are irrelevant while taking into account the interpretation's purpose. A concept itself does not have intrinsic meaning. The actor identifies the information consigned in the representation that corresponds to the explicit information for the representation.

Figure 5-1 illustrates that the granulari*ty* would not make any difference if the observer's knowledge were not enough to perform an assertion on the interpretation. This follows with the recognition of the current investigation that there should be an *a-priori* existing relation of the cognitive agent to the representation, embodied in the agent's background knowledge. As was mentioned, interpretations depend on non-observational factors such as the *level of knowledge* of the concept in a specific domain and the observer's experience with the intended concepts among others.

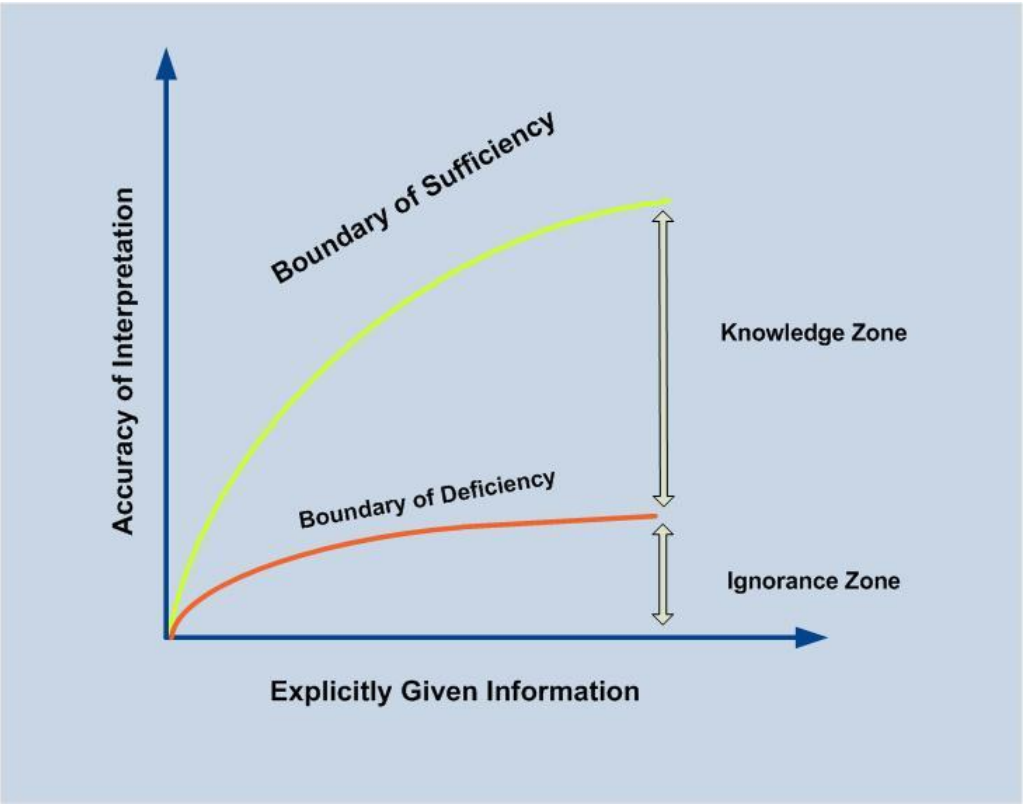


Figure 5-1. Qualitative relationship between quantity of explicitly given information and accuracy of its interpretation.

Figure 5-1 was developed to exhibit this level of knowledge factor, when the characterization of the representation intersects the *boundary of sufficiency*. Thus, if the level of knowledge is not enough to perform a plausible assertion concerning the concept representation, the observer reaches the ignorance zone. However, if the case is that the description of the information of the representation is poor and the observer has a proper level of knowledge to perform a plausible assertion, the observer reaches the 'boundary of deficiency'. The 'boundary of deficiency' in the graph indicates that the characterization of the concept in a representation is not enough at any level of the observer's perception to perform plausible interpretations. The

interpretation is a plausible assertion, and it is contingent on the cognitive agent. The word contingent is used to refer to things that are true in only some possible worlds (Appiah 2003)

In summary, the *boundary of sufficiency* that accounts for the details and *situational conditions* of the representation depends on the construction participant's needs or purpose and past experiences in order to fully interpret that representation. If the *boundary of sufficiency* of the details and *situational conditions* are not satisfactory for inferring the meaning of the representation, the actor will clearly face the 'boundary of deficiency' of the details and *situational conditions* of the representation. Therefore, the 'boundary of deficiency*'* depends upon the actor's needs or purposes and upon comparing experiences. Our study advocates that any representation of the concept should be consistent and coherent at the *boundary of sufficiency* of the details and *situational conditions* from which the observer can find semantics of the intended meaning and from which the observer can derive plausible interpretations.

Conceptualization

A *conceptualization* accounts for all intended meanings of a representations used in order to denote relevant relations (Guarino 1997). This means that a *conceptualization* is a set of informal rules that constraint a piece of an observed physical construct or of an abstraction. An actor or observer uses a set of rules to isolate and organize relevant relations. These are the rules that tell us if a piece of such a concept remains the same <u>independently</u> of the states of affairs. One particular set of rules, which describes an interpretation of the domain, is called the intended model.

A *conceptualization* of any physical construct or abstract concept in the construction domain must include details that will independently describe the construction concept from its states of affairs. *Situational conditions* will describe the concepts by reflecting common situations or relevant relations to the *states of affairs*.

Guarino (1998) further clarifies the *conceptualization* notion, which refers to a set of conceptual relations defined on domain space that describe a set of *state of affairs*, by making a clear a distinction between a set of state of affairs or possible worlds and intended models. For better illustration of *conceptualization*, consider Figure 5-2, which schematically depicts a *conceptualization* into a specific domain, and indicates components that help define a *conceptualization*. The components are minimal ontological definitions of the entity, logical axioms that use the syntax and vocabulary of a language, and additional semantic relations, which help describe several states of affairs.

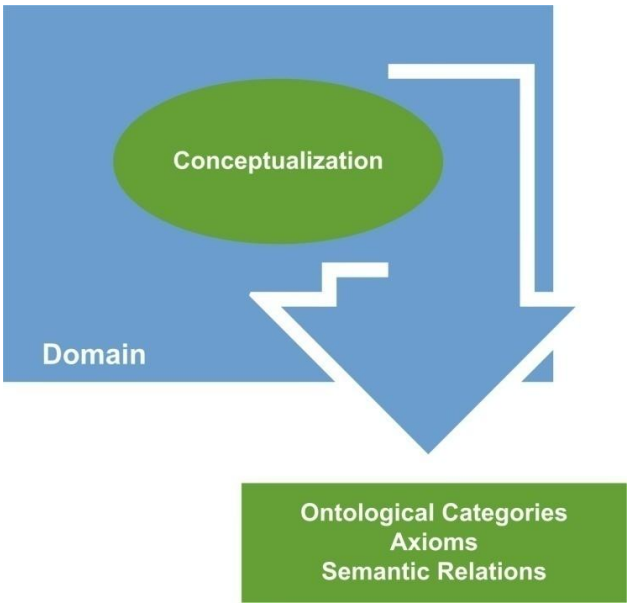


Figure 5-2. Conceptualization on a domain.

The *conceptualization* of the concept 'wood frame window' involves an explicit formalization of the ontological properties. The description of the 'wood frame window' concept can be broken down into details, and into the detail's specification of their relations (e.g. has hinges, opening or fixed components). Additional description of the concept specifications, which comprehend context relations and other constraints that do not change with the *states of*

affairs of the concept (e.g. the relation ‘set by’ and ‘on’ of a detail do not change with the position of the window), will help to define the ‘wood frame window’ concept for further interpretation.

In order to clarify the *conceptualization* notion in the construction domain, the reader has to keep in mind that a concept in this domain can be described by its *details and situational condition relations.* Construction concept *details* comprise their geometric features, their components or parts, additional or assembled items, and their functional characteristics. The concept *condition*s are the *situational conditions* or *state of affairs*, which embrace the concept location, position, site, place, and settings; the *status condition,* which is the stage of the concept (e.g. completed, installed, delayed), and its *relations* with other products or *context descriptions* (e.g. set by, part of). The details and *situational conditions* then are minimal ontological definitions of the concept that can be formalized by including logical axioms that use the syntax and vocabulary of a language, and additional semantic relations, which help describe several states of affairs.

A construction domain example is shown in Figure 5-3. The *conceptualization* of this ‘wood frame window’ involves an explicit description of the ontological definition. This ‘wood frame window’ concept description breaks down into details, and into the detail’s specification of their relations. Additional description of the concept intension, which comprehend context relations and other constraints that do not change with the states of affairs of the concept (e.g. the relation ‘set by’ and ‘on’ of a detail do not change with the position of the product) will help to define the ‘wood frame window’ concept for further interpretation.

Thus, conceptualization involves the explanation of relevant details and unintended relations from the *situational conditions* of the concept of the construction domain. Note that

*conceptualization*s are described by a set of informal rules used to express the intended meaning through a set of domain relations and that these meanings are supposed to remain the same even if some of the *situational conditions* change.

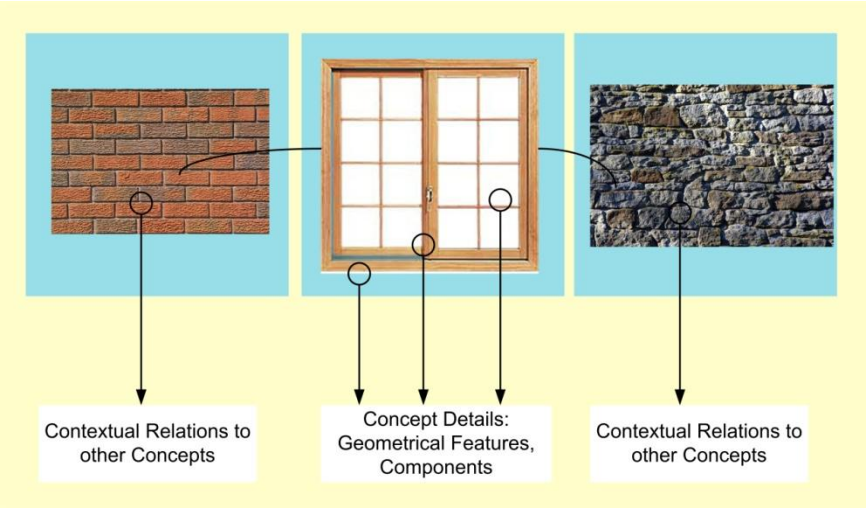


Figure 5-3. Context relations and details for conceptualization.

As shown in Figure 5-2, *conceptualization*s become extractions of the domain knowledge and are specified by ontological categories, relations, and constraints or axioms. Categories are forms of classifications of the ways cognitive agents see the world. *Conceptualization*s, through the use of relations and constraints or axioms, attempt to formally define the cognitive agent's views or their perception of the world according to the nature of the concepts themselves and the categories cognitive agents use.

In summary, *conceptualization*s become extractions of the domain knowledge and are specified by ontological categories, relations, and constraints or axioms. Categories are distinction or forms of classifications of the ways cognitive agents or actors see the world. The ontological refinement processes are explicit formalizations of the concept conditions and the concept details. *Conceptualization*s, through the use of relations and constraints or axioms,

attempt to formally define the cognitive agent's views or their perception of the world according to the nature of the concepts themselves and the categories that the cognitive agents use.

Summary

Our study addresses the understanding of interpretations of concepts in the construction domain that express explicit forms by transforming concepts into models, schemas, or conceptual models. It also suggests that expressions that embrace symbols cannot claim truth that characterizes an objective reality in the world. For example, the ontologies for information systems as knowledge representation structures assign variables in order to describe some phenomena in a domain. These structures cannot hold true characterizations. Similarly models cannot hold true characterizations; they state axiomatic relations under a set of assumptions.

Our investigation also claims that assignation of variables are *interpretations* by the modeler of the observed entity. Our investigation also rejects the notion that these interpretations are tantamount to truth. Within the perspective of this investigation, this is a significant problem in communicating meanings of concepts in any domain, as well as modus operandi for the representation of these concepts. An example of this complexity is the need for human intervention for interoperability. The reconciliation problem is a manifestation of this significant communication problem.

The current investigation advocates that there is no exact classification, axioms, or rules that define concepts for the construction community. The meaning of a fixed set of axioms cannot be "fixed" truth. The creation of categories from the physical world assigns "fixed" conceptualizations contrarily to the dynamic nature of the observed physical world. The dynamic nature should be understood as evolutionary. Therefore, the conceptualization of construction concepts should follow the same evolutionary line. At the same time, meanings depend on the level of understanding of the interpreter. In addition, the meanings of what is represented are

adjusted by subsequent interpretations within the cognitive agents' mind. A scheme to articulate the cognitive agent's perception of explicit information is suggested at various levels of granularity for the interpretation of concepts. The resulting granularity indicates that the construction actor contrasts his or her intention for interpreting concepts with his or her own level of understanding of the real world. Consequently, there is a strong relation between semantics and the 'grain' size for interpretations and the reasoning behind 'grain' size is powered by the intention of the actor. Therefore, interpretations are cognitively associated with a certain level of granularity by the agent.

CHAPTER 6
NATURAL MODUS OPERANDI OF CONCEPTS

An analysis of the natural forms of concept representations, typically employed in the construction community, gives a sense of perspective for their *modus operandi*. Our research studies the characterization and definition of concepts by the construction industry (see Chapter 3 for further details). The result reveals that the industry is aligned on a consensus on employing and developing standards, common conceptual frameworks, and ad-hoc schemes. These are conceptual structures and artificial formalizations, dictated by a small group of the construction community, and they are used to communicate and represent construction concepts with the purpose of interoperating.

The *sine qua non* of the *modus operandi* of concepts in the construction domain is mainly *cognitive.* This cognitive function is considered *natural* and its dynamics do not involve artificial processes, such as the use of algorithms for efficiency. This *modus operandi* is used to formulate a framework for the characterization of concepts in the construction domain. This illustration contributes to the understanding of the use and nature of the representations employed in this domain. The purpose of this presentation is to clarify fundamentals of the relation between the representations and the construction project participants as cognitive agents. This relation is central to the understanding of problems of representations generated from multiple sources within interoperability. One paradigm example is the reconciliation problem for integrating, mapping or merging sources of information, which was introduced in Chapter 3. This analysis facilitates the introduction of the additional levels of knowledge representation proposed within this approach based on semantics, intentionality, and granularity.

The examination of the *modus operandi* particularly addresses the perception, and interpretations of the representations and their components that hold concepts from the domain.

The relations between concept representations and the actor's interpretation are aligned with the actor's sensory experience, the internal conceptual role, and the use of representations as existing methods to communicate construction concepts among the community.

Sensory Experience and its Role on Concept Interpretation

The perception and interpretations of *modus operandi* are in the simplest form a sensory experience and a cognitive process. The general aspects of the sensory experience and cognitive-process's dynamic can be seen as obvious. This triviality is borrowed from an ordinary commonsensical perspective that ignores the fundamental nature of representations and the complexity of cognitive processes. The current analysis is supported by concepts derived from the areas of the philosophy of language and the cognitive sciences.

The perception is an approximation of one or of a set of isolated physical entities in the world through the senses. It is the response of the mind to elemental uses of knowledge. The uses become more complex when the agents adjust their goals for perception. This process is internal or embodied, which entails that concept structures and linguistic structures are shaped by the peculiarities of our perceptual structures (Lakoff and Johnson 1999). Meanings or semantics are embodied and, consequently, entirely internal. The truth conditions of the isolated physical entities are provided by thought and perceived by the senses. The semantics are rendered by the interpretations performed on the conditions of the stimuli. The actor performs an internal representation of external stimuli through the set or inter-related concepts learned by experience. The internal representations resemble other representations that the actor already knows. This reasoning is performed by employing metaphors (Lakoff and Johnson 2003). The internal structure that forms a concept is complex and intricate and whenever the actor must work with such a concept, the actor interprets the concept in terms of an easier or simpler part of the whole concept (Minsky 1986). The easiest and simplest form is the *primitive* construct of that concept.

The reasoning over the *primitive* construct is a form of the particular skeletal method of understanding about a concept that is central whenever the agents need to communicate a concept.

The level of granularity of a concept representation is critical for interpretation, as was explained in the granularity section in Chapter 5. The actor's perception isolates the relevant parts of that representation. The isolation allows mapping an internal, skeletal or primitive construct. It can be observed that if a representation describes a primitive form of a concept, it is explicitly expressed in the primitive form, and at the same time, it can be communicated easily. The actor in this case will barely need or not need to isolate the concept to perform internal mappings.

Figure 6-1 illustrates an interpretation of a visual representation by two actors that belong to a construction project. Each one of the actors performs interpretations of the available explicit information of the drawings. They map their perception into an internal skeletal or primitive construct that constitutes a form that gives the semantics to complete the interpretation. The mapping is the reasoning mechanism that each agent uses. It can be noticed that a representation

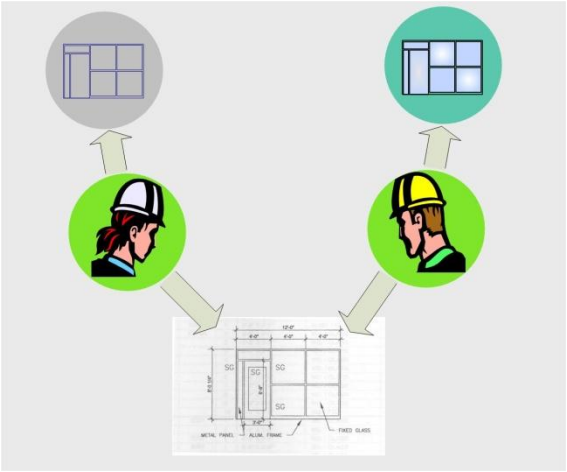


Figure 6-1. Two actor's interpretation of the same visual representation.

accomplishes two functions: inference of thoughts for (1) interpretation and (2) communication. The inference consists of the internal reasoning and the communication refers to a "calculus" on the accurate level of granularity to generate a representation in order to communicate its meanings.

Representations and Interpretations

Representations attempt to describe an extension of a concept in the real world. The representations themselves are simple *metaphors* that give meaning to some concept. Concept representations are not merely elaborations of signs in the mind, but are extended to something physical, such as the context space, in order to be realized or instantiated (Emmeche 2004). This means that representations of concepts cannot fully describe the meaning of the concepts if the relations to the other concepts are not taken into account. These relations are termed *contextual relations*.

Contextual relations attempt to identify possible agent's relations, which might influence the current concept interpretation, and to link such relation to other concepts. This line of characterization of the interpretation has roots in the semiotic tradition (Luger 2002). The *contextual relations* rest on the cognitive agent's purpose in interpreting a concept. Our research takes into account *contextual relations* in the consideration of a valid construction participant's interpretation.

Observational and Non-Observational Factors for Interpretations

There are observational and non-observational factors that allow the observer to perform assertions for interpretations of representations. An example of an observational factor is the semantic relations that the observer is able to find in the details or in the situational conditions of a construction concept in order to apply a reasoning process. An example of a non-observational

factor would be the observer's previous experiences with a construction concept or its representation.

Another non-observational factor is the observer's purpose, which influences the actor's interpretation. The observer's purpose forces the observer to identify or discard details, and to find suitable semantic relationships when the interpretation is performed (Sowa 1999; Thagard 1996). When construction participants perform an observation, they "abstract" relevant concept details and situational conditions. This abstraction is a simple re-creation of the representation that the observer will use. The abstraction is motivated by the observers' purpose for interpreting a representation of a construction process.

Consequently, it is clear that not only observational factors but also non-observational factors affect the interpretation of the representations. A good balance of these two factors will aid in performing better interpretations.

Interpretation as a Cognitive Process

Interpretation is a cognitive process that involves mappings of the representations from several sources. Although a mapping of several sources is not essential when performing an interpretation, a mapping from more than two sources produces more certain assertions than those that are derived from only one source. In construction projects, mappings are critical in performing accurate assertions.

As was previously mentioned, when the *intension* or the *sufficiency* of the set of properties, details, and conditions, that give and apply meaning to a concept are not enough to elaborate a correct interpretation, the construction participant is forced to find other sources of information that complement the set of properties of that concept. In other words, construction participants map various representations that aid them in the understanding of representations of construction concepts. Mappings are matches of abstractions of a construction concept that has several

representations, or that is described by more than one representation. Figure 6-2 shows the mapping representations described within three layers: regulations, drawings, and document specifications. In Figure 6-2, the mappings are performed by an observer of any construction concept; for example, a construction concept, such as 'a wood ladder', that was created by a designer (e.g. architect) and that is interpreted by an observer (e.g. contractor) by mapping the 'wood ladder blue prints', the specifications for 'wood ladders' (e.g. fire protection layers), and the local regulations about ladders (e.g. safety details).

The mappings are not simple connections of concepts; they are links that find semantic relations among concept representations. The relations are not only found among the details, but also with situational conditions which help interpret the representations by examining states of affairs and context relations. For example, Figure 6-3 shows construction participants' mappings of the visual representation's components with text representation components of the construction documents. They map the visual representation (Wood Frame, Double Hung

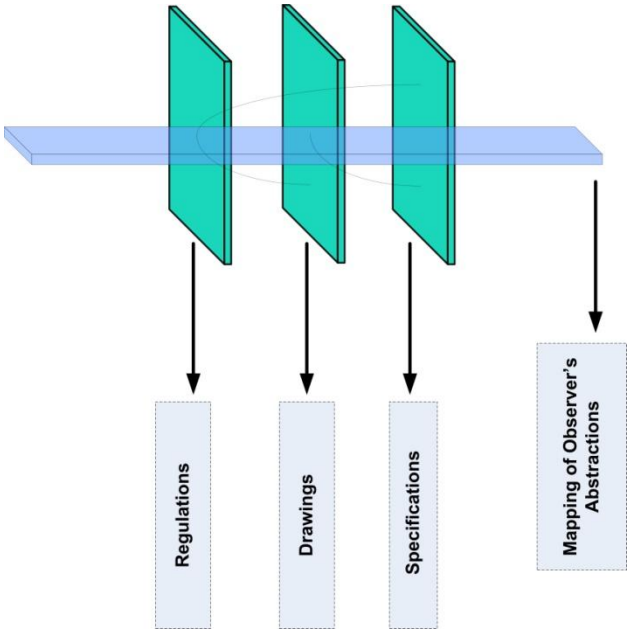


Figure 6-2. Mapping representations (layers) that describe the same concept.

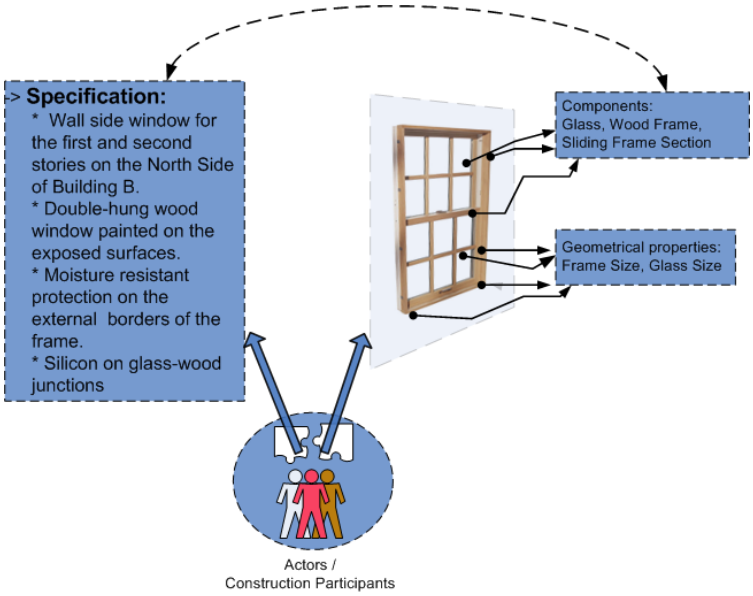


Figure 6-3. Relations between visual and text-based symbol representations.

Frame') to the text-symbol ('Double-hung Wood Window') from the specification documents. In addition to the visual representation symbol details (e.g. geometrical properties in the visual symbol such as frame size, or glass size) and details description of the text representation (e.g. silicon on glass-wood junctions), actors identify additional situational relations such as set on (e.g. set on a wall), or split by (e.g. split by internal and external environments). These mappings are generated for the cognitive agent's purposes. In other words, the actors find correspondences according to the intentions that they have with the representations. As the reader can infer from the above explanation, mappings or semantic relations include a reasoning process. This reasoning process will be illustrated in the next section.

Reasoning on Interpretations

Interpretation is a *cognitive process* that reifies a concept. These concepts are abstract, universal notions, of an entity of a domain that serves to designate a category of entities, events, or relations. Construction participants find semantics of the concepts of their body of knowledge.

The goal is to *reify* concepts on their *extensions* or possible *instances* from the actor's world. In the *cognitive* process, the actor maps observational representations, non-observational concepts (concepts from the actor's world or concepts from the actor's body of knowledge), to the *extension* of that concept. Figure 6-4 illustrates the relations of the abstractions among physical constructs, concepts, and representations in the popular *Meaning triangle* (Ogden and Richards 1989). In Figure 6-4, the image of the *wood window* is the physical construct, the cloud surrounding that image is the actor's world concept, the text '*wood window*' represents the text-based representation and the picture of the *wood* window surrounded by the frame represents the visual representation. The meaning triangle shows the relations that help identify a concept through representation within the construction participant's world in order to reify the construction concept. This is a simple way to describe semantic relations of the representations and to show how the relations occur during the cognitive process within the actor's world.

As was introduced in Chapter 1, the reasoning process for interpretation can be described by the following steps:

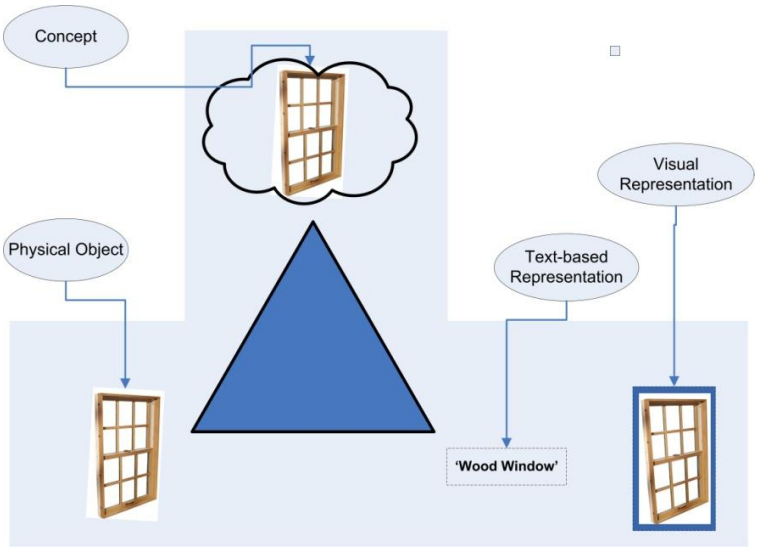


Figure 6-4. The meaning triangle.

- identify the concepts of the observable source by finding details and conditions of the representation;
- perform concept abstractions according to the observer's purpose;
- map the abstractions to other observable sources which describe the concept but employ different representations;
- find additional details and other situational conditions for one another's sources;
- evaluate the mappings and assert the semantics of the concepts according to the observer's purpose.

Mappings of representations, which are separate representations that describe the same concept, rest on the purpose of the cognitive agent (refer to the mapping of text-base representation and visual representation example). These mappings attempt to reduce the risk of misinterpretations that can occur when an actor derives the meaning of a representation from only one source.

Figure 6-5 illustrates the steps involved in a reasoning process:

- a construction participant reads a representation of a concept (e.g. drawings of 'wood window');
- performs abstractions of that concept (e.g. 'sliding wood window', 'double hung wood window');
- finds representations that contains the same referent in order to map those representations (e.g. construction documents for 'wood windows', 'wood windows charts', and 'wood window drawings');
- evaluates the mapping by finding semantics (e.g. only 'sliding fire protected wood windows' are allowed by regulations); and
- performs assertions of that concept (e.g. type of 'wood window' identification according to a catalog).

In summary, when an actor reifies a construction concept, he/she performs an interpretation of unprintable mental representations concerning a particular construction concept. At the same time, the representation can further be analyzed by its details and situational

conditions. In fact, multiple representations that have the same referent can be mapped among them in order to find semantic relations. The purpose of this mapping or of these semantic links is to assert the original concept intention(s). For example, the visual and text concept representations are mapped and analyzed in order to obtain an interpretation of the representation creator's intention. Consequently, when actors perform an interpretation, they project its 'existence' or extension according to their 'understanding' of the construction concept. The actors use non-observational factors to interpret the concept such as experience and body of knowledge that they may possess of that construction concept.

Concept Generation: A Translation

The internal thoughts are *correlated* and *translated* to an external representation, at least in the primitive form. The process of translating a concept into a representation is called concept generation. Figure 6-6 shows the generation of a concept by an actor on a construction project and its communication to another actor. The assumption in Figure 6-6 is that the representation is the only means for sharing information between the actors.

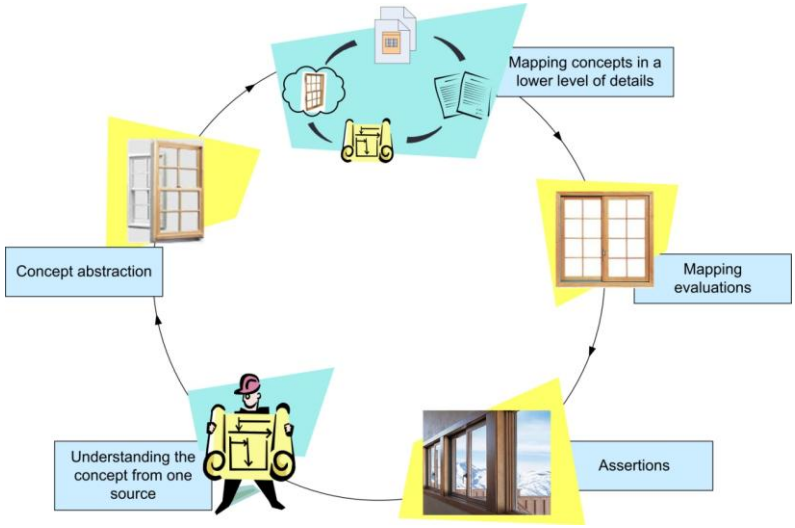


Figure 6-5. Proposed reasoning process for interpretations

The actor *correlates* internal forms of representations: the syntactical expression 'aluminum windows' and the actor's primitive construct that resembles the concept "aluminum window" that is visually represented. Then, the actor *translates* these associations into the drawings, a *visual representation*, which is done as an attempt to communicate the 'aluminum window' concept to other construction project actors.

The representation implies a purpose of translating "truth conditions" that one actor asserts about a concept. These "truth conditions" are better stated as beliefs that are translated into the representations. The *beliefs* are not intended to create senses of ambiguity on the assertions, but to underline that any assertion does not convey truth or logical necessity. In its capacity, the representation translates the concepts from the actor's mind. Otherwise stated, the representation is an instantiation of the actor's concept. The translations cannot be understood as literal by virtue of the differences of the mental constructs from the other actor. Even if two actors perceive the same representation, as illustrated in Figure 6-6 the semantics of the representation for each actor is different. If two actors share the same concept, the role of the concept is not exactly the same, although it can be similar. A conceptual role differs in each actor's internal concept network (Rapaport 2002).

In Figure 6-6, the resulting differences in the internal, conceptual roles are represented through the semantics differences, by color of the components of the mental constructs from each actor. The actors interpret the semantics of the representations in terms of the actor's own concept. The semantics relationships are consigned and are part of the large network of the actor's mental constructs. This investigation attempts to approximate the semiotic experience with the shaped concepts in the actor's mind. This experience gives answers of the form of the correspondence of the perceived phenomenon, i.e. entity, event, or relations, in the domain to the

concept in the mind. In addition, this experience establishes the method of how semantics should be understood in order to give interpretations of concepts.

The assertion action can be included into the interpretation action. Assertions are believes from the interpreters. The assertions cannot be taken for granted as truth. They are approximations that express the set descriptions that communicate meanings to the community. They reflect how the agent understands the concepts. Then, representations implies translated "believes" that one actor assert about a concept, as the reader can notice in the Figure 6-6. These "believes" cannot be understood as assertions with ambiguity senses. Any assertion does not convey truth or logical necessity. They hold the translated concept from the actor's mind at the granularity level or in the representation capacity.

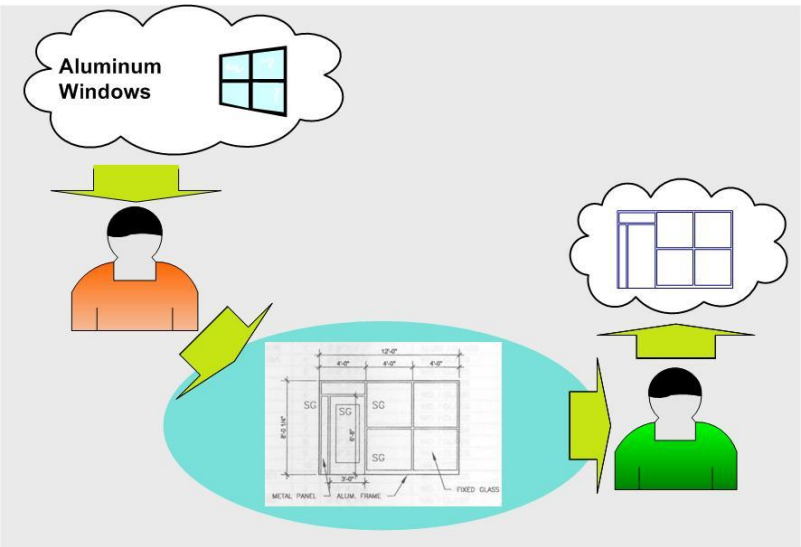


Figure 6-6. Generation and interpretation of the translated concept.

Social, Context Character of the Concepts

As the representations of concepts cannot be understood as literal, by virtue of the differences of the mental constructs between actors, there is not a "*unique*" relation between any

symbols or representations and its semantics, which fixes the meanings for a social network or for a community. The semantics of the representation cannot be fixed. The representation generated from other sources play a role that gives a social, context dynamic to the semantics of the representations.

The semantics of the representation that is attempted to be communicated cannot be de-contextualized from the associations that involve social, human activities. This social role of a representation is analogous to the spirit of the idea of Wittgenstein (1973) that of the semantics of a word lies in its use. The semantics does not lie in fixed learned meanings for the future uses of a word. It can be noticed that the possible actors of a social network are not possible to *a priori* be defined in their totality. In consequence, the context, social dynamic of the semantics of a representation involves indetermination. This dynamic leads to an *infinite* level of granularity for defining meanings. New approaches should focus on the social, contextual role in the representation to slender the *infinite* definitions of meanings.

Current representation in the construction industry ignores the contextual, social dynamics. To follow the spirit of this idea, this research suggests a new layer for the social role. This layer should serve as a combined 'situation' for the counterpart interpreters. It should have the function of delivering and capturing the social interaction. As a preliminary exploration for this social, contextual dynamic, a framework for construction organizations is suggested by the author (Mutis et al. 2006).

Following the spirit of this proposition, this research states that the meanings for communication are based on social conventions. The representation's signs must be generated by considering social practices along with social conventions. If the signs are not aligned with these conventions, the representations have *solipsistic* character. Actors must be involved in a network

where a social interaction to communicate meanings takes place. The suggested layer for the social role should contain the elemental joints to the future counterpart interpreters.

Concept Communication

The social, contextual role of the concept embraces a mutual understanding of its notion for effective communication among a network. The mutual understanding is similar to finding a common ground or a same, combined situation. When communicating, actors within a network almost always fail, yet the actors almost always succeed, in explaining the paradox of communication (Rapaport 2003). As was explained, actors intend to communicate concepts through representations, either in natural or artificial language, or by employing signs. The role of representations is to serve as connectors for the actors in the network. Actors respond at the representations through their senses, and their responses depend on each particular cognitive agent. The experience at interpreting the signs and the accuracy or sharpness in their interpretation is a virtue of each particular actor's experience.

Our research rejects the idea of having a literal meaning on concepts to succeed in communicating them, which is the basic tenet of enforcing standards within a network. There are only needed skeletal and primitive conventions. It can be noticed that the translated concept into a skeletal form in a representation is a *belief* in the simplest form or in a form with the fewest, possible constraints. This primitive form is further shared within a social context with the purpose of creating conventions. From here for successful communication, the level of sharpness in granularity exclusively depends on the actors' intention, which must be reflected on the representation. If the primitive form suffices to communicate the intention, then the sharpness of the communication is more adequate to represent the concept.

The societal, contextual role for communication of the representations can be seen as analogous to the role of joint actions carried out by coordination and participation of actors in

order to communicate in natural languages. In using languages to communicate, it is the joint action that emerges when speakers and listeners assemble actions such as communicative acts and signals in order to indicate another agent's recipient action (Clark 1996). In the case of concepts, it is the learning experience from each of the other actors that guarantees the assembled actions, allowing communication.

In Figure 10-6 actors translate the concept 'aluminum windows' into a visual representation to communicate it to other members of the community. In the example, a more developed primitive form is consigned within the representation. The product of this development is a more complex form that plays a role of "drawings of a particular aluminum window" The settings of this more complex form have the intention of communicating the spatial arrangement of the components of the 'aluminum windows' concept and of displaying constraint values such as the concept dimensions. If the representation as well as its conventionalities or its social usage are socially understood, the counterpart actor-interpreter should be able to recognize the representation.

The visual representation showed as drawings hold semantics from the perspective of the actor who generates it. If this visual representation is launched to communicate its meaning, the counterpart should find a common ground or a same, combined situation to understand it. Although by nature, the learning of concepts is different for each one of the actors that participate in the action, the commonalties of the representation should suffice for understanding it. The identification of the concept takes place when the interpreter recognizes the set of signs, metaphors, and constraints that exists in the actor's mind. The assumption is that the sets must indicate an accurate description of the '*aluminum window*' concept that the representation refers

to. Under this assumption if the other agent does not understand the set of signs, metaphors, and constraints, the translated representation has a *solipsistic* character.

The meanings or semantics of representations are provided by thoughts, not by truth conditions; the visual representation, '*drawings of aluminium windows*', is the product of a concept translation, not by truth conditions. The representations are skeletal forms of understandings and, in the basic form, are primitive metaphors. If there is only one source of the translated concept, the counterpart interpreter only has this representation to identify with certainty. However, the physical, perceived, material entity or *qualia* also influences the identification process. By nature, the material entity is the source of the stimuli. Some distinctions produced by the material entity can be identified by the interpreters, but others cannot. Thus, the translated concept cannot be conclusively known from its representation.

Discussion

Misinterpretations, errors, rework among other typical construction problems are the resulting, roadblocks that affect the effectiveness of sharing, exchanging, and integrating of information in construction projects. The effective communication of information is the goal during the *modus operandi* of the actors on the construction projects. Our research significantly advances the understanding of the role of the actors and of the concepts embedded within the representations.

The nature and character of the forms of representations and the difference between symbol manipulation and semantic operations form the basis for the understanding of complex practical problems in establishing interoperability on construction projects. Our research explores the nature of signs and intentionality through a semiotic experience with the purpose of finding answers concerning the perception and interpretations of the representations that hold concepts from the domain. The approach emphasizes the relations among concept

representations and the actor's sensory experience, and the use of representations as existing methods to communicate construction concepts among the community. Examples from the construction domain are used to illustrate the concepts and to show the promise of this approach in facilitating interoperability on construction projects.

CHAPTER 7
A SEMIOTIC PROPOSTION

This work quests for the understanding of the forms of representation in their *prima naturae* and in their *prima character* states. The objective is to comprehend the role of their semantics, their relationship with the actor's or the role of their interpreter, and the extent of their ability to capture the richness of the construction domain. A clear distinction has been made in Chapters 4-6 between (1) the nature of representations, (2) their semantics, and (3) the role of their interpreters. A close analysis of these elements has indicated a missed stratum where the semantics of the representations that articulate the actor's interpretations can take place. The semiotic experience is an approach that embraces these three suggested aspects. The semiotic experience studies the fundamentals of the features that are related to any forms of representations.

This chapter approximates semiotics as an *experience* that illustrates the reasoning process from external representations and the role of intentionality in employing external representations. This *experience* inquires about the form of the *correspondence* of the perceived, entity, event, and relations, or, in other words, a *correspondence* of a phenomenon in the world with the concept in the construction participant's mind. In addition, the purpose of this experience is to provide direction to the method of how semantics aspects should be understood to give interpretations for concepts employed in the construction industry. This chapter extends semiotic analysis to a construction industry case.

Semiotic Analysis

The best way for explaining a semiotic analysis for representations is through examples derived from its corresponding theory. The principal purpose is to set up a framework for the nature of the interpretation of concepts and, for the purposes of this research a framework for

interpreting the nature of the construction domain concept representations. Accordingly the following analysis is conducted based on Peirce's (1991) theory of signs and his trichotomy: *independence*, *relative*, and *mediating*. Peirce was a logician who challenged the tradition of understanding thoughts not as *ideas* but as *signs*. The signs are external to the agent, who is responsible for the thoughts and actions of an individual to which they are ascribed, and they do not have meaning unless interpreted by a subsequent thought. Signs, under the semiotic experience, are *representations* that contain meanings and purposes, which are prescribed by Peirce's trichotomy *independence*, *relative*, and *mediating*. The *representations* take the form of a *visual representation*, of a set of markers that describe a formal language, and of markers that are used to represent natural language, among other possible representations, such as a collection of hexadecimal numbers. In this analysis, the language that previously was used to describe *symbols* is replaced by the terms used in semiotics for *signs*.

This semiotic analysis is an examination of the compromise between the meanings of a representation *per se* and the concept associated with the understanding of such representation. The semiotic analysis gives a perspective from the nature of understanding of the concept from each one of Peirce's categories. Pierce's semiotic theory is based on his *firstness*, *secondness*, and *thirdness* categories. "*Firstness* is the conception of being or existing independent of anything else. *Secondness* is the conception o being relative to, the conception of reaction with, something else. *Thirdness* is the conception of mediation, whereby a first and a second are brought to a relation (Sowa 1999). The following section presents Pierce's framework according to *Material*, *Relational*, and *Formal* aspects of the signs organized within the trichotomies. The first and *Material* trichotomy consists of *Qualisign*, *Sinsign*, *Legisign*; the second trichotomy

consists of *Icon*, *Index*, and *Symbol*, and the third includes the *Rheme*, *Dicent Sign*, and *Argument*.

Qualisign

Qualisign is a sensory experience originated due to stimuli of some material on the actors' senses. It has not reference or any additional indication to identify a meaning on it, but it has a character of being *qualia*. In the broad sense of the term, '*qualia*' refers to the phenomenal aspects of the actor's reaction. Figure 7-1 shows a *representation,* which in this case should be perceived by visual senses. Any actor can perceive it through *visual stimuli*. The source of this *stimulus* is a '*contrast*'. This first distinction that the actor possesses by contrasting a representation is a sensory experience. *Qualisign* is simply the sensory experience and, as an experience itself, it is independent of the source. It has the same quality as an appearance. *Qualisign* is founded on Peirce's *firstness* category, which is independent of anything else. In the example, the *visual-representation contrasts* are themselves independent from the source. They could have originated from printed drawings on paper, or from a computer screen. When the agent perceives the representation, here by visually contrasting dark and light, a set of relationships originating from what is perceived are internally created within the agents mind. These relationships are used to create distinctions in the actor's mind.

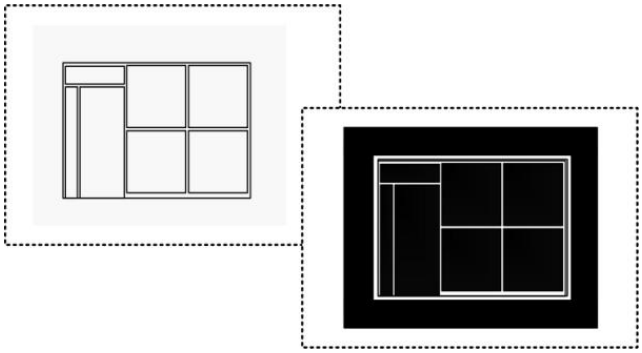


Figure 7-1. Visual experience as 'qualisign'.

Sinsign

This category is named material *indexicality* and relates *qualisign*, or the perception due to stimuli, to an internal concept that resembles an entity or an event. *Sinsign* is the result of the recognition of the simple material quality or *qualisign*. The recognition assigns meaning or semantics to the *qualisign*. The assignment of relations to the perceptual experience is the identification of semantics. According to this tradition, it takes place in *secondness*.

The fact that *sinsign* has been identified implies the recognition of a particular mental construct or concept within the actor's mind. In the semiotics experience, the source is recognized by perception and it is related to a specific source that has previously been understood by experience. Figure 7-2 shows a section of drawings that are chunks of traces of ink on paper and are recognized as a source that allows assigning meaning to the traces of ink on paper as drawings. In other words, this recognition identifies the concept drawings by *visual perception*. In the Figure 7-2 example, the recognition of this *visual perception* implies a match within the actor's mind of an *a priori*, learned, piece of drawings concept. However, the recognition of pieces of drawings does not imply the definition of the convention or a consensual semantics of the *sinsign*.

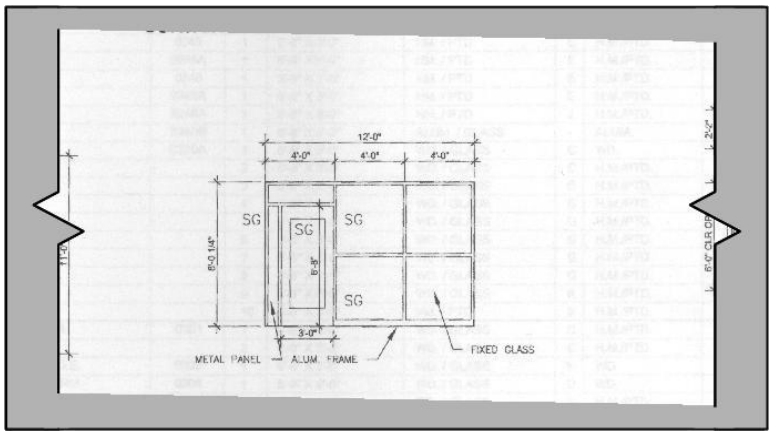


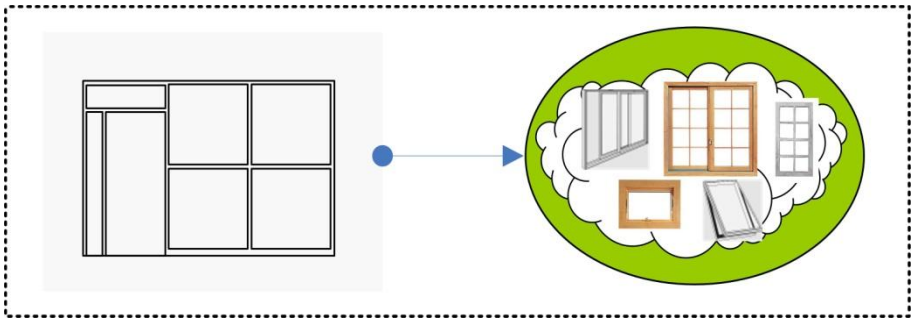
Figure 7-2. Sinsign.

Legisign

Legisign's main feature is the essential character of obeying a social consensus about the semantics of a particular concept. *Legisign* has a force of convention or a social understanding of the sort of recognized *sinsigns*. *Legisign* is under a mediation category, which indicates that the actor's reasoning does not add additional semantics to the interpreted sign. *Legisign* identifies the convention or social understanding of such a particular concept. If the representations correspond to *legisign*, the actor's reasoning about the meaning of the perceptions identifies that the representations or signs have relations to the learned and socially agreed upon concept, and performs assertions about these relations. These relations are inferences from previously learned concepts within the actor's mind.

The lack of social consensus about a concept, an agreement, or an enforced legislation negates the possibility of considering a representation as *legisign*. The meaning of a concept is shared in commonality within a network. The understanding of the signs is based on a common set of constructs that constitute a concept. The interpretation of *sinsigns* can be a positive reaction towards an association of a previous, social consensus. If this reaction is performed, the interpreted sign are consider *legisigns*. In the example, the visual distinctions of a group of parallel and perpendicular lines grouped in a certain layout infer a form of a window in the agent's mind. In the example of Figure 7-3, the distinction implies the identification of an arrangement in a layout of parallel and perpendicular lines. The '*arrangement*' of lines corresponds to *sinsign*, which corresponds to the schema shown in Figure 7-3 (a). The result of the association of the '*arrangement*' into a concept that resembles the concept 'window' is a *legisign*. The concept 'window' was learned *a priori* and corresponds to a socially agreed upon concept that is supposed to have a definition that stands for: a physical device that isolates two environments by keeping a visual contact between them. The convention of the window

definition should resemble multiple *a priori* mental constructs that meet the description of this definition. Figure 7-3 (b) illustrates the hypothetical internal representations for a certain agent that stands for the concept that resembles the *a priori* learned concept of windows.



(a) Arrangements of signs in a schema (b) Hypotetical internal representations.

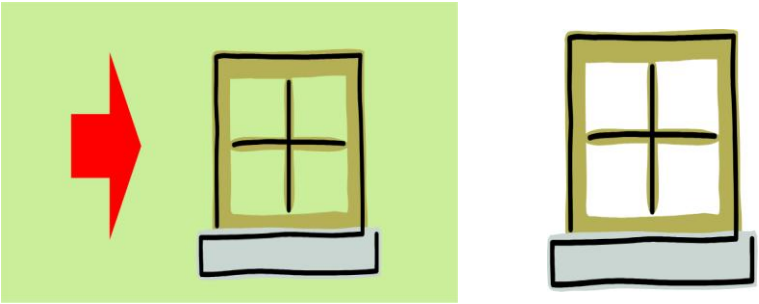
Figure 7-3. Legisign.

Icon

This category is part of the relational trichotomy, which is determined between a representation and an entity. A sign is a representation when it is recognized *per se* as a representation for the cognitive agent. To define an icon is to define a *resemblance* to a concept in the agent's mind. An icon is a *representation* that *resembles* a specific entity. The distinctions of the icon as an entity are possible as a result of the learning process within the actor's mind. The cognitive agent interprets it by establishing relations or finding semantics. The representation is not interpreted as *qualia* or as pure material, but the nature of the material has the quality to be recognized as a representation by the actor. The relations that the actor identifies are apprehensions based on *similarity*. The *similarity* is a property of the perceived phenomena and it is employed to find relations to the mental construct of the actor. *Similarity* does not

designate the characteristics of a concept. It establishes general indications of what a representation of a concept refers to.

An icon through the effect of the similarity distinctions does not implicate true existence of that entity. An icon makes clear the resemblances to a concept that has been a priori elaborated. The primary distinction through similarity in the agent's body of knowledge does not assign further semantics to the icon. The similarity is a contrasting reasoning that formulates indication to a concept. Figure 7-4 (a) shows an example of a representation that it is visual. The form of the representation resembles a concept that the actor is already familiarized with and which is depicted in Figure 7-4 (b). This *a priori*, primary, distinction is derived from similarity contrasts, and it is supposed to resemble a concept, in this case, the concept 'window'. Icon distinctions depend on the cognitive agent's experience. Thus, in the example the representation could resemble the habitat of insects or the design of a marine, emergency flag.



(a) A visual representation (b) Actor's form of a concept.

Figure 7-4. Icons.

Index

The constituents of *index* are markers or icons whose semantics exclusively indicate a relation to a specific concept. An *index* loses its semantics if it does not react upon a concept, i.e it '*declares*' the existence of a concept. The *index's semantics function* is to *afford* the existence of a concept. An interpretation of the concept can be guided by the *index*, although the *index* may

not be necessary for its interpretation. The *index* serves to make connections to a concept in the cognitive agent's mind. The indication to the concept does not imply the distinction of the concept's properties or some additional semantics. *Indexes* provide nothing other than the *indexical* relation.

The nature of the *index* can be of any type such as a physical or material entity, relations or events, or even an imaginary thought. A cognitive agent does not need a physical or material connection in order to get an *indexical* "relation". A visual representation such as a photograph serves to identify a concept on the photograph and it is not physically connected. In the same way, a set of markers that form the student ID number, which possesses semantics and constitutes a social concept for identification purposes, provides for indexical functions and is not physically connected. Physical connection means a direct contact that produces a *stimulus* to the actor's senses. By virtue of the connection or relation with a concept, *index* is part of the relational trichotomy that establishes a relation between a sign and an entity. The connection, expressed through the *indexical* relation, is independent of any *similarity* relation to the entity. The indexical function is an internal inference that generates distinctions to a particular concept within the actor's mind. *Index* conveys mappings to a concept that rests in the cognitive agent's mind. If an *index* is learned by experience and it is identified through social conventions or consensus, this index points to a concept that can be recognized by other members of the actor's network. An index that possesses a social role has non-solipsistic character and its nature is not imaginary.

Although, Peirce suggested that *indexes* point to objects or facts, this study treats objects or facts as concepts that actors identify by *stimuli*. The concepts must be commonly recognized by social actors, i.e they are common, shared concepts. This particular, social, inclusion feature of

index implies a purpose of sharing concepts among the community. This purpose, then, should make any *index*, by virtue of its semantics, be an artificial signal to point to a concept. The pointed or mapped concept, by virtue of the indexical relation, must be the same, independently from which actor performs the interpretation. A photograph is an *index* that can be read by any other actor, and the *indexical* relation always maps to the photographed entity. Under this social dimension, indexes map to a unique entity and they serve as an identification of that entity. However it is important to note that *indexes* are not 'identities', they are artificial representations that, under a social consensus, afford the *indexical* relation. The set of markers that compose a social security number can indicate identity or ownership of a boat. *Index* just points to a concept and social conventions convey the semantics of what is pointed at.

Within the social, convention role, *index* has the character of being dependent on the mapped object although it is an artificial representation that can exist by itself. The reasoning process consists of performing inferences with the purpose of finding matching to the identified entity. The social security number is an *index* that serves as a means of matching other sets of numbers in a knowledge base of social security numbers. The inference for a search of matches of social security numbers is based on *similarity* relations. In Figure 7-5, the set of markers "Type H", at the bottom of the visual representation 'drawings', indicates a map to the concept 'aluminum windows'. This indication to the concept encompasses the set of showed constraints of size, of spatial arrangement of the components of the 'aluminum windows', and of the displayed values such as that of the concept's dimensions. The reasoning behind the "Type H" index consists of performing searches for matches to other representations that contain the set of markers "Type H" within a knowledge base. This knowledge base can be construction specifications, schedules or any documents that contains the representation, *index* "Type H". In

the same way, the inference that acts on other sets of markers, such as the social-security-number index, searches for matches that are based on the *similarity* relation.

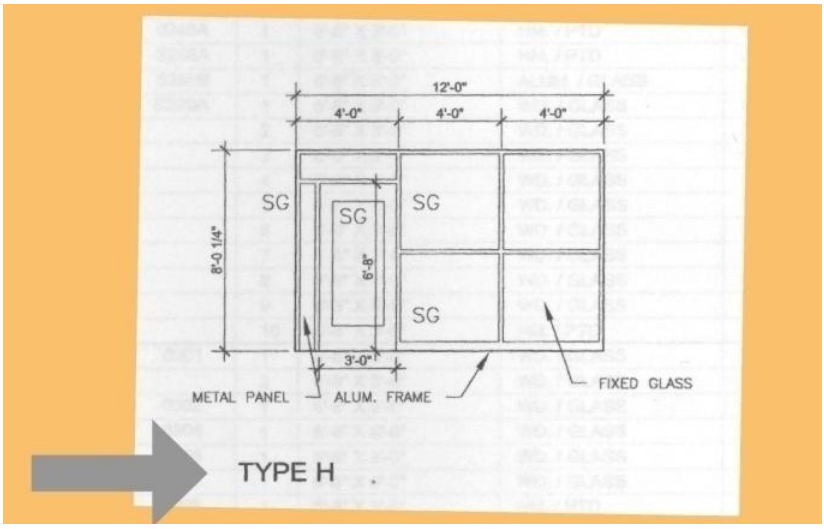


Figure 7-5. Index.

Symbol

Symbols are the result of a rule or association for a sign by virtue of the experience or of the learning ability of the cognitive agent. This rule governs the representation of signs or indexes. Symbols are the outcomes of the learning process that has shaped the concept for a particular meaning. The actor establishes the semantics of a concept by learning. When an actor recognizes a symbol, it is simply associated to a concept, i.e. the actor understands the semantics of that *symbol* with no additional inferences or aids from other sources for its comprehension.

The interpretation of symbols depends on the previous actor's experience and its assertion responds to the actor's *understanding* of such a symbol. In the actor's learning process, the addition of semantics to other representations and rules, such as syntax rules, can be a very complex process. This semantics addition should respond to any perceived *sign* during its interpretation. This suggests that there exists *symbols* only under interpretation, and that their

character of existence is embodied in the actor's mind. The *symbol* interpretation is the result of a distinction of an *a priori,* learned concept in the actor's mind, and the resulting perceptions are instances or replicas of the agent's concept. Figure 7-6 illustrates a *symbol* on a computer screen. The symbol is an instance of some printed drawings. The actor associates the perceived signs with the concept drawings. At the same time, the actor identifies further semantics in each one of the distinctions performed and perceived from the provided *signs* on the computer screen. The role of the computer screen is to serve as a means of replicating the signs that represent the symbol of the concept 'drawings', or in other words instances of the concept 'drawings'. The computer screen mediates the representation of the concept drawings through the *symbols* on the screen. Clearly, the symbols are presented in *visual representation* form.

The agent can find additional associations for additional semantics during the resulting reasoning concerning the symbols on the computer screen in Figure 7-6. The additional associations are mediated through the signs shown on the screen. The screen mediates for additional associations or additional semantics in order to be distinguished by the actor. The lines on the top and the left side of the scheme on the computer screen are signs that add semantics to this visual scheme. The actor might read these signs as symbols for defining and delineating 'size' properties of the visual scheme. Therefore, the actor associates additional semantics to the mediated concept. Clearly, the screen serves as a device that mediates for a representation, which in this case is a *visual representation,* of the concept 'drawings'. The symbols on the computer screen afford information that the actor has *a priori* learned and defined by experience. The learned concept 'drawings' should guarantee the necessary semantics without the need for employing a mechanism of reasoning such as additional inferences or the use of rules or

propositions. A cognitive agent elaborates a mental image from the *symbol* that mediates a representation of an entity. The entity, in this case, is represented in the drawings.

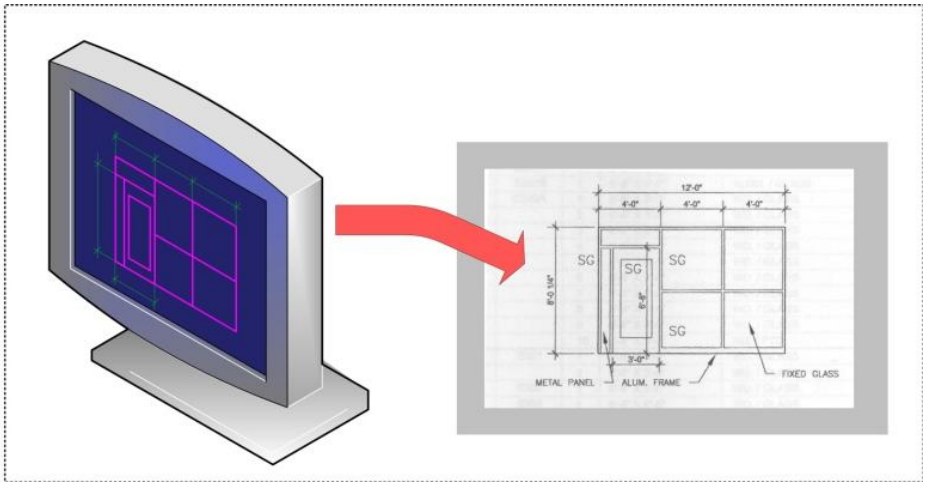


Figure 7-6. ‘Symbol’ on a computer screen.

Rheme

This category represents a set of markers that afford a proposition or relation to some concept. *Rheme* are the makers that have been identified by the actor as signs that have a form of representation and that hold information of a concept. *Rheme* essentially represents the signs that belong to a formal language and that can be either natural or artificial. For example, the word ‘bell’ is composed of a set of markers that hold information about a concept: “A simple sound-making device or a percussion instrument that has a form of open-ended hollow drum and resonates upon being struck.” The markers ‘b’, ‘e’, ‘l’, ‘l’ as set hold this definition. The actors that perform the perception of the markers have learned the concept and they imply a consensus or a social concept description, which is part of the features of a formal language.

Rheme’s components have the quality of *quilisign* and they can be identified as signs or markers; they can be recognized as representations. The resulting identification of the primary information of the markers is their recognition as a representation. *Rheme* affords some

information that holds meaning to the cognitive agent. The information does not have any additional indication than the possible identification of a concept. The series of markers 'aluminum window' might afford the information for an actor about a material element that resembles the role, the form, and the properties of a window, which is made of aluminum material. This example takes an ontological account by naming properties and forms, with the purpose of explaining the possible concept characterization that an actor might possess. Then, the set of markers 'aluminum window' represents a qualitative possibility in a formal way in the example. Although Peirce (Peirce 1991) defines *Rheme* as *terms* that have the ability to conserve a blank in a set of a proposition, *Rheme's* definition can be extended to signs to be used in formal languages in general.

Dicent Sign

Dicent sign, also expressed as *dicisign* or *dicent*, represents a formal category of indici. *Dicent sign* is the assertion of a concept, which, in turn, is the result of identifying the semantics of the concept. The actor reasons on the perceived sign, shapes its semantic, and expresses an assertion. *Dicent sign* can be interpreted as true or false, but this interpretation is embodied. Then a truth or false character rests on the semantics that are refined through the distinctions made on the perceived entity. The actor's interpretation has the character of being true or false. Therefore, the sets of markers that compile the representation and constitute *dicent sign* have the capability of being true or false. The result is an assertion produced when the actor assigns semantics. *Dicent sign* affords grounds for interpretation and its purpose is to perform an assertion about what is perceived by the actor.

Dicent sign can adopt indexation signs due to its nature. An example of *dicent sign* is as follows: the project manager makes the following assertion, "The subcontractor fixed the window." This phrase is an assertion built in natural language that is composed of a series of

words that in turn are a set of markers that afford information and that assert the existence of an entity or event. In the example, the cognitive agent, who perceives the set of markers that form the phrase, might take for granted the truth or might reject the assertion. This means that the phrase still affords grounds for interpretation.

Argument

Argument is a sign that involves formality in the interpretation of a *dicent sign* and it falls under the formal mediation category. It is the reaction to the perception of a learned concept without further reasoning for finding additional semantics on the perceived sign. Argument has the form of law to the actor and does not give grounds for interpretations other than that intended. Although argument suggests an intended interpretation, the cognitive agent processes it as a *definitive "belief."* In other words, this argumentation is taken as "*belief*" and its reasoning about premises concerning the argument validity are not examined. For example, "The window must be made of aluminum, and not from any other metal." Therefore, the assertion is created to represent a constraint in the type of metal of a window. The interpreter or cognitive agent might vary the interpretation according to his or her belief concerning the meaning of aluminum metal.

The mediation level of *argument* represents a further result than the addition of semantics to the signs. The derived result of the sign perception and interpretation reflects intentionality. With argument, the intentionality reaches a level of formality, which does not require additional reasoning for assigning semantics for the actor. Clearly, the basic reasoning of *argument* consists of the identification that is learned and refined *a priory*. The basic argument for interpretation is regarded as previous knowledge.

Summary

The purpose of introducing the semiotics theory through this investigation is to analyze the role of the construction-actor's experience within a representation of a concept. The analysis

includes aspects of reasoning among signs as forms of representations and aspects of the actor's interpretation. Current efforts that quest for efficiency in interoperability fail to notice the dynamic of signs and the use of natural language within any activities on construction projects. Errors, misinterpretations, and rework with the employed representations in their *modus operandi* are common problems found during current construction practices. This analysis suggest an opportunity to understand the *nature* of the multiple practical problems with the actor's experience with signs, natural language, and, in general terms, other forms of representation of concepts in interoperability.

Interpretations involve the observation and distinction of syntactically defined symbolic notations and of other visual representation forms. These notations are deliberately organized to define concepts. The understanding and characterization of concepts into symbols and other forms of representations can be addressed in the semiotic framework. From this framework, the analysis of the systematic, common forms of symbols *questions* the current employed forms of representation in their ability to express meanings in interoperability. The following example illustrates how the semiotics experience is part of any interoperability activity in the construction industry when the relationship between and actor and a representation takes place, as well as the implications.

From the aforementioned semiotic framework, consider the following interoperability situation. Suppose that one actor shares information with other actor in a construction project. One actor generates the information and the other receives it. They do not previously arrange meetings, nor do they work in collaboration for generating the information. The recipient obtains the information in tables as well as their corresponding meta-model which it is shown in Figure 7-7.

The meta-model and the tables are forms of representation that are intended and structured to describe some instances of concepts such as the construction company budget. The recipient's or interpreter's problem is to comprehend the semantics of the meta-model. From the semiotics standpoint, the meta-model satisfies the definition of *sinsign,* since it represents the recognition of the internal understanding of the diagram as a meta-model as well as the syntax of meaning of the words. However, the interpreter does not recognize the meaning of the relationships of these words within the meta-model. The metalevel does not have the character of a symbol for the interpreter. Thus, the metalevel does not embrace a mediation stratum where the social understanding of the arrangement of the shown entities has a social meaning. Therefore, in order to determine semantics on the metalevel, the interpreter will demand additional information from the source, which is an activity that requires multiple resources.

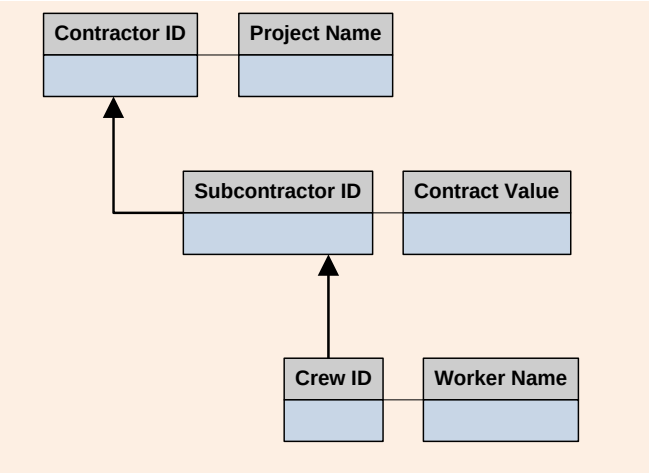


Figure 7-7. Meta-level representation.

Sharing concepts among the construction industry community is limited to the captured content in the representations producing errors and misinterpretations in these operations. A further analysis of the relationship between concepts and their associations to a more primitive sense of signs as well as a strategy needs to be considered for advancing semantics in

interoperability. The analysis should include the relationship between concepts and the systematic, common forms of symbols that can be embedded in models or in computers, as well as the role of the agents with the representations of concepts and the domain.

CHAPTER 8
CONCEPTUAL ROLE SEMANTICS FOR INTERPRETATION

Currently the construction industry interoperates by transforming concepts into models, schemas, or conceptual models. An interoperating approach addresses efforts on mapping, harmonizing, integrating, and aligning, among other methods. However, they do not direct the fundamental problem of understanding the information that is generated by different sources. Evidence of this problem in the construction industry is found in the difference between the semantics contained in conceptual models such as standards (Mutis et al. 2005). The manifestation of this divergence takes place when actors perceive representations generated from different sources. This situation is found in interpreting representations of concepts that were generated with the purpose of communicating them. Actors in this domain continuously generate representations to communicate concepts, which are further interpreted and perceived by other actors within the community. This investigation explores valid reasons for the divergence of semantics in the actor's interpretation of the representation.

The purpose of this chapter is to introduce a concept that helps advance the understanding of the nature of the current methods to represent concepts within the construction industry in order to identify the deficiencies that inhibit sharing of information among actors. These deficiencies cause difficulty in creating efficient methods of exchanging, sharing, transferring, and integrating information from distributed sources.

Conceptual Role Semantics and the External World

Truth concerning a description of a phenomenon in the world is not fully established by observation due to the different cognitive levels of understanding. The levels depend on the exposition for interpretation of the phenomenon and the experience of the cognitive agent. The concepts that a society manages or that a community understands are the common and shared

situations with which they have been involved. The meanings or semantics of concepts are absorbed by the daily experience and by the learning processes that shape the concepts in the mind. Thus explicit and direct correspondences from one concept to another concept, and then in turn, from concepts to the world, cannot possibly be established with certainty.

An actor's interpretation of a form of representation has to be conclusive on its *semantics* in order to assert an understanding concerning its form. The internal role of a form of representation is the actor's understanding of that representation at the state when the representation is recognized and reasoned. Concepts are abstract, mental structures of an entity, events, or relations of a domain and the internal *role* of these abstract, mental structures for conclusive semantics is called *conceptual role semantics*.

Conceptual role semantics is a framework rather than a theory concerning the roles of representations, their reasoning of thoughts or caused inferences, and their contribution of cognitive abstractions to meanings (Block 2006). Although theories of roles of meanings go back as far as Kant (Whiting 2006), this framework has recently been scrutinized within the area of philosophy of the mind and has been extended in linguistics, especially in formulating theories of meanings processed by natural language expressions. 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 the *use* the actors put on such representations. In philosophy and linguistics, the famous dictum of Wittgenstein, "the meaning of a word is the use in the language" (Wittgenstein 1999), influenced major well known advocates of *conceptual role semantics'* theories, such as Wilfred Sellars (1963) in linguistics and Gilbert Harman (2005) in philosophy.. Sellars' theory of meaning distinguished the use of inference that discriminates between various meanings such as:

translation, sense, naming, connotation, and denotation. The core of Sellar's theory on *conceptual role semantic* is on meaning as translation (Rapaport 2003).

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 Frege. Fregean 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 defining meaning instead of a reference in 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 and content of syntactic forms and other forms of representations arise from and are explained by the *role* of these syntactic and of other forms of representation (Greenberg and Harman 2006).

Conceptual role semantic theories explain how the roles 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 and Harman 2006). For example, an '*aluminium window*' is a syntactic expression or a label of an element for distinguishing it in later operations for a variety of purposes. The actual feature '*made of aluminium*' could have been be labeled and further classified 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-aluminium windows*'. This suggestion consists of the way they were assigned to be used within the external world. The content of the element '*aluminium window*' enables the actor to treat it as in the *openings* category or as in the *metals* category. The uses of the syntactic forms determine the meanings and the element's additional functional aspects, although not essential or unique, are relevant to the use of the '*aluminium window*' syntactic form.

Harman brought forward the account of whether an external or referential or truth-conditional theory plays a role, or if the *conceptual role semantic* framework embraces a theory that is internally based for recognizing semantics. Thus, meanings of natural language expressions are determined by the thoughts, with which the expression is correlated, and not by true conditions. The contents of the expressions are determined by their functional role in the actor's psychology (Harman 2005). Within the *conceptual role semantic* 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 agent'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 expressed through an action. According to conceptual role semantics, the actor's understanding consists of their knowledge of how to *use* the expression.

Representation Forms and Significance of Conceptual Role Semantics

In the current authors' investigation, conceptual role semantics is extended to other forms of representations used in the construction domain. The possible forms of representations are not listed in this study, but their forms of expressions such as visual, syntactic, or formal are recognized as expressions of construction concepts. The characterization of the concept notion involves the description of abstract, mental structures, of entities, of events, or of relationships

from a domain performed by an actor as cognitive agent in the construction domain. The description is the translation of the concept into syntactic or natural languages, visual representations, or formal structures such as models with the purpose of sharing or communicating the concepts to other actors of the construction community. As an example consider

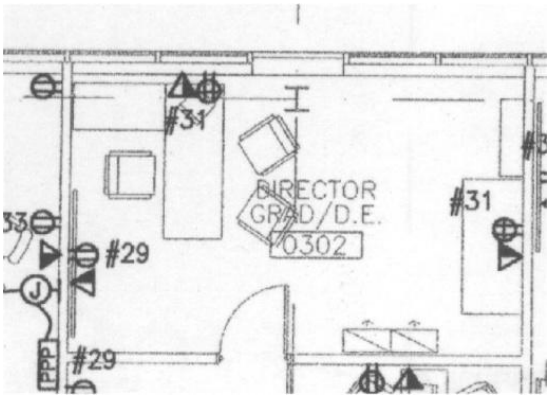
Figure 8-1 which shows a visual form and a syntactic form of representation respectively. One can notice that construction project participants continually employ these types of forms.

The act of describing concepts into some form of representation does not guarantee the understanding by other members of the community of what is described. The choice of a form or representation does not guarantee the understanding of the meaning or content of the representation. Current forms of representations implicate different kinds of problems primarily influenced by the purposes and the uses in the external world or environment. No form of representation can be deemed the right choice to represent concepts. A syntactic form of representation does not guarantee the understanding of the expression by other actors in the community. A visual form of representation does not guarantee the assimilation of the indexical contents by other actors in the domain.

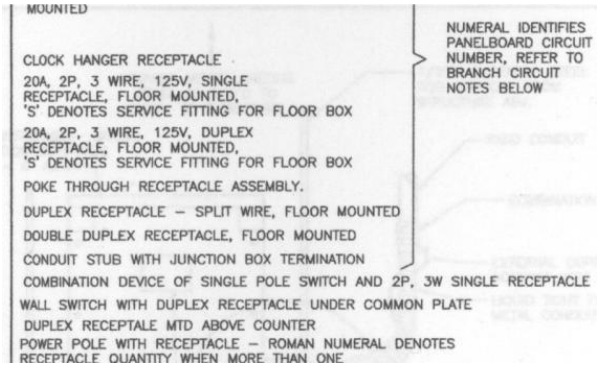
Deficiencies of Forms of Representation

The choice of representing a concept in a model through formal logic involves the lack of a subset of logic expressions to determine meaning of what is intended (Sowa 1999), and for what it is used. In the construction industry for example, the choice of representing concepts through standards and taxonomies implicates different choices to categorize concepts, and different forms to name the same concepts. New forms of representations such as ontologies in the construction industry suffer the same type of problems, especially within different approaches for axiomatization.

This choice of employing models, which are symbolic approaches for characterizing 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 pipes and water pumps for buildings can be complemented as much as possible with more axiomatization. The result might be more accurate for modeling pipes in buildings for the hydraulic engineering, but might be seen contradictory if the electrical engineer attempts to reconcile his model with the hydraulics ontology on the specifications on electrical, local regulations.



(a) Visual.



(b) Syntactic

Figure 8-1. Visual and syntactic forms of representation.

Instead of perusing the approach of the right "choice" of representing concepts, this investigation attempts to direct attention toward the process of interpreting a concept from a representation and of interpreting a concept from the actor's mind. Conceptual role semantics provides the framework. The functionalist approach within the interpretations of concepts scrutinizes the role that is played in the actors' minds from one mental state to another state. The roles give meaning to the interpreted concept. The central issue is to illustrate that the forms of

representation do not guarantee the communication of the semantics of the attempted interpretation.

Examples with Some Forms of Representations

In interpreting forms of representation, *conceptual role semantics* plausibly set the account on the element that plays the role of finding semantics under the psychology of an interpreter or actor. In order to clarify the significance of the framework of *conceptual role semantics* within the construction industry, consider the following examples. The examples illustrate the *conceptual role semantic* plausibility. Although the examples are obvious cases, the purpose is to illustrate and to emphasize that "the interpretations from the employed forms of representation do not guarantee the semantics in communicating construction concepts". The first example employs a visual and a syntactic representation, while the second example employs a symbolic, formal representation. Under the view of *conceptual role semantics*, the later shows a case of divergence on finding relationships by *similarity* as the main form of reasoning for finding semantics among representations.

Visual and Syntactic Forms Example

Conceptual role semantics should indicate how actors *react* against the perceived representation. An actor finds the content and semantics of a concept in order to assert an interpretation from representations generated from other sources. This is the case of many operations and processes in the construction industry. Actors frequently perceive visual representations such as sketches, drawings, schedules, etc., and react by asserting interpretations. Consider, then, the case of Figure 8-2 (a) where a visual representation is to be interpreted by an actor. The square on the right of Figure indicates a "series of step" of a simplified reasoning for interpreting the visual representation. The "series of step" is not a rule within this research, but

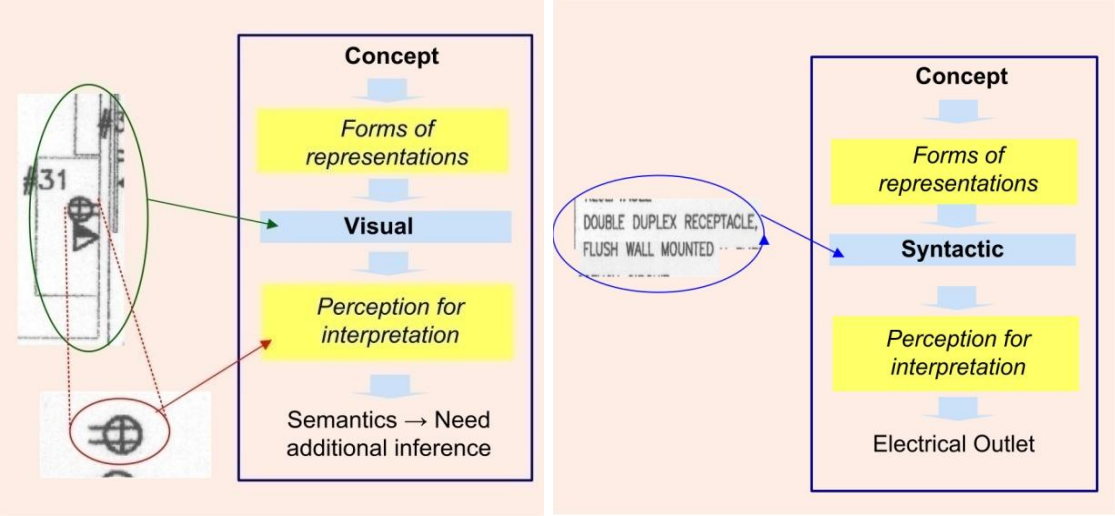
they are only shown here for illustration purposes. In this research, other forms of reasoning are also considered as valid, such as metaphorical reasoning (Lakoff and Johnson 2003).

It is central to emphasize that the representations under the *conceptual role semantics* are means for *reasoning* for the interpreters or actors. Thus, the relations from a representation such as syntactic markers or symbols serve and aid the thinking to establish semantic relations. In the case of the *visual representation* of Figure 8-2, the interpreter searches for these relations through resemblances that are made by setting *similarity* relations. The actor finds resemblances of the visual representation or sign shown in their body of knowledge by employing *similarities*. This reasoning includes the uses of this sign. The findings are the semantics relations that must indicate the content of the 'concept' that this sign refers to, i.e. these identified relations are apprehensions based on *similarity*. The *similarity* is a property of the perceived phenomena and it is employed to find relations to the mental construct of the actor. *Similarity* does not designate the characteristics of a concept. It establishes general indications of what a representation of a concept refers to. The designation of the characteristics of a concept suggests its *content*, which must conform to its role.

The reasoning illustrated in Figure 8-2 (a) shows that the relations for semantics were not found. The sign as visual representation is not recognized for performing interpretation. This is the case that the actor does not have a relevant conceptual role for distinguishing semantics. In continuing with this example, the actor needs to find additional sources of information to aid finding the semantics relation. For this purpose consider Figure 8-2 (b), where the form of representation is syntactic. In the left part of Figure 8-2 (b), there is a set of markers that, by some method, the actor reasons like the ones that contain and indicate the semantic *content* of the sign of Figure 8-2 (b). For clarity, the set of makers is a syntactic form that for a more primitive,

cognitive expression are signs. The markers of Figure 8-2 (b) conform to a natural language expression that states the semantics of the visual representation.

The resulting path for reasoning concerning the representations of Figure 8-2, (a) and (b), is the one played by the semantic role. This path for reasoning implies the description of how to *use* these representations. The reasoning should indicate the content of the concept. The uses are features learned *a priori* by the actor. It can be noticed from the example that the designation of the characteristics of a concept or content anticipates the reaction or the reasoning of the actor. This designation should make the actor produce accurate assertions of the expected results.



(a) Visual (signs or symbols) (b) Syntactic or text

Figure 8-2. Reasoning forms of representation.

Formal Form Example

Consider a taxonomical form of representing concepts, which can be employed for certain actives, such as estimating or planning. Under the *conceptual role semantic* view, the assumption is that the actors translate into representations their knowledge that corresponds to certain construction concepts. The representation is tantamount to "languages of actors' thoughts". In this example, these thoughts are *formally* represented as a formal form.

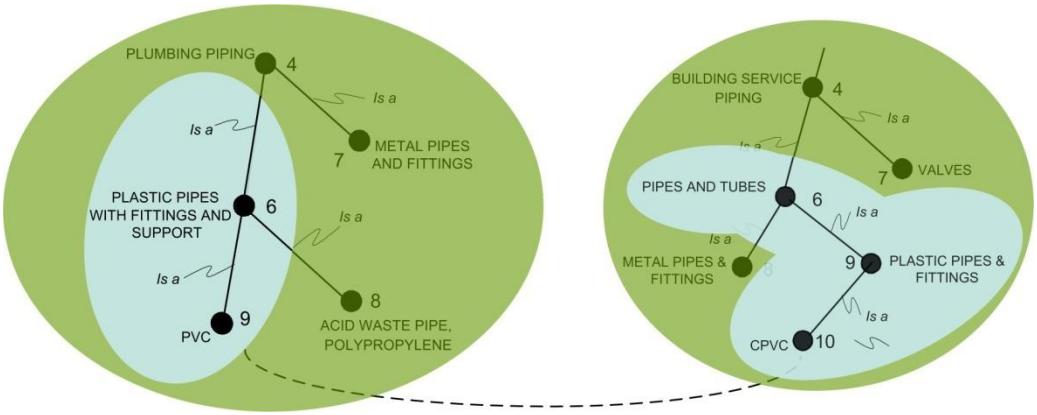
The resulting concepts represented by this form of representation must bear some relationship to properties, objects, or situations in the external world by virtue of that domain nature, in this case, construction industry concepts. These relationships do not imply correspondences of the concept to the physical world as true conditions. The relationships are from *common* set of properties, objects, or situations to that are shared and, in turn, perceived by a group of actors, such as a construction industry network. The resulted representation is not grounded to the external world; instead, it is the outcome of the translation to a formal form from the author's thoughts.

For clarity, a taxonomical form breaks down a particular area of knowledge that shares certain features by classifying it into categories or items. The relationships between the items have automatic *inheritance* features, which can be interpreted as free path for *inferences* among the related items. The resulting items from the breakdown are actors' *assertions* generated from this form of representation. According to the selected features of the knowledge domain, a criterion is used to evaluate the multiple sorts of properties of functional aspects, among others, in order to assert the items and relationships for building the taxonomy. Thus, this taxonomical form can represent objects, properties, relations, situations etc., and the represented forms are the nodes that shape the taxonomical structure.

Figure 8-2, (a) and (b), shows two sections from two different taxonomies, which are formal forms of representation. The sections shown in the example of Figure 8-2 are parts of two taxonomies that characterize elements of hydraulic components used in buildings. The assumption for this example is that the sources from two different sources or actors translate their thoughts or knowledge concerning the hydraulic components into representations according to each one's criterion. Under the *conceptual role semantics'* view, the judgment that aids the

breaking down process into classification, should take into account the *role* that serves the item's semantics. The role enables these items to relate and constructs a relationship between them. For example, suppose that an actor wants to relate two concepts from these two sections of the taxonomies. This can be the case for any operation where an actor needs to share information concerning building components with another construction project participant. The actor, who generated the taxonomy in Figure 8-3 (b), needs to share information with the other participant who elaborated the taxonomy of Figure 8-3 (a) by querying information from the taxonomy of Figure 8-3 (a). For this purpose, the actor accesses the taxonomy of the other participant by some method. As the main form of reasoning for finding their semantics, construction participants base their reasoning on contrasting the *similarities* of the items, which represent the concepts of hydraulic components used in buildings.

As shown in Figure 8-3, finding *similarities* is possible through contrasting syntactic expressions with the purpose of establishing syntactic relations among the compared items. However, if a syntactic relation is established, it does not give *consistent* results on equating the semantics of the compared items. The semantics of the represented concepts from the taxonomy structure cannot be equated, they can be associated. The roles of each one of the structures for the compared items differ. The semantics is given by the role that the compared item plays in the own actor's system. In Figure 8-3, the actor contrasts the form of representations, expressed as a 'syntactic' form, through a *similarity* relation. Contrasting is performed between node 9 of Figure 8-3 (a) that has a syntactic content of 'PVC' and node 10 of Figure 8-3 (b) whose syntactic content is 'CPVC'. Asserting a correspondence implies the identification that the



(a) Taxonomy with syntactic content (b) Taxonomy with syntactic content

Figure 8-3. Example of formal forms of representations.

'PVC' has a semantic role in the system of Figure 8-3 (b). The content of node 9 of Figure 8-3 (a) has a conceptual role in the system of Figure 8-3 (b). Note that if the correspondence between these two systems is established, this relationship does not consist of the matching of the 'PVC' of node 9, in Figure 8-3 (b), and the content 'CPVC' of the node 10, in Figure 8-3 (b). It consists of 'translating' the 'PVC' to the system of Figure 8-3 (b), and it must describe the semantic role of that system.

There is no implication that two nodes similarly marked 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 between the content of node 9, 'PVC', and node 10, 'CPVC', from Figure 8-3, (a) and (b) respectively, 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. As was mentioned, in Sellars' language games, the correspondence should be given in terms of *position* and *move*.

For further illustration of the plausibility of *conceptual role semantics* within formal forms of representation, consider other highlighted components or nodes in Figure 8-3. Under *conceptual role semantics*, a consistent result on the semantic of a representation is definable, if the set of the terms are taking 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 8-3, the semantics content of node 9 of Figure 8-3 (a), 'PVC', and that of node 10 of Figure 8-3 (b), 'CPVC, are not taken into consideration. In the same way finding the role that nodes 6 and 9 play in Figure 8-3 (b), involves the set of syntactic contents of 'Pipes and Tubes' (node 6, Figure 8-3 (b)), 'Plastic Piping & Fitting' (node 9, Figure 8-3 (b)), and 'CPVC' (node 10, Figure 8-3 (b)). The definition of the semantics of the shown set of nodes has to be taken into consideration for understanding their functional uses.

Summary

Conceptual role semantics open new perspectives to understand the modus operandi of sharing and communicating concepts in the construction industry. This research rejects the idea of having a literal meaning for concepts in order to succeed in communicating them, which is the basic tenet of enforcing standards within the construction community. The meanings or semantics of representations are provided by thoughts, not by truth conditions. Conceptual role semantics serve as the framework to find semantics based on the role and the concept of the forms of representation used.

CHAPTER 9
A FRAMEWORK FOR ANALYSIS OF CONSTRUCTION CONCEPT

Analysis of Construction Concepts and a Methodology for Aiding Their Interpretations

In this research, a *conceptual framework for interpretation of construction concepts* has been generated from the analysis of the (1) forms of representation of construction concepts, the (2) the modus operandi of the representations and of the concepts, the (3) the proposed disjunctive of the modeling paradigm, the (4) the granularity and its relevance for interpretation, the (5) the analysis of the semiotic framework, and (6) the inclusion of the role concepts for semantic interpretation. The framework is presented in this chapter.

This conceptual framework articulates the theoretical propositions that this investigation advocates. The purpose is to develop a methodology that supports a novel way for interoperating semantically within the interpretation step. The understanding of the role of semantics through representations of construction concepts contributes to the illustration of the semantic interoperation. The framework is a mechanism that articulates this understanding through the propositions stated in the previous chapters. The framework explains *how* the articulation of the theory propositions takes place.

The conceptual framework has the following components (1) knowledge acquisition, (2) knowledge organization, and (3) querying. One of the major differences of these components is that the actors who participate or use the framework do not necessarily work in each component. The actors do not participate in each component or their roles in each component are different. Within the *knowledge acquisition* component domain experts who can essentially perform interpretation of the domain concepts are involved. Other actors participate in the *knowledge organization* component by using the resulting product from the *knowledge acquisition* one. Finally, the users are actors in a construction product that query the concepts that have been

organized. The users are the direct actors who participate in this component. Figure 9-1 illustrates the dynamic of the different actors that intervene in the framework.

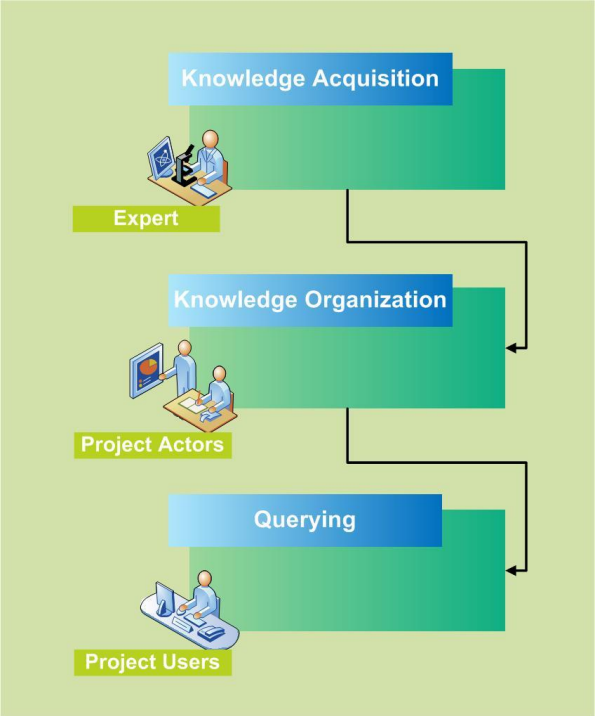


Figure 9-1. Intervening actors and subsequent components of the conceptual framework.

Knowledge acquisition is a methodology employed to capture domain concepts from experts. It explains the systematic procedure for analysis of construction concepts in a formal representation, named conceptualization. For the knowledge acquisition component, a *scheme* is formulated for conceptualizing a phenomenon or an activity, a process, a resource, or an actor that intervenes in an interoperability activity in a construction project. The scheme articulates the theory that connects the relationships of the phenomenon defined in the theoretical propositions. For example, the characterization of concepts can be articulated by employing a scheme through the influence of situations and of contexts in representing them, the reasoning and the actor's

role, as well as the boundaries of sufficiency and deficiency. The scheme describes the *relationships* of contexts and of situations for interpreting a social, domain concept.

The knowledge organization component stipulates the method used for storing the information which has the *ability to provide* semantic *associations* of concepts. The organization can be specified through a knowledge representation structure named in this research as *'concept cluster'*. This knowledge base has the ability to store and to provide the semantic associations of the concepts. It semantically organizes concepts to facilitate the storing and retrieving queries about a concept in construction. The mechanism used as a knowledge structure is the ontology for computer systems.

The querying component illustrates the *competency* of the approach for aiding the framework users in interpreting a concept. The queries are elaborated in a GUI (Graphical User Interface) for a clear understanding of the dynamics between the knowledge-bases, the interpreter and a concept. The interface facilitates the comprehension of the components of the proposed, semantic interpreter tool.

The explanation and description of the components of this framework is the objective of this chapter. In the first segment of this chapter, the mechanism for characterizing concepts and the scheme is illustrated; the second segment shows the approach for knowledge organization, and the third, the querying method of information.

Knowledge Acquisition

The mechanism for acquiring knowledge consists of translating a concept that is represented in a human readable form into other knowledge representation form by using a judgment and the input of an expert. Thus, observable elements and non-observable elements are included in the translation. The main reason to develop other knowledge representation forms is to facilitate its manipulation, storage, and querying through the use of computer systems. This

knowledge representation form is expressed as semantic networks. A *semantic network* is a declarative graphic notation for representing knowledge in patterns of interconnected nodes and arcs, and for using reasoning on the representation (Sowa 2006). These *semantic networks* can further be transformed into a logic based language for computer implementations.

The translation is performed through interpretation of the observed representations. The observable elements of the translation correspond to what the interpreter perceives in the human readable form. The reader can notice that the human readable forms correspond to the quality of material and to the character of symbol from the semiotic framework. Also the reader can notice that what the interpreter is able to observe in the representation corresponds to the relevant elements or details of the concept. These elements are the explicit information located within the boundary of sufficiency in order to be interpreted by that particular observer. The non-observable elements correspond to the added details, categories, properties, and semantic relationship to informal form. The resulting non-observable elements are generated from the interpretation of the observed or perceived representation. Chapter 6, which analyzes the *modus operandi* of representation of construction concepts, explores the procedure for the reasoning on the representations.

The inclusion of all possible domain features and constraints in a knowledge representation form are required to conclude the knowledge acquisition process. A description of what is only represented in a topology that stands for the '*wood interior door*' concept in the drawings, in order to be represented into other knowledge representation form, is an example of a translation of an observed representation. The inclusion in the formal form of additional domain features such as project name, location, environmental conditions, among others, are examples of non-observable elements and, therefore, there are not included in the visual representation. In this

example, the purpose of topologies in construction drawings is to represent the concept visually as well as its associated details. The details that are usually indicated in the visual representations are the dimensions in the space domain. The dimension is an observable constrain feature that can be included in the other form of representation.

However, the translation process from an observable representation to a knowledge representation form is complex. The mechanism for knowledge acquisition should be harmonized to the theoretical propositions of this research. It should be consistent and homogeneous for different interpreters. For this purpose, a *scheme* that serves as a mechanism and as a theory articulator is proposed. This scheme helps analyze consistently and homogenously any concept that it is perceived by the interpreter.

The scheme is based on six basic questions which is similar to the analysis of language ('*what*', 'who', '*where*', '*how*', '*why*', '*when*'). This scheme works as a structure that guides the interpreter to organize and to associate each aspect of the concept to the answer of each question. Thus, each question is in principle a course of action of the interpreter. This research proposes that each course of action, defined by each question, has to be related to an ontological analysis. Therefore, each course of action indicates a direction for defining the observed concept through ontological categories. An illustration of the scheme is shown in Figure 9-2 .

Figure 9-2 shows the scheme and the three levels that help differentiate the components of the scheme. The first level indicates the top ontological categories that are associated with the second level or the course of action ('*what*', '*how*', '*where*', '*who*', '*when*', '*why*') of the scheme. *Top ontological categories* are basic distinctions that are neutral from any domain and on which basic relationships can be grounded. An analysis of a concept through the scheme must at least be defined by the categories showed. Although the purpose of our research is not to

design a methodology for concept ontological analysis, our investigation does suggest that this framework must follow a systematic analysis of concepts. Other valid ontological analysis methods in the literature, which define top ontological categories (Guarino and Welty 2002; Sowa 1999), can be applied to the framework.

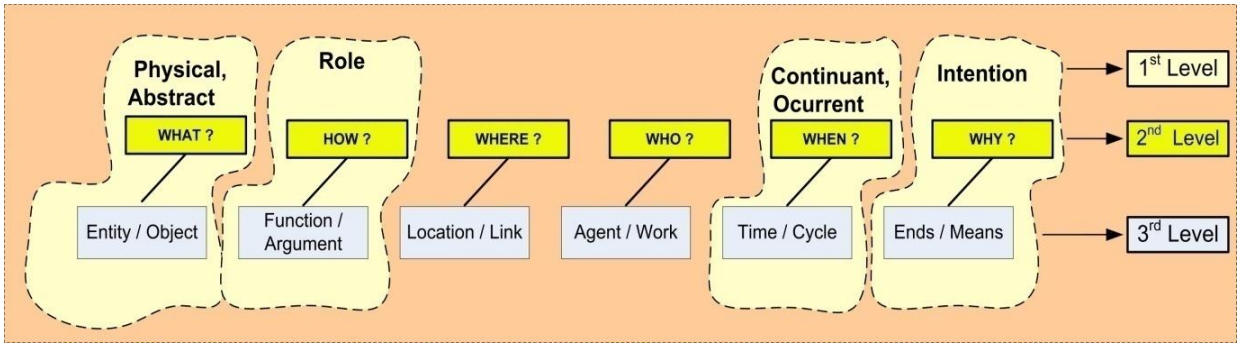


Figure 9-2. Scheme for concept analysis and the associated top ontological categories.

Figure 9-2 illustrates how top ontological categories act upon the proposed research scheme. For example, top ontological categories defined as continuant, which is the category that describe an object or abstract that has stable characteristics over a period of time, or occurrent top ontological category (Sowa 1999), that describes a concept that has enduring characteristics, can be set up by using the scheme.

The scheme represents a methodology that classifies concepts ontologically. It is critical to highlight how ontological categories act upon the scheme. The third level of the scheme defines the relations that the cognitive agent or expert makes associations with based on the selected top ontological categories. For example, the expert recognizes the concept representation itself, finds semantic relations, and identifies ontological aspects of the concept (e.g. the cognitive agent's role, in the scheme of Figure 9-2). The top ontological categories, such as abstract, physical, continuant, among others, capture the instances in which an agent reasons about a concept. Top ontological categories guide a classification of the concept into categories of existence. These

categories identify a common denominator of the analyzed concept within a domain, which is by definition the ontological specification of the concept.

The analysis of the concepts through the scheme implies the expert's point of view, which by definition must be reflected in the agent's organizational role. The analysis makes the explicit distinction of the relation of the cognitive-agent's social role and concepts under the agent's domain. The '*who*' guidance represents the beginning to this analysis, and is the link to the available *conceptualization* of the agent's social role. The assumption is that experts play a social role in the organization of a construction project.

The resulting analysis through the scheme is organized into a knowledge representation form in order to be manipulated, stored, and queried. This analysis is similar to the conceptualization process of information systems. However, in this approach the interpreter has to follow the course of actions of the scheme to ensure homogeneity and consistency in the analysis of the concepts. Taking this difference into consideration, the following is an explanation of the conceptualization and its dynamic within the proposed scheme.

Conceptualizations

A conceptualization is a set of informal rules that constrain a form of representation that describes a predefined social concept or concept of a domain. The meanings of those concepts are supposed to remain the same even if some of the situational conditions change (Guarino 1997). Conceptualizations are described by a set of informal rules used to express the meanings through a set of domain relations.

Top ontological categories are employed as a mechanism for structuring the ground of the informal rules. The ontological distinctions support the domain conceptualizations, which in this case is the construction domain. This structure is a semantic network. Figure 9-3 shows an example. The top categories are the red boxes in the Figure. Figure 9-3 is a graphic notation of

interconnected nodes and arcs. The nodes represent a declarative distinction and the arcs the relationships.

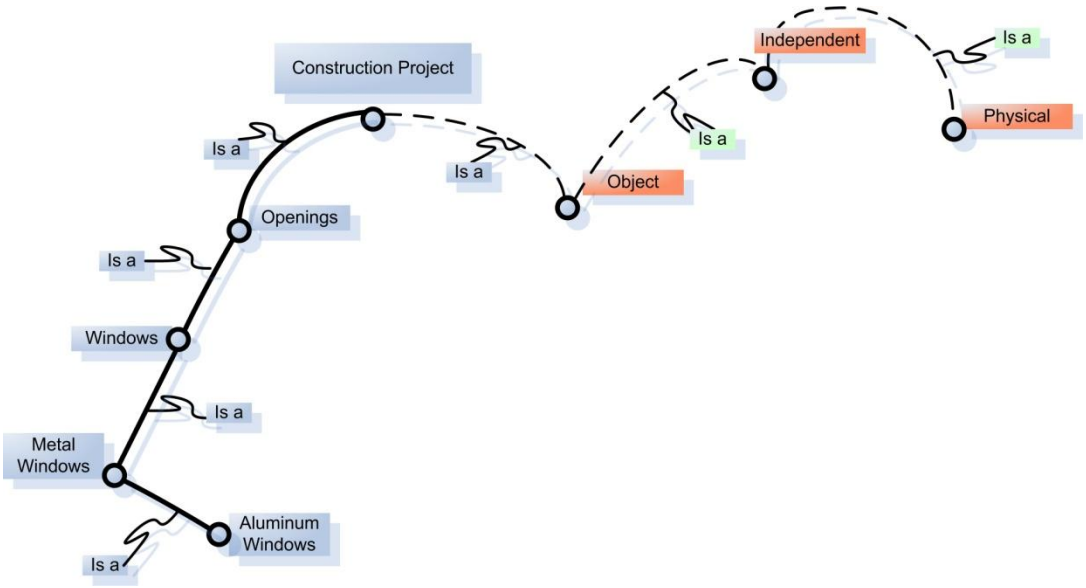


Figure 9-3. Top ontological category analysis of the 'What' basic form of question.

As can be observed in Figure 9-3, there is the subtype or *is-a* relationship between declarative distinctions. This relationship is also called a generalization or subsumption hierarchy. It is employed with the purpose of supporting the rule of inheritance that replicate the properties defined for a super-type to all of its subtypes. Our research does not recognize that top ontological categories are unique or valid as a basic structure. Other top ontological categories could have also been employed to provide the distinctions in the framework or in the example. The employment of these ontological distinctions, however, has to be in a systematic method with the purpose of providing a conceptual analysis.

Conceptual Analysis

The second level of the scheme, shown in Figure 9-2 has the course of action expressed as questions ('what', 'how', 'where', 'who', 'when', 'why'). These courses of action help the

interpreter, who is an expert as was mentioned to query and to address the description of the analyzed construction concept. As was explained previously, the first level indicates basic neutral distinctions through the top ontological categories. In addition, the boxes, which correspond to the third level of the scheme, have examples that help the readers analyze the concept in each course of action.

In Figure 9-2, the '*what*' is a basic question that discriminates the observed concept as a *physical object* or as an abstract *scheme*. An abstract *scheme* is a pattern (e.g. geometrical forms, syntactic structures), which describes visual representations as object 'symbol', as a object's topology, or as text-based 'symbol' used in natural language.

The '*what*' question motivates the expert to perform *contrasts* of the analyzed concept to other concepts from the expert's experience. This is a basic step of the inferential reasoning used in defining *what* a concept is. A metaphorical reasoning takes place and the interpreter faces the boundary of sufficiency or deficiency in identifying the concepts. In other words, the observer is able to identify a concept based on their own experience or own knowledge by contrasting the *relationships* between them. The *relationships* are essential for further analysis in the framework in order to acquire additional knowledge from the expert. The expert's input corresponds to the non-observable elements that are not included in the representation of the concept.

The boxes below on the third level of the scheme contain the possible *form* in which the concept is represented. The forms also facilitate further analysis about the strategy for the manipulation and the computation of the translated concepts. If the concept is represented as a function, for example, then procedural aspects are needed for describing the concept. If the concept is represented as an object, declarative relationships that describe the concepts such as the relationship of containment are needed.

Figure 9-3 shows examples of the '*what'* course of action within a semantic network. The examples illustrate an ontological definition from a top-down approach by employing top ontological categories from the first level of the scheme. In Figure 9-3, the left semantic links portion corresponds to the semantic network '*Aluminium Windows*' that defines this concept. The node '*Aluminium Windows*' is shown at the bottom level however the complete ontological description of the concept '*Aluminium Windows*' is not shown in the semantic network. Additional levels can be added at the bottom to the node '*Aluminium Windows*'. These are explicit levels of specializations that further '*Aluminium Windows*' concept. However, note the syntax '*Aluminium Windows*' is a natural language representation used for manipulating the description of this concept within construction documents or within speech acts. The syntax '*Aluminium Windows*' is also used for computing within a computer application. Explicit levels of specialization or explicit ontological representations are not used for the concept manipulation and for the concept computation.

The resulting semantic network is the expert's description of the concept '*Aluminium Windows*'. If a collection of concepts is the objective to be analyzed, then a collection of semantic networks elaborated by the expert's description is needed. Thus, if '*Wood-Window*' concept is analyzed, then the expert's input through the analysis is needed.

The '*how*' fundamental question or course of action describes the functionality of the analyzed concept. If the concept has components or parts, the description includes how the parts are organized for a given function. When the concept contains parts, the distinctions made in the semantic network can define one or more functional relations among them. As was described in the modus operandi of concepts, the concepts encompass roles within the space-time dimensions.

The functional relations describe this role as well as the role of the concept to others within space-time region. As it shown in Figure 9-4 in red boxes, the role of the concept is described ontologically through the top distinctions. The concept '*Aluminum Windows*' has a role within its functionality. The concept should contain components that have properties and attributes. In Figure 9-4, the components meet certain properties specified in the regulations.

The '*where*' course of action of this form of fundamental question describes the relationship in the space time domain in which the analyzed concept is perceived. In addition, the analysis must identify situational conditions, which embrace the concept's location, position, the

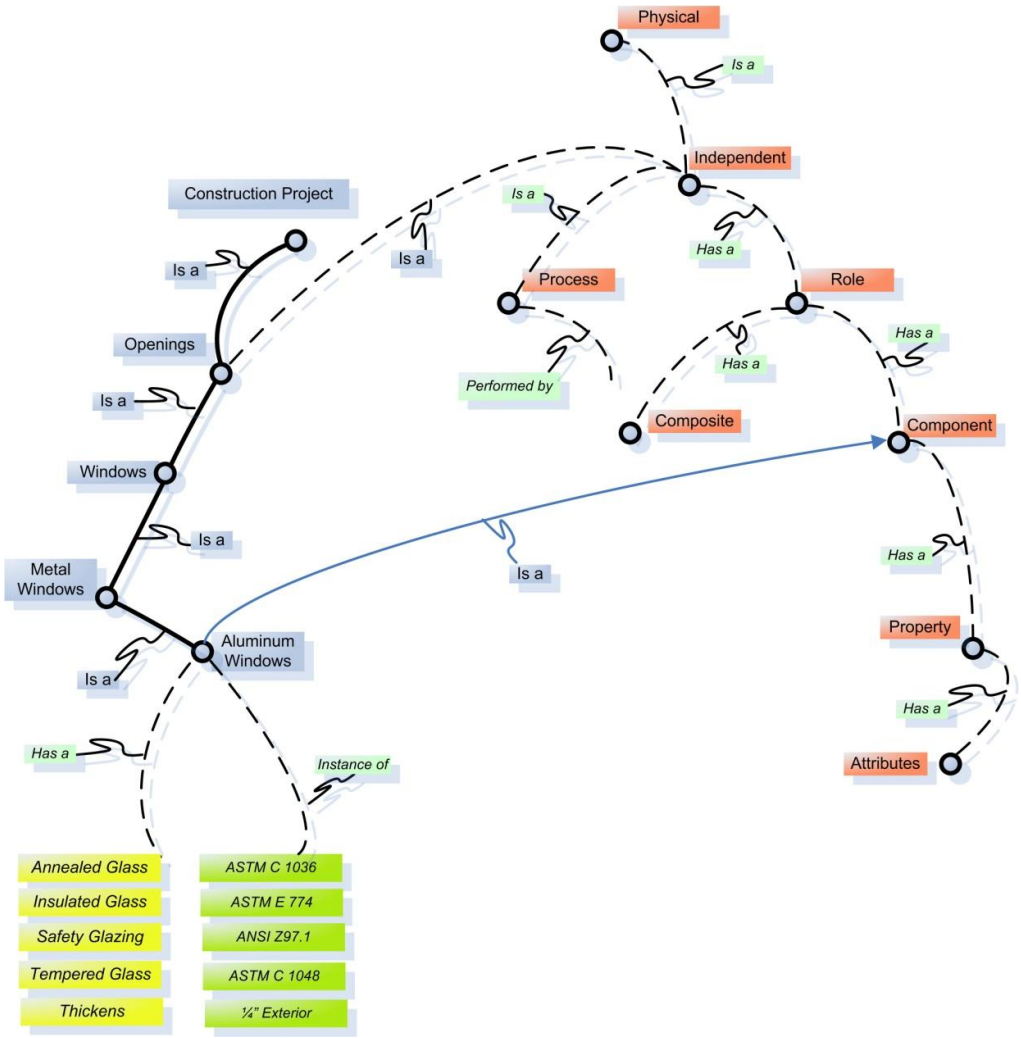


Figure 9-4. Top ontological category analysis of the 'How' basic form of question.

space time domain in which the analyzed concept is perceived. In addition, the analysis must identify situational conditions, which embrace the concept's location, position, site, place, and settings as well as *situational conditions* concerning *context relations*. Further explanation concerning the relationships between the concept and space domain are described in Chapter 6 (modus operandi) and in Chapter 4 (concept in the construction domain). Since concepts can be associated to a particular instance in space, the '*where*' course of action situates the concept when the relation about a specific place or location is instantiated. For example, the concept "Rolling door" is associated to the location first floor of the A39 platform in UF building 272. Figure 9-5 illustrates the course of action the '*where*' basic question in a semantic network for an '*Aluminum Windows*'. In Figure 9-5, context relationships are explicitly described. Although the context relationship are instantiated in the example for the '*Aluminum Windows*' concept, the ontological distinction are neutral for other concepts in the domain. In other words, the ontological distinctions, which are the red boxes on the right side of the Figure 9-5, can be used with other concepts in the domain.

The course of action of the basic question 'when' conceives the status condition of the concept during its life in the time-space region. This is a specification of the stage of the concept (e.g. completed, installed, delayed) during its lifetime. It describes its process through the ontological distinction. The following example includes Sowa's top ontological distinctions occurrent or continuant to specify the status of the concept within its lifetime. The reader can notice that the description of a concept depends on the characterization of its time scale. The concept can be considered as a process, as a part of a process, or as a stable entity. Thus, the concept status is a description of a *view* of the interpreter or of the expert by identifying this concept. The interpreter perceives the entity in an unstable or stable state at a given period of a

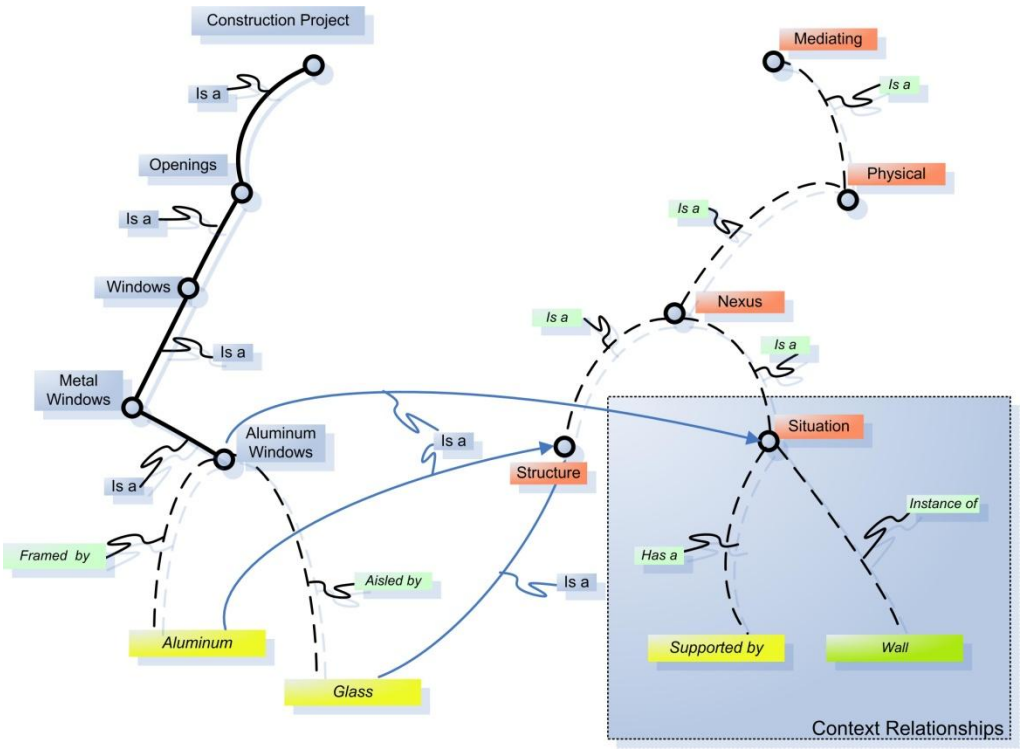


Figure 9-5. Top ontological category analysis of the 'Where' basic question.

time scale. This situation is labeled by this research as *situational conditions* or *status conditions*. Chapter 4 fully explains the research behind the situational condition notion and its relation to the stability of situations. Figure 9-6 shows the definition of the '*Aluminium Windows*' under the analysis of the basic question '*when*'.

The '*why*' course of action specifies the *intention* behind the interaction of the concept with other concepts, and the '*who*' course of action describes the relationship of the user's role played within a social context, such as an organization, with the observed concept. The role is exclusive and it is the one played based on the course of action that the user has with the observed concept. The '*who*' course of action represents the link to the available *conceptualization* of the user's social role. The purpose is to anticipate the user's role associated

with the analyzed concept. This research recognizes that each construction participant plays a role within a social context such as the construction project organization.

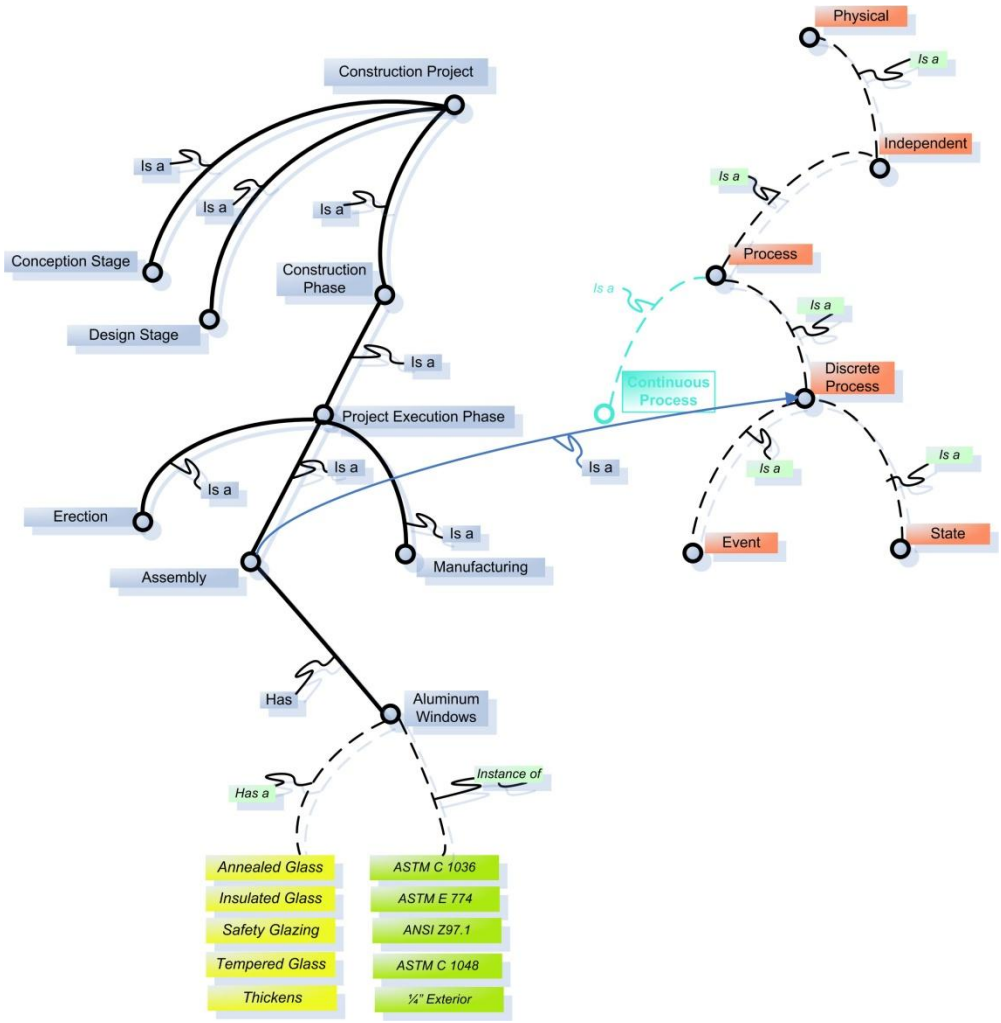


Figure 9-6. Top ontological category analysis of the 'When' basic question.

As the intention is the explicit association of the observed concept to other concepts, the expert identifies the *intention* of the observed concept to others. This identification is performed exclusively for each one of the roles played by users within the observed concept. For example, why is the concept "Rolling Door" relevant to a "project manager"? It can be noticed that the relationship of the concept "Rolling Door", which could be represented in some form such as a

visual representation in the drawings, with the role of an actor in organization, the "Project Manager", is already established. The '*why*' specifies the purposes of the interaction of the "Rolling Door" concept with other concepts in relevant situations, such as the purpose of the interaction of the "Fire exit stair" concept and the "Rolling Door" concept. The *intention* defines *why* these two concepts are related (e.g. the minimum distance specified by the local fire regulations) under the actor role. A careful analysis on associating two concepts is that this action is a semantic enrichment act. The risk of a combinational explosion on associating concept is subdued to the actor's role within the observed concept. The actor's role is a common denominator which factors any association among concepts. In other words, the *relevant* associations, as a criterion, are the only ones considered by assuming a particular actor's role.

The intention and the role have to be considered by the expert in analyzing an observed concept in the knowledge acquisition stage. The expert has to identify the actions played by the users in particular roles. The expert makes explicit the actions that characterize the users' role. If the *purpose* of one concept is described by an expert, the relationships between two or more concepts needs to be identified under a particular user's role. The *purpose* is a dichotomy of the cognitive agent's intention. In other words, a relationship of at least two concepts has to explicitly be identified in order to specify the user's intention with one concept.

As Figure 9-7 shows, the course of action of the 'why' basic form of the question is the first association of the intention of the cognitive agent within an ontological distinction. In Chapter 6 (*modus operandi*), Chapter 5 (granularity), and Chapter 8 (the semiotic proposition section), clearly the role of the user for interpreting a concept, as well as the intentionality within the concept, are recognized. The identification of the relationship between the observed concept and the interpreter's role, and the relationship between two or more concepts under the

observer's role, are central aspects of this research. The ontological distinction of the 'why' basic form of the question is illustrated in Figure 9-7.

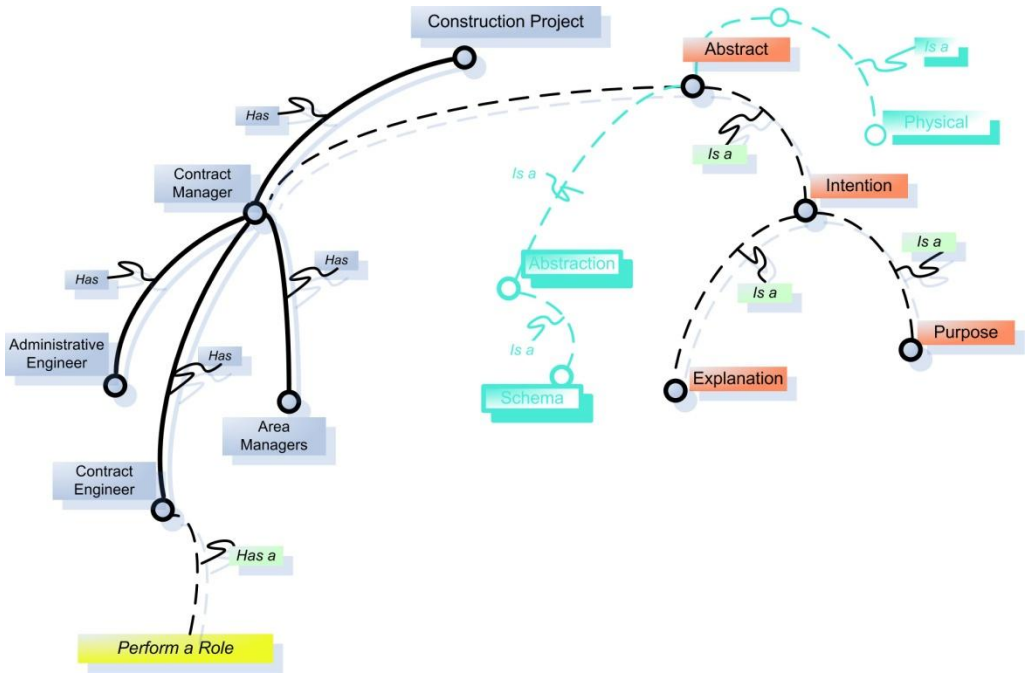


Figure 9-7. Top ontological category analysis of the 'Why' basic form of question.

The 'why' basic form of inquiry helps the expert find the intentions of employing a concept by the actions of the role of a particular actor who belongs to a social organization. The expert anticipates the user's role associated with the analyzed concept.

The role is defined and delimited to the user's view towards the analyzed construction concept. The user's ability to perceive an observed concept depends on the user's understanding of that concept. The assumption is that the actor's roles within an organization result in limited actions in manipulating the representation of a specific concept. Thus, the role of the expert in the knowledge acquisition stage is to anticipate the user's actions. The expert's conceptualization of an observed representation is independent and not biased towards one specific user's role. As

the user's actions are limited, their perceptions are also limited to the intentions of the user's with the observed concept.

As was explained previously, the user's perception is a function of the granularity of the representation. Therefore, the user's perception of the concepts depends on how the concept is represented and on how it is conceptualized. The granularity level of the observed entity is related to the user's role in the organizational domain. For example, suppose a construction participant observes the layout of Porcelain-enameled reflector with 30°CW x 30°LW shielding. The layout is intended for the electrical subcontractor's level of knowledge and not for other participants. The granularity level of the representation of this electrical concept is relevant only to the electrical subcontractor. In the case that a subcontractor attempts to perform an interpretation of this electrical concept, the conceptualization for the subcontractors' roles should be performed.

Knowledge Organization

As it was explained, the conceptual framework is aimed at associating the observer's world or cognitive agent's world to the representation of the construction concept by finding explicit relationships between the agent and the observed concept. The framework guides this analysis and helps to define semantic associations to the concepts. Once the analysis of the observed concepts has been made through the scheme, the resulting knowledge has to be organized in a form of representation. Although the semantic network is a form of representation that was used in the knowledge acquisition component, this form is more useful for facilitating the visualization of the semantic associations of the concepts. The semantic networks, however, express semantic associations that can be transformed into a logic based language for computer implementations. An arrangement of the concepts and of their semantic associations through other forms is required to perform effective manipulation and computations. These forms are

based on levels of representation that assure a systematic and harmonious re-use of the concepts by other actors in the community. They are also required to facilitate computational applications of the acquired knowledge.

The knowledge organization within the framework is based on the distinction made by Brachman (1979) concerning the different levels of knowledge representation formalisms from the epistemological point of view. Epistemology deals with the '*forms*' of knowledge representation. The epistemological levels define how knowledge of the physical constructs or abstract notions can be represented (Kronfled 1990).

For clarity, an analogy on these levels of representation can illustrate the knowledge organization. Suppose that some experts in the biology domain introduce a new concept by observation of some phenomenon. Initially the experts describe this new concept through visual representations and define it within biology taxonomies. However, even though the visual representations and taxonomies are forms of representations that hold semantics for these new concepts, additional levels for representing this concept are required for its manipulation and for its computation. This new concept, for example, was related to existing ontologies within the biology domain, which are semantically richer forms of representation than that of the taxonomies. Also, pragmatic aspects of this new concept are required to be associated within its definition as well as the definition of variables and quantifiers for computing. For example, the property *'xyw*' of the concept has the ability to be reproduced two times in two week of incubation. Therefore, if actors query any system on the number of biology concepts that can be reproduced two times in two weeks of incubation, the semantic associations to this new concept will be queried.

The following levels incorporate the strategy for representing knowledge and the input from the cognitive agent. The levels are based on the distinction made by Brachman (1979), which differentiates knowledge representation formalisms from the epistemological point of view. The epistemological point of view is concerned to the nature of the forms and method for acquisition of knowledge of the physical constructs or abstract notion (Kronfled 1990). The levels of Brachman are complemented with the levels of representing knowledge from Guarino (1993), who emphasized that the intended meaning of the concepts must be performed *a-priori* in knowledge representation formalisms. As was introduced in Chapter 5, the conceptualization method is an *a priori* strategy for analyzing concepts.

- Logical. Symbol logics, predicates, and quantifiers, among others, that give formal semantics in terms of relations among entities within the real world. These relations are non-aligned concerning the intended meaning of concepts.

- Epistemological. Structures of concepts, objects, frames, inheritance, among others. These forms restrict interpretation from the logical level. The 'structure' per-se involves or takes on meaning by capturing semantic relations.

- Pragmatics. All the arbitrary syntax and functions other than those specified in the epistemological level.

- Ontological. The use of ontological relations to define a-priori formalism in a structure. The fact of being a-priori facilitates the definition of the concept intention into the formalism. These formalisms are defined from top ontological distinctions to more refined ontological ones. In other words, the formalisms at this level can define general meanings of the concepts for the cognitive agents, or they can define a concept with a higher level of accuracy of the meaning by making additional ontological commitments.

- Conceptual. Conceptual relations, primitive objects and actions, linguistics roles, among others. These are the connections that infer particular meanings. However the meanings are subjective and, do not reflect any ontological commitments (Guarino 1995).

The *levels of representation* define what is needed for representing a concept, by taking into account the primitives (e.g. predicates, structure relations) and the characteristics of each level (e.g. define concepts, meaning, forms etc.), as well as societal agreements on forms, on symbols and among other commitments. These aspects are used in the *conceptual framework* to

identify ontological distinctions, cognitive agent's purposes and additional semantic relations that are close to the agent's pragmatics. The purpose is to define forms for organizing construction concepts, and the method that should be used to represent the knowledge as well as the actor's purposes in using the representation.

Organization in Clusters

This research uses an abstract structure to organize knowledge in clusters. This structure is named *Concept Cluster*. *Concept cluster* is analogous to a *metaclass* of an ontology for information systems. This structure includes the aforementioned levels of representations and the semantic relationships of the semantic networks derived from the scheme within the knowledge acquisition stage. This structure gives a discriminate description of the components and relations of a concept. *Concept cluster* provides links to clusters with the purpose of organizing knowledge.

Figure 9-8 illustrates the categories of the proposed *concept cluster*. The cluster groups are specified by (1) pragmatics, contain semantics only inferred from the pragmatic actions; (2) contextual relations, holds strictly locative relationships with other concepts; (3) intention, specify the purposes that define the relationships of the analyzed concept to other concepts; (4) part whole-relation, makes explicit relationships of containment and of the composite; (5) topology, describe the metaphors and symbols used for reasoning about the concept; and (6) cognitive agent role, explicitly states the social role of the actor within the concept. The cluster groups are specified by pragmatics, contextual relations, intention, part whole-relation, topology, cognitive agent role, and possible metaphors that represent that concept.

The organization of the concept through the concept clusters structure is the subsequent analysis step from the one performed within the knowledge acquisition stage. It explicitly defines

additional semantics according to 'conceptual links' of the concept cluster or, in other words, according to the categories of the metaclass. Experts or other actors perform this analysis and suggest a categorization for a concept. The 'categorization' is an assumption taken from the epistemological level analysis. A concept is related to the clusters through 'conceptual links'. These links are formal inferences made by the actors about a relationship between one concept and other defined concept (Woods 1975). These links are inferred by the actors. In this case, the links connect the analyzed concept from the semantic network to the clusters. The clusters per se have a category, a distinction. This distinction is an additional semantic specification, which gives additional semantics to the concept.

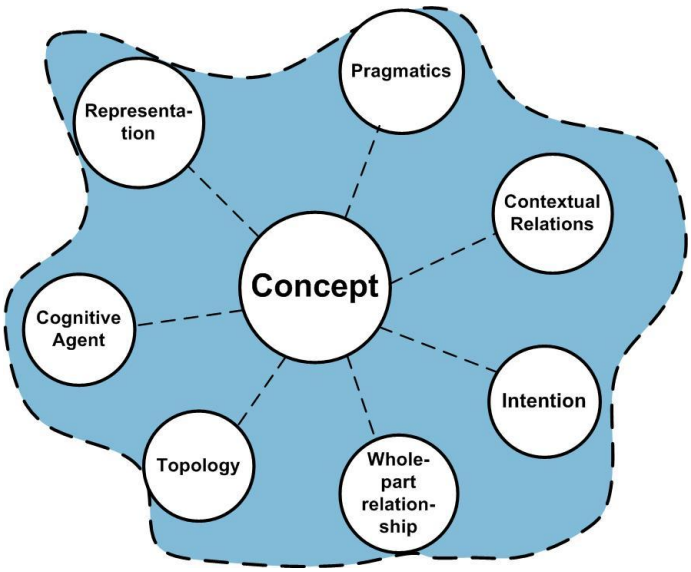


Figure 9-8. Concept Cluster structure.

The following is an example that illustrates the course of action of the knowledge organization component, subsequent to the knowledge acquisition analysis step of the conceptual framework. An expert assumes the role as a *contractor* for analyzing the concept "Rolling door". Suppose that only the expert finds the "Rolling door" concept in a syntactic form or in text based

representation in a construction document. In this case, the "Rolling door" representation stands for a natural language form of a concept. Under the contractor's role, the expert's perception must be on the border of *sufficiency* to derive the analysis of the fundamental questions of Figure 9-2.

The starting point in the scheme of Figure 9-9 begins with the expert's identification of the concept "Rolling door" in the '*what*' fundamental question. The analysis must distinguish that "Rolling door" is a *physical object* (*physical category*), and that the current representation is an abstract scheme in natural language ("Rolling door") (see Figure 9-10). Assume that the expert's does not have the expertise to assert an interpretation about the role or functionality of the concept, as well as its status or stage of life in the time region (e.g. completed, installed, and delayed). Thus, the expert approaches the *boundary of deficiency* to interpret the functionality and the status of the provided text-based form representation, "Rolling door". This means that the expert is not able to interpret the functionality of the "Rolling Door" concept, and is not able to recognize the concept as a process, part of a process, or a stable entity. This portion of the analysis correspond to the '*how*' and the '*when*' basic questions in the scheme of Figure 9-9. For clarity within the example, these entries are shadowed in Figure 9-9.

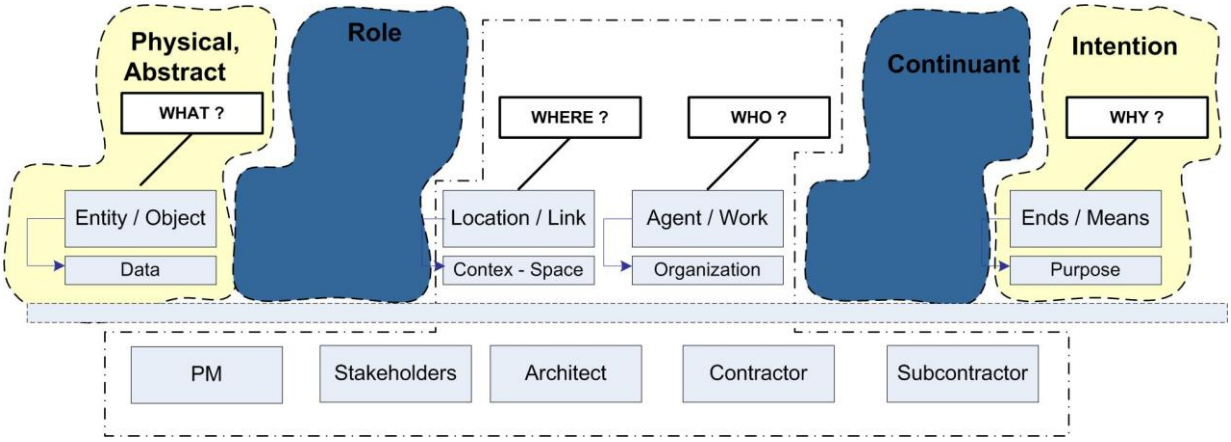


Figure 9-9. Scheme for concept analysis and the associated top ontological categories.

The expert, then, is able to perform an analysis of two additional entries. Assume that this actor, in this example a *contractor*, is aware of the *situational conditions* (e.g. location, position, site, place) that are described in the analysis of the '*where*' basic question. In the same way, the expert is able to identify the intention towards the representation of "Rolling door" that corresponds to the '*why*' course of action. In other words, the agent answers *why* the concept "Rolling door" is relevant or *why* "Rolling door" is able to interact to other entities in particular situations, such as the need that made the contractor interpret that concept. For this particular example, suppose that the intention of the contractor is the installation of the metal curtain doors in a specific construction project, yet the agent has only the information of "Rolling Door" concept extracted from the construction documents. This analysis step makes the agent's concept intention explicit. The reader is reminded that the explicit definition of the intention is central as a factor for finding semantic associations in the scheme.

The '*who*' course of action represents the link to the *conceptualization* of the social role. The actions defined by the actors' roles are different as well as the manipulation of any concept representation within each role. The interpretation of a representation depends on the role played by the actor within the representation. In the example, the construction participant's social role is a "contractor". With the resulting analysis from the knowledge acquisition stage, the expert links or associates the information to the concept clusters. This is the knowledge organization step.

So far the information obtained from the scheme concerning the representation "Rolling Door" and the identification of the agent's role as a contractor is: the "Rolling door" representation stands for a natural language form; the reference to physical object; the identification as an abstract scheme in natural language, the *situational conditions* (e.g. *location*, *position*, *site*, *place*), and the intention towards the representation concerning *why* the concept

“Rolling door” is relevant (installation of the metal curtain doors in a specific construction project).

Concept cluster provides the expert additional semantic associations to analyzed information. In other words, the metaclass suggests additional semantic specifications that should be associated with the information extracted from the scheme. The sources of this additional information are other actors or experts, as was previously explained and illustrated in Figure 9-10. Figure 9-10 shows the structure and the links to each of the clusters. It is easy to observe that the concept-cluster associations constrain the formal meaning through ontological commitments in order to facilitate computation implementations.

Figure 9-10 represents the structure and semantic links to the clusters of “Rolling door”. In the example, the concept “Rolling door” is linked to the representation, pragmatics, contextual relation, intention, part-whole relations, topology, and cognitive agent cluster. The result is that the syntactic form “Rolling door” that stands for the concept-rolling door is semantically associated to the following clusters:

- Representation. This cluster holds other type of representation such as the section of the specifications in the construction documents that describe “Rolling door”. As shown in Figure 9-10, the representation in the cluster is constructed in natural language.

- Pragmatics. Pragmatics includes the semantics upon pragmatic levels of a concept. The example shows two syntactic forms service doors and coiling doors that are other type of forms, which are equivalent to the form “Rolling door”, and which stand for the same ontological concept.

- Contextual relation. This cluster holds possible and strictly locative relations with other objects. These relations indicate the state of affairs of the concept. Their property is that they do not change with the states of affairs of the concept. Figure 9-10 shows the relations ‘protected by’, ‘supported by’, and ‘on’ for this type of object.

- Intention. The intention cluster contains purposes that the cognitive agents have with the concept and reasons for the interaction of the concepts with others. The purposes make explicit ‘why’ the concept is relevant to the cognitive agent. In the example, the “Rolling door” concept is relevant to the contractor concerning the installation of the metal curtain doors in a specific construction project.

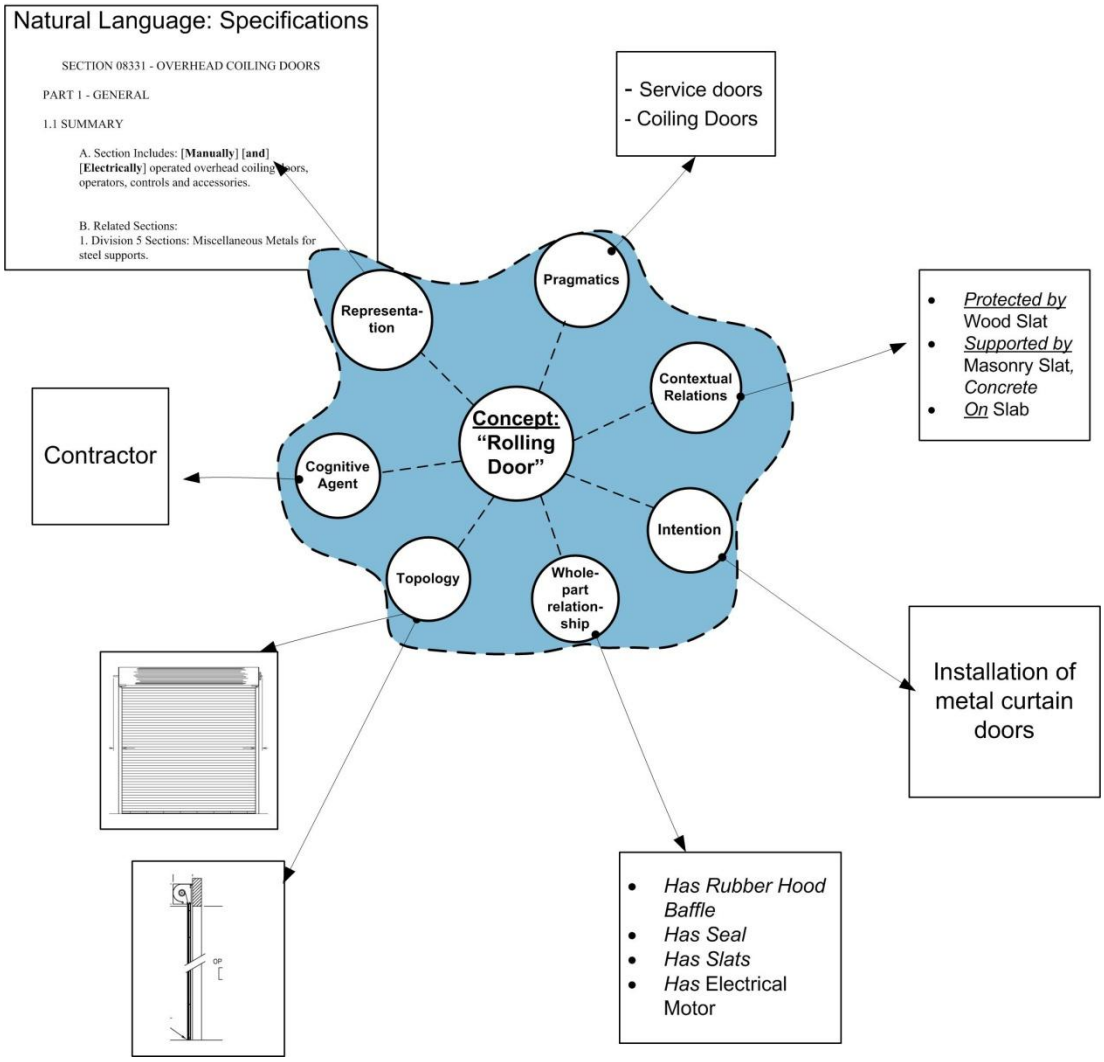


Figure 9-10. Concept cluster structure of "Rolling door concept".

- Part-whole relations. This cluster supports relations that the analyzed concept bears as composite or as components of other objects. For simplification purposes, it contains only the significant composites, which are independent of the concept, as well as components, which are dependent on the concept. In the example the primitive relation '*has*' is the relationship of containment of the components rubber hood baffle, seals, and slats. Also, the electrical motor composite is shown.

- Topology. Topology contains image or visual schema representations, which are metaphors that transfer information from the author domain to the cognitive agent domain. From these representations, the cognitive agent can induce the relation to the analyzed concept. Figure 9-10 shows two visual representations, which illustrate an image of the concept "Rolling door".

- Cognitive agent. This cluster stores the available conceptualization of the agent's social role in the organization. The assumption is that different roles in the organization make the agents identify a concept differently. In the example, the construction participant's social role is "contractor".

With the information obtained from the previous analysis, a group of experts or actors are able to build a structure to be queried for helping the users interpret the "Rolling door" concept. This form of conceptualization resembles a systematic method to construct domain ontology. The resemblance is on the logic level and in the conceptual level of representations. The difference is that the concept cluster captures the cognitive agent's intentions from an analyzed concept and the pragmatic aspects of the analyzed concept.

Querying

Querying consists of requesting information from the *concept cluster* or domain ontology. As illustrated in Figure 9-11, querying information from the concept cluster depends on the details or the sufficiency levels needed for the representation by the interpreter. The query process starts when the user or interpreter reasons on concepts in harmony with his or her needs during certain activities on a construction project. As was stated in this research, additional semantics on other representation are searched by the construction participant. For clarity, the actors who participate in this component are the users or construction project actors who perform interoperability actions. This search depends on the user's needs for interpreting the representation of a concept. Chapter 1 explained these needs in an interoperability scenario.

The focus of the querying component is to develop a strategy for information systems applications. The design of the component is adjusted to build a structure for which computation is possible. The strategy privileges the employment of symbols in order to make the computation possible. The employment of visual representations and reasoning forms such as topologies are not directly addressed for querying. The information systems are based on the computation on

symbols. The use of other forms involves complex transformations in order to be computed through current technologies. Therefore, symbolic representations such as natural language are the representations employed for directly querying the concept cluster or ontology domain component.

The query component is based on a process for searching the ontology for information systems or the knowledge bases that contain the information which has been conceptualized from the concept cluster. Figure 9-11 shows the workflow for querying additional information from the concept cluster or ontology domain, which constitutes the main mechanism for querying the component. The workflow describes the steps of this mechanism which consists of a series of searches for matches. The search will provide semantic associations to the user. These associations will grant explicit semantics to the interpreter. The associations offer explicit information by aiding the user to perform interpretations on the boundary of sufficiency. Once the user has identified the representation to be interpreted, or at least the unknown syntactic form, the user has to input this syntactic form into the querying process for searching.

As was explained before, the social role of the interpreter as well as the interpreter's intention with the observed representation is taken into consideration. This is a fundamental assumption of the framework. The objective is to reduce the computational complexity of the semantic association search on the queried concept. Additional information, if possible, is valuable for narrowing the search space. For this purpose, the example of Figure 9-11 shows that the user knows the project location.

Then, the user is able to input this additional information. This input is subjected to the intention and to the interoperability activity requirements. As shown in Figure 9-11 the input information is parsed and processed in the search engine. A search algorithm matches the syntax

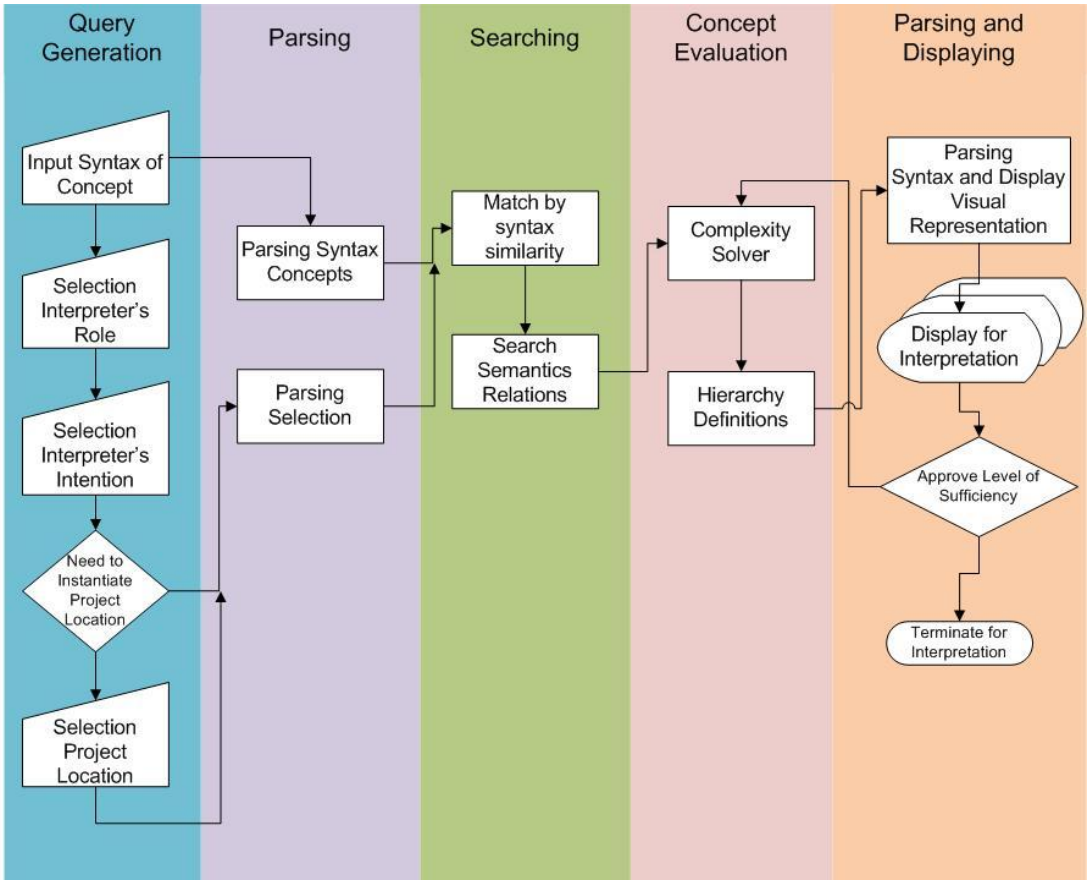


Figure 9-11. Query workflow.

in the ontology or clusters or repositories. This information is parsed into a module that evaluates and weighs the multiple results. The evaluation results consist of a list of alternatives that semantically enrich the queried concept. This information is displayed for the interpreter who examines if the displayed information suggests additional semantic associations for his or her interpretation. If the provided or displayed options do not reach the level of sufficiency for interpreting the concept, additional information is needed. The additional information, which consists of the additional semantics for aiding the interpretation of the concept in the observed representation, will be determined through the query workflow mechanism of Figure 9-11.

A visualization of the query through a GUI (Graphical User Interface) facilitates the understanding of the aforementioned workflow. Figure 9-13 illustrate a GUI that displays the query for interpreting a concept. The interpreter inputs the concept by using natural language. Thus, the first entrance will query the corresponding syntax representation of the concept. In order to avoid multiple outputs, or a combinatorial explosion, additional inputs are requested for the search. Therefore, the additional information for the initial input constrains multiple results by refining the search and by improving (O) complexity times. The rest of the inputs will constrain the search. In Figure 9-12, 'Single Hung Windows' corresponds to the first syntactic input.

In Figure 9-12, the additional input corresponds to the box 'My role'. This option corresponds to the social role of the actor who requests additional information to interpret the concept. The option specifies the main intentionality about the queried concept, which in this case is 'Single Hung Window'. This social role is similar to the description of the division of labor of a construction organization. The intention is associated with the social role that was input by the user. Obviously, the intention is previously defined by a conceptualization process of the social role of the construction participant. The social role description in Figure 9-12, corresponds to a 'Designer', and the intentionality to 'Find Specifications'.

The 'Project location' will further constraint the search and will give additional information to describe the concept 'Single Hung Window'. Thus, if additional information is added to 'location', it will aid the interpretation for locations' related purposes for the interpreter. The 'Educational Building' in the State of Florida in 'Alachua County' in Figure 9-12, will help the interpreter in finding regulations for such an Educational Building Type in Alachua County from the queried concept.

The left part of the GUI corresponds to an organized set of results of the queried concept. The results are symbolized by the tabs Dictionary, Context, Purposes, Parts, and Symbology. Thus, the results of the query will be shown within one of the tabs by querying the concept cluster knowledge bases. For example, Figure 9-13 contains the results of the “Pragmatics”, concept, cluster query or “Pragmatics” knowledge base. The search mechanism tool represents this cluster by naming it ‘Dictionary’. The purpose is to display to the user or construction participant any other alternative name for the concept ‘Single Hung Windows’. In addition, this analysis gives the results of other possible senses that the text ‘Single Hung Windows’ may have. The purpose is to semantically enrich the description of the concept.

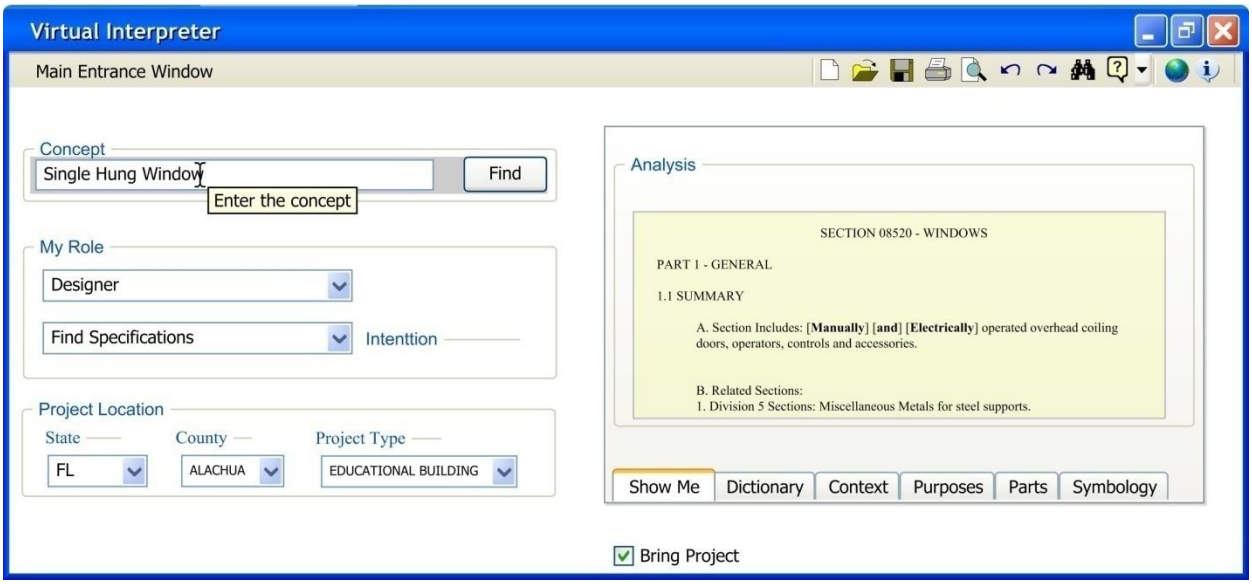


Figure 9-12. Graphical user interface of a query.

As a further illustration of the query, Figure 9-13 shows the last tab, ‘*Symbology*’, which corresponds to the *visual representation* of the concept and the *visual representation* of its parts and components. The tab corresponds to the query at the ‘topology’ concept cluster. It guides the

actor to visually identify aspects of the concept that are difficult to describe by employing natural language. The objective of the 'topology' concept cluster is to show the semantic link between the concepts' syntactic mode and the symbols or drawings. It is important to note that the symbols are not part of the construction participant's *drawings,* which are saved in graphic files. Symbols are not part of a mapping result between the topology and the drawings of the construction participants. The topologies are visual extensions of conceptualizations which are not instances of any project. However, the symbols in the 'topology' concept cluster can match a similar symbol of the construction participant's drawings. In other words, some construction participant components of the drawings can match a typical, visual representation stored in the 'topology' concept cluster.

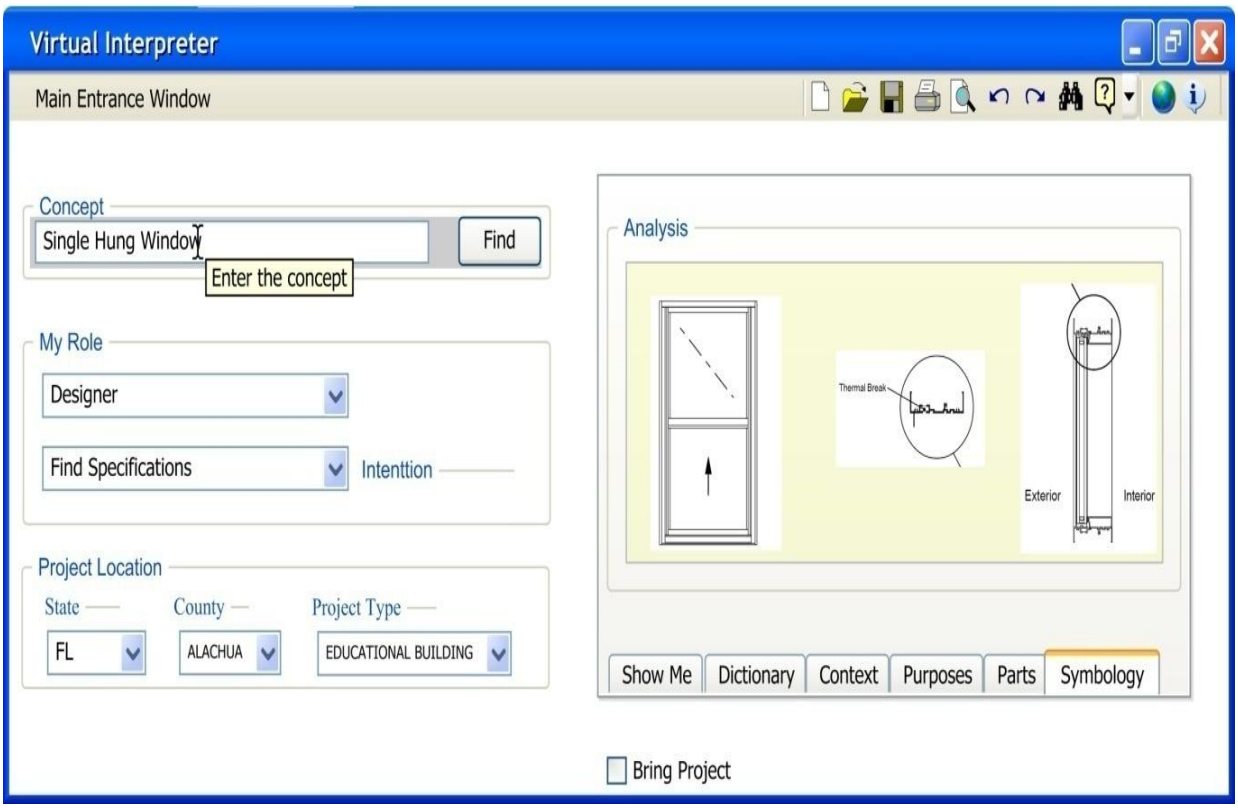


Figure 9-13. A graphical user interface that queries the topology clusters.

Summary

In summary, when any interoperability activity during a construction processes triggers the need to interpret a concept, the use of the *framework scheme* will aid the cognitive agent in analyzing the concept, and the *concept clusters* will assist the interpretation through the application of the *structure* that links the analyzed concept to other semantic specifications.

CHAPTER 10
RESEARCH VALIDATION

The validation of this research demonstrates the theoretical propositions for semantic interpretation through the use of examples which illustrate the relationships and the actions that take place between the actors or cognitive agents and the representation of concepts. The examples contain information used in past construction projects. The scenarios were recreated where typical situations of semantic interoperability activities are executed. The validation uses the *conceptual framework* for interpretation of construction concepts as a vehicle for searching why problems in an actor's interpretation of construction documents occur and where to look for relevant evidence, within the recreated situations and contexts.

This chapter illustrates the examples in a case study format. The set of case studies were deliberately developed for testing the theoretical propositions as well as for illustrating the dynamic in construction project scenarios. The theoretical propositions serve as a template to compare the resulting construction project information of the case study.

Case Study as a Strategy for Validation

The philosophy of this research validation is aligned with the theory constructions of Weick, who suggests that the validation process should guarantee the usefulness of judging the plausibility of the theory proposition in a *conceptual framework* (Weick 1989). The nature of this research inquiry, which contains abstract speculations that fall under semantic interoperability scenarios, compels the use of validation methodologies other than the traditional data-recollection-testing methods. This research validation method is not based on previous literature and empirical observations, but is based upon the evaluation of the proposed *conceptual framework* through the simulation of scenarios. By definition, a *conceptual framework* contains an evolutionary process of theory propositions wrapped in the logic of constructs.

This research is explanatory. Its nature exhibits an inquiry to unveil an epitomized phenomenon under the semantic interoperability paradigm. Therefore the validation will be restricted within the evaluation of the following factors: the *plausibility* of the theoretical constructs, and the *effectiveness conceptual framework* of interpretation activities.

Validation Mechanisms

The validation method consists of a recreation of scenarios in which an interpretation of a construction concept will be performed by a construction participant. The simulation is used as a mechanism that explains the sets of steps and logical propositions in interpreting the construction concept in order to explain an empirical event. The proposed *conceptual framework* contains these steps and logic propositions and support theoretical discussions. Therefore, the proposed mechanism validates the *conceptual framework* by circumscribing the simulation in the scientific methodology.

This simulation of the interpretation will employ a set of construction concept representations and will be executed in two ways: first, the interpretation will be performed as a regular procedure of a construction activity; and second, the interpretation will be performed by using the *conceptual framework* proposed in this research.

The following are the actors and resources that will be employed in simulating the interpretations:

- Cognitive agents. Actors will perform the interpretation of the construction concepts. The experts must play a role as a member from different areas of a construction project organization (e.g. PM, electrical contractor).
- Construction concept. Sets of concepts from each of the specialized construction areas will be selected. The concepts must be represented in natural language and visual or image schemas. The main objective is that the representation must be as close as possible to the common representation that construction participants find in a construction project.

- Conceptual framework tool. The strategy will employ a simulation of the queries where the conceptual framework is assembled, in order to facilitate the analysis of the concepts by the cognitive agents.

Evaluation of the Validation

The expert's judgments of the framework must be viewed under the scientific perspective. These judgments must take into account the units of analysis, the plausibility of the theoretical constructs and the effectiveness of conceptual framework factors.

In addition, the judgments must be observed through ideal scenarios of semantic interoperability activities. Ideal scenarios are those in which an ideal exchanging, sharing, transferring, and integrating of information from distributed sources such as customers, contractors, and owners is effectively performed. Ideal scenarios are those cases where construction participants manage to effectively communicate the content of information such as products, processes, and documents. Ideal scenarios also enable exchanging, sharing, transferring, and integrating of information with the purpose of helping construction participants make decisions or work on concurrent engineering. The selection of these scenarios will be made based upon the most pressing research needs. The needs account for the social, technical, and economic impact in the construction project. Therefore, it is anticipated that the most significant scenarios occur within reported results, quantity takeoffs, submittals, online purchasing of materials, and notification of design modifications, among others.

Illustrative Case 1: Estimating 'Fixed windows' Concept from Construction Documents

- Unit of analysis: Construction Concepts
- Actor(s): Estimator – Secondary Actor(s): Architect and Specialty Engineer
- Roles: Estimator: Perform a quantity take off in order to generate an estimate of a construction project.

- Architect and Specialty Engineer: Architectural designs of a construction document. They are the authors of the construction documents that accompany the architectural design.
- Action: Interpretation of construction documents within an information sharing activity.

Context

The objective of the estimator in this case study is the prediction of the cost of performing the installation of the 'fixed windows' of a construction project. The estimator analyzes the construction documents and predicts the scope of work for installing the 'fixed windows'. As the construction documents are elaborated, the project progress is on the final cost estimate stage. The overall design, then, is complete and the technical specifications are finalized, including the finishes.

In the case study, an estimating activity takes place between the architect, the engineering designer, and the estimator. The project estimator needs to ensure that the design of the 'fixed window' is being elaborated in such a manner that can it be constructed within a certain budget. For this purpose, a quantity take-off of the conceptualized 'fixed window' takes place. The assumption is that the estimator possesses the skills and experience to identify the costs and the scope of work for installing the 'fixed window'. For this purpose, the estimator needs to perform interpretations of the construction documents that were elaborated and generated from other construction participants.

During an estimating activity, the estimator reads the construction documents and continually searches for additional information concerning the components of the item to be estimated. The estimators interpret items on construction documents that where elaborated by other actors such as the architects or the specialty engineers in the design department. The estimators identify the items to be estimated in the construction documents. The items are concepts in the construction domain represented in these documents. Thus, a selected

representation corresponds to the observed item. The observed concept was generated as well as was intended to be communicated to other actors on the construction project. The concept identification is followed by the full interpretation of the concept. The interpretation also implies the association to other project resources and the prediction of problems related to the interpreted concept. In the case of the 'fixed window' concept, the estimator needs to foresee problems such as the required equipment for its installation or the mandatory care for storing in order to determine the associated costs. Note that these are additional interpretations of the concept 'fixed-window'.

Given the information in the construction documents, the estimator needs to possess the knowledge and skills for understanding the conditions and the related amount of work for installing the 'fixed-window'. Within this case study and as a fundamental and critical step, the questions are how the interpretation process works and what strategy can be used to aid the dynamic of the interpretation process. For this purpose, the interpretation process for the 'fixed window' concept is broken down into the following steps.

The Sharing Information Case for Interoperability

Sharing information means the distribution or the contribution for a particular purpose of a resource by a project actor to others within a construction project. This resource is obtained by other actors who belong to an internal or an external organization and who participate in a construction project. The objective is the completion of an activity by the other actors during a construction process. This resource is a form of representation of information that is either elaborated by any actor or just manipulated. An architect *elaborates* a wall design for a building project that is represented on the drawings, and a contractor interprets and manipulates the wall design.

There is a relationship between the resources and actors of an organization. The actors play a specific role on an activity in a project. However, even if the roles are different within a project, the actors can have a joint purpose with the resources that are taken into consideration. The purpose is to define the relationship between the actor and the resources. An architect has the role of designing the exterior finishes of a building in certain project. The architect's design is the resource that it is shared with other members of the project network. This resource is represented through drawings and specifications. Another actor, the design engineer, has the role of reviewing these shared resources by providing observations to the drawings in order to meet local standards. The design is corrected and complemented by the architect according to the design engineer's suggestion. Thus, these actors have a joint purpose with the shared resource.

Alternatively, construction project participants can individually perform a role and convey an individual purpose by sharing a resource. An architect and a contractor can share the same resource such as the architects' design. The contractor does not participate in any architects' role and is not involved in the design purpose. The architect's and contractor's roles are performed individually and they also share the same resource. The reason for outlining the relationship actor-resources is to identify the nature of interoperability in a construction project, by recognizing the actions, the actors, and resources.

How sharing information for interoperability is relevant in the 'estimating fixed-windows case'?

The estimator is an actor of a construction project as well as a recipient of construction documents from other actors such as the architect and the design engineers, which is a sharing information case for interoperability. The employed documents are the shared resources mentioned in the above paragraph. These documents resources are the drawings and the

specifications, which are human, readable forms of information. The drawings are visual typologies, i.e. visual representations, and the specifications are text based representations. The documents were created and elaborated by the architects and by the design engineers. These documents are employed or manipulated in order to be interpreted by the estimator. The shared information, then, is generated by the architects and is received by the estimator. These actors perform a different role but share the same representation. Their purpose with the representation is also different. The estimator has the purpose of executing quantity take offs over the documents while the architect has the purpose of elaborating a creative and functional design over the same set of documents.

Clearly these actors do not work on collaboration for generating these documents. The architect or design engineer distributes packets of their work as a product among the construction project network. These packets are arranged for their distribution in a computer or human readable forms. The purpose is that other actors, such as an architect or a contractor, are able to manipulate these forms in the workflow.

Semantic Interoperability Step

The semantic interoperability paradigm stands for the understanding of what is represented within the information constructed by other actors within a domain. The agents' abilities for exchanging, sharing, transferring, and integrating the meanings of information are the quest of semantic interoperability. This current interoperability example explains the case of the actors' ability to understand the meaning of the *shared* information from other actors. A contractor, for example, shares information or resources by obtaining construction documents from the architect and performs interpretations on these documents. The estimator also requests information from the architect and performs interpretation of representations in the construction documents. Figure 10-1 illustrates the continuous sharing, requesting, and exchanging of information. Figure 10-1

also shows the flow of the construction documents, which are human readable forms of representation of information, from the architect or specialty engineer to the estimator.

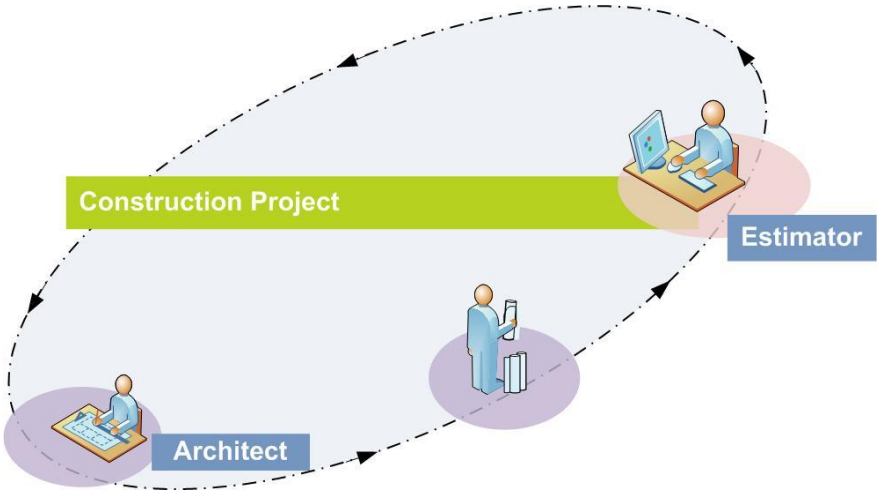


Figure 10-1. Continuous sharing information among construction actors.

In Figure 10-1, the architect or design engineer generates information by translating and representing the concepts into the documents. Therefore, the estimator's understanding requires an interpretation of the observed representations of the construction documents. The requesting, sharing, and exchanging information between these two actors are manual operations. Typically, there are no networking technologies that facilitate the request for information operations among architects, design engineers, and estimators. In addition, the estimating of the architect's concepts represented in the construction documents are performed manually. The estimator manipulates the construction concept for interpretation. If the architect translates the concepts into a computerized form of representation, such as Computer Aided Design (CAD) formats, the estimator has to interpret the translated concept from the CAD format in order to perform any estimating activity. The CAD files are in human readable forms that make the interpretation possible. Subsequently, the estimator manually observes a representation from CAD format with

the purpose of reasoning and finds meanings of the represented concept. The strategies for understanding of what has been represented within the shared information or shared construction documents and the methodology as a framework for interpretation are explained later on in the illustrative case.

Estimator's role: interpretation of representations of construction concepts

A function of the estimator is deciphering what has been represented on the shared construction documents in order to prepare the estimate. The estimators have the ability to execute quantity takeoffs from the construction documents. The elaboration of the estimate is an ultimate objective of the estimator's role. The understanding of construction documents generated by other construction project actors is a step towards the developing of the estimate. The *assumption* is that the estimator has developed the experience and judgment to perform the interpretations on the documents. By visualizing construction processes, this ability should facilitate the estimator in the understanding not only of the explicit information represented in the documents, but also of the implicit information concerning the project, such as job conditions, material storage, and productivity rates. However, the elaboration of the construction documents implies the generation of details and conditions that cannot be fully recognized by the estimator. The estimator's ability is limited to the recognition of the details and conditions of past experiences. These past experiences aid the estimator in identifying errors or problems, but not all the details, conditions or construction process out of the level of expertise or even pragmatic aspects such as the terminology used to name construction resources in the documents in a particular local area.

One aspect to outline within the estimator's role is that the actor examines the human readable forms of representations without the aid of computation for examination or for interpretation. Thus the examination takes places by observing the form that describes the

construction concepts. In other words, the estimator observes the construction documents and analyzes a form of knowledge representation for characterizing the construction concepts found in the documents.

Identification of the concept from the representations

As was explained, construction participants are committed to building projects based on the drawings and specifications they have been furnished as part of the construction documents. The documentation will help them in understanding the scope of the specific activities of the project. Designers rely on this documentation to communicate the design intent and contractors rely on the documentation to interpret this intent. This is a case of sharing information within interoperability. In this step, there is also an interpretation by observing and analyzing a specific representation in the documents. For this analysis, the actor observes the representation and identifies a concept. During this observation, as was mentioned, the actor identifies a concept described on these documents. The actor's search for meaning of the observed representation depends on the purpose of analyzing the representation.

How do these representations describe a concept and how do the actors identify the concept in the documents?

As the specifications and the drawings describe a collection of construction concepts through their form of representing information, the specification describes the concepts through text-based representation and the drawings, through topological or geometrical forms. These representations themselves are simple metaphors that give meaning to some concept. Thus the method to obtain meanings of concepts from the documents is through their forms, either from text based or from topological forms. These forms express the characterization of the concepts employed within the documents.

Figure 10-2 shows the metaphor of a concept. This metaphor is a visual representation that was generated for facilitating the reasoning to the interpreter. The visual representation in Figure 10-2 consists of a set of symmetrical lines. This visual representation is an image that has been selected from specific architectural drawings. The interpreter or estimator observes the set of lines on this construction document and reasons about the concept and its meaning.

The construction industry in general employs the "details" and "conditions" as modes of expressions for defining characteristics in a project, as opposed to complex and formal forms of any construction concept. The *details* and *conditions* are common words for defining the characteristics of the resources that play a particular role in a construction project.

Typically what is considered a description of a concept is a poor characterization through "details" and "conditions" of some observed metaphor in a construction document. The description of concepts comprises geometric features, components or parts, additional or assembled items, and functional characteristics. For example, the description of a visual representation of can be extended through other topologies that describe the same concept. Figure 10-3 shows these topologies. The topologies are constrained by other dimensions and by text-based representations that indicate the concept's size. The *constraints* are concept characterizations which are embraced under the "details" rubric.

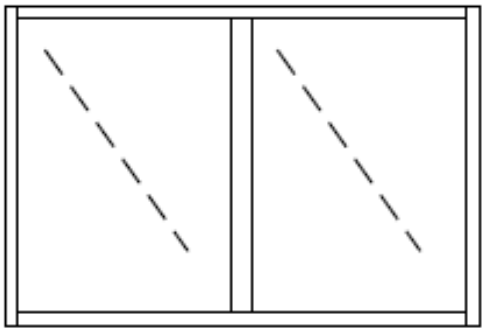
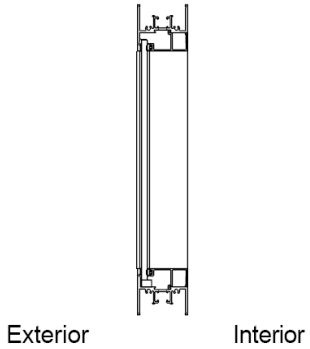
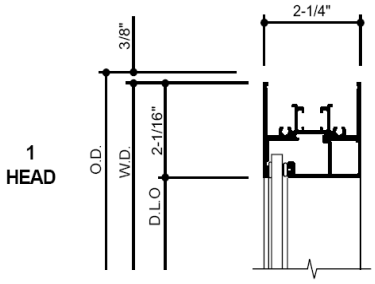


Figure 10-2. A metaphor represented within the construction documents.



(a) Visual representation of a section

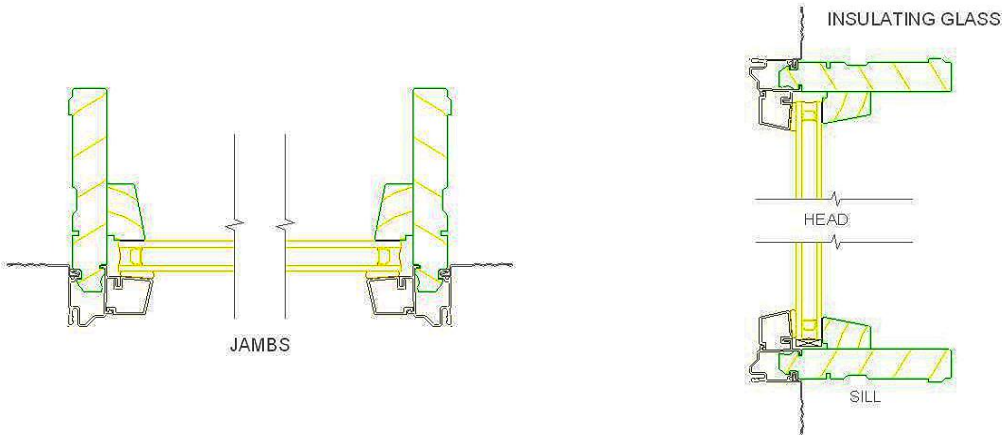


(b) Details of the visual representation.

Figure 10-3. Topologies of a 'Fixed-window'.

The interpreter is able to not only reason through the topologies or metaphors but also through the syntax that are symbols that aid the definition of the concept. The sections in Figure 10-3 show additional geometric features, components or parts and assembled items of the topologies shows in Figure 10-3. This additional information is an explicitation of the information for describing the concept represented in the Figures. The interpreter or estimator has more elements for reasoning about the observed concept.

Figure 10-4 shows additional metaphors or visual representation of the same concept. These representations show functionality features as well as other components of the concept for facilitating the reasoning. The topologies of Figure 10-4 are CAD images represented by a computer in a human readable form. The visual representation illustrates the concept from bottom and top sections. As in shown in Figure 10-4, text based representations or syntactical symbols aid the reasoning of the metaphor shown in Figure 10-2.



(a) Bottom Section. (b) Top section.

Figure 10-4. Computer Aided Design images of the 'fixed-aluminum windows' topologies.

An additional form for characterizing concepts is the explanation of the *conditions* of the concept. In the construction industry, the *conditions* are commonly bounded in the space time dimensions, and they are named as *situational conditions*. The description of *situational conditions* includes the states of affairs, the status condition, and contexts relations of the represented concept in the construction documents. The states of affairs includes the location position, site place, and settings of the concept; the status conditions comprises the stage of the concept life cycle (e.g. completed, installed), and context relations embraces the description of the associations to other concepts within space dimension.

These situational conditions are described through the text-based forms of representation in the construction documents. The situational conditions are expressed through general regulations, project documents, or owner's requirements. The specifications document is an example of the text-based form of representation. Figure 10-5 shows the same concept as Figures 10-3 and 10-4, except its descriptions are in text-based format.

1.6 DELIVERY, STORAGE, AND HANDLING

A. Protect glazing materials according to manufacturer's written instructions and as needed to prevent damage to glass and glazing materials from condensation, temperature changes, direct exposure to sun, or other causes.

B. For insulating-glass units that will be exposed to substantial altitude changes, comply with insulating-glass manufacturer's written recommendations for venting and sealing to avoid hermetic seal ruptures.

1.7 PROJECT CONDITIONS

A. Environmental Limitations: Do not proceed with glazing when ambient and substrate temperature conditions are outside limits permitted by glazing material manufacturers and when glazing channel substrates are wet from rain, frost, condensation, or other causes.

1. Do not install liquid glazing sealants when ambient and substrate temperature conditions are outside limits permitted by glazing sealant manufacturer or below 40 deg F.

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100% CONSTRUCTION DOCUMENTS

Figure 10-5. Situational conditions of the 'fixed-aluminum windows' concept.

Figure 10-5 describes the situational conditions of the concept components of Figures 10-3 and 10-4, a 'fixed window'. The exposition of the glass to other materials is described in the *Section 1.6 A* of the text based representation. This is an explanation of a contextual relation of the component '*glass*' with the environmental conditions of the construction project. An action is suggested to protect the component *'glass'* against the environmental conditions. The association of the '*glass*' component to the environmental condition is a characterization of a construction concept performed by the architect or design engineering who generated the representation of Figure 10-5. In *Section 1.6 A*, the level of specifications of the environmental conditions can be further identified. Thus, the association to the '*glass*' component to the environmental conditions is described in more details by considering *the condensation, temperature changes, and direct exposure to the sun* which are constituents of the environmental condition concept.

The text-based representation can also describe properties of the concept of Figures 10-3 and 10-4. The properties are determined by the functionality in the concept. The concept '*glass*' has to comply with certain properties for serving particular *purposes*. Figures 10-6 shows a section of construction documents that describes the properties of the concept of Figures 10-3 and 10-4.

The description of the properties shown in Figure 10-6 is done by the text-based representation or syntactical representation in the Section B 1.a of the 'fixed-aluminum windows' concept. If the concept glass is required to resists wind loads, then the description of 'glass' component purpose. The design engineer or architect describes the properties of the component 'glass' in order to resist wind loads. The satisfaction of this component's ability

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B. Glass Design: Glass thickness indicated is minimums and is for detailing only. Confirm glass thickness by analyzing Project loads and in-service conditions. Provide glass lites for various size openings in nominal thickness indicated, but not less than thickness and in strengths (annealed or heat treated) required to meet or exceed the following criteria:

1. Glass Thickness: Select minimum glass thickness to comply with ASTM E 1300, according to the following requirements:

   a. Specified Design Wind Loads: As indicated.

   b. Probability of Breakage for Vertical Glazing: 1 lite per 1000 for lites set vertically or not more than 15 degrees off vertical and under wind action.

      1) Load Duration: 60 seconds or less.

   c. Maximum Lateral Deflection: For the following types of glass supported on all four edges, provide thickness required that limits center deflection at design wind pressure to 1/50 times the short side length or 3/4 inch, whichever is less.

      1) For monolithic-glass lites heat treated to resist wind loads.
      2) For insulating glass.
      3) For laminated-glass lites.

   d. Minimum Glass Thickness for Exterior Lites: Not less than 6 mm.
   e. Thickness of Tinted and Heat-Absorbing Glass: Provide the same thickness for each tint color indicated throughout Project.

Figure 10-6. Text-based representation of the properties of the 'fixed-aluminum windows' concept.

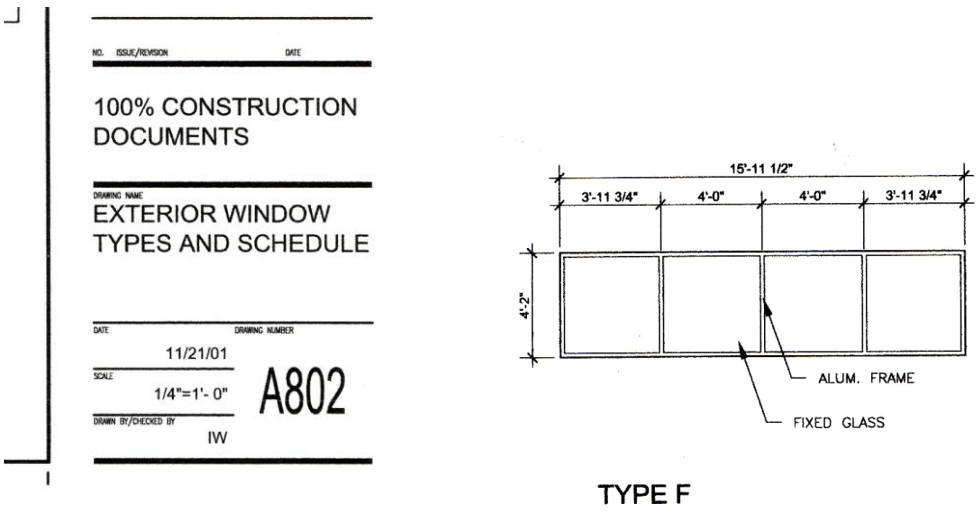
is instantiated by including the number of the regulations that define the ability of the material that the component '*glass*' is made of.

How is a concept identified by the estimator?

The estimator should locate the object or item in the documents by observation. However, the estimator's role defines the actions to be performed with the representation. Therefore, the estimator's role limits the reasoning and interpretations of the representations. The actions are procedural operations which are not analyzed in the interpretation of the observed concept. However the intentionality of the actor is a basic tenet for interpreting the representation. This intentionality describes *why* the estimator performs the interpretation. As intentionality is the explicit association of the observed concept to others concepts, the estimator has to identify the associated concepts. Thus, if the estimator's intention is to verify minimum thickness of the '*glass*' concept from Figure 10-3 and 10-4 to estimate the component cost, then the estimator needs to search for the description of thickness in the construction documents. The thickness could have been described as a constraint of size in Figures 10-3 and 10-4 As it is shown, these Figures do not contain the constraint *thickness* of the 'glass' component. Then, the estimator has to search for the *thickness* description in other construction documents. Figure 10-6, which is a text based representation, has a description of the *thickness* concept constraint. Note that the estimators need to search for similarity relationships between the estimator's understanding of the syntax for the '*thickness*' feature and the existing syntax in the construction document of Figure 10-6. In this case, the similarity relationships are semantic associations established only for the purpose of costing the *thickness* of the glass component. The intention defines why the 'fixed-window' and the 'thickness' constraints are related under the estimator's role.

This identification of a concept within the construction documents is performed by searching similarity relationships. The estimator matches the possessed notion of the concept and the observed description in the documents. Thus, if the estimator first searches a concept through the syntax form of representation, then this actor looks for the similarity relationship between the possessed notion and the observed representation in the documents. A typical search for similarity relationships is when the actor focuses their searches on the indexes of the representations. Figures 10-7 (a) and (b) show examples of the indexes of the concept 'fixed window'.

The estimator uses similarity relationships to perform the identification of a concept within the construction documents. If the estimator searches the concept 'window' by relating the possessed notion of this concept with the representation within the construction document, then the estimator *affords* the existence of a concept. *Indexes* are markers or icons whose semantics exclusively indicate a relationship to a specific concept.



(a) (b)

Figure 10-7. Indexes of the '*fixed-aluminum windows*' concept. A) As '*A802*'. B) As *'Type F*'.

‘A802’ in Figure 10-7 (a) is an index that semantically associates the concept ‘exterior window’ in the construction the search for indexes will facilitate the identification. The index’s semantics function is to documents. Note that the concept ‘exterior window’ is expressed in a syntactical form. The index serves to make connections to this concept in the estimator’s mind. The index to the concept does not imply the distinction of the concept’s properties or some additional semantics. Indexes provide no other than the indexical relation. An interpretation of the concept can be guided by the index, although the index may not be necessary for its interpretation. ‘A802’ in Figure 10-7 (a) serves as a guide for interpreting ‘exterior window’.

In the same way, the estimator searches for other syntax representations, such as the window concept in the Figure 10-7 (b) that can be located within any construction specifications, schedules or documents that contain the representation, index “Type F”. In Figure 10-7 (b), the syntax “Type F”, at the bottom of the visual representation, indicates a map to the concept ‘fixed-aluminum window’. This indication encompasses the set of showed constraints of size, by the displayed values of the concept in the Figure 10-7 (b), and the spatial arrangement of the ‘*fixed- aluminum window*’s’ components. The “Type F” index is employed by the estimator to perform searches for matching other representations that describe the concept ‘*fixed- aluminum window*’, through similarity relationships of the syntax “Type F” within the construction documents.

For example, the estimator identifies the section where ‘*fixed- aluminum window*’ is located through similarity relationships either by matching syntactic expressions such as ‘windows’ in the drawing schedule or by identifying similar, geometrical topologies. The estimator, then, locates the topology or the schedule in the drawings that describe the ‘*fixed- aluminum window*’ concept. The purpose is to fully recognize by observation additional features

described in the drawings. The estimator selects the characteristics of the '*fixed- aluminum window*' concept expressed in the documents in order to perform a particular activity. As was explained, the activity is defined by the estimator's role such as performing quantity take offs. These role activities are human manipulations of the representation which are expressed in human readable forms. There is not a computational device that helps to identify the concepts on the drawings for executing the quantity take offs.

The concepts must be commonly recognized by social actors, they are common, shared concepts. In interoperability, the assumption is that architect, design engineering, and the estimator are social actors that commonly recognize the concepts they interoperate on. The architect and estimator recognize the existence of a concept '*fixed- aluminum window*'. However, its recognition does not indicate that their interpretation of a concept is the same with the exact and same concept features. The particular, social, inclusion feature of *index* implies a purpose of sharing concepts among the community. This purpose, then, should make any *index*, by virtue of its semantics, be an artificial signal to point to a concept. The pointed or mapped concept, by virtue of the indexical relation, must be the same independently from which actor performs the interpretation. Within the social, convention role, *index* has the character of being dependent on the mapped representation although it is an artificial representation that can exist by itself. The index '*A802*' in Figure 10-7 (a) has the character of being dependent on the '*exterior window*' concept in the construction documents. The artificial representation '*A802'* does not have semantic meaning by itself. In summary, index is an artificial representation that facilitates the identification of a socially recognized concept within the construction documents.

Are the representations within the construction documents accurate to perform interpretations?

The representations on the construction documents are poor translations made by the actor that generates them. The architect or design engineering describes a concept through topologies, text-based representations and other forms of representation at certain levels of granularity which limit the interpretations to the intended purposes. The committed level of granularity of the representation is semantically poor for other purposes. The architectural drawings are generated for general purposes to be integrated by the general contractor, the electrical contractor, or the municipal council. The architectural drawings are complemented with the specifications to have better granularity level description. However, they do not fully describe the concepts at certain granularity level for other actors within interoperability activities.

For example, the architectural drawings, as shown in Figure 10-8 do not describe information concerning finishes for the estimator. The estimator must include the cost of protection of the aluminum frame for estimating purposes.

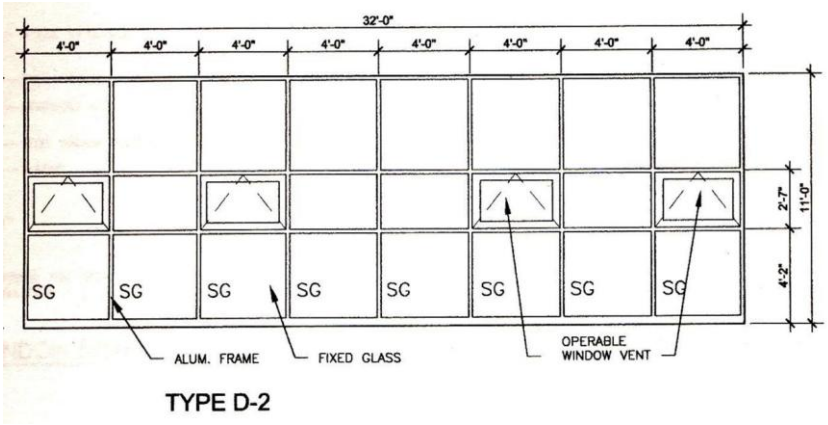


Figure 10- 8. Limited description of the 'fixed-aluminum windows' concept as a visual representation.

Any additional component associated to the '*fixed-aluminum windows*' in a project has an additional cost. Not only the cost of the additional items has to be included in the project, but also their installation cost.

The architectural drawings, shown in Figure 10-8 only provide information about the special distribution and size constrains of the concept 'fixed-aluminum windows.' Additional semantic associations, such as the installation of the 'fixed-aluminum windows' in the project, needs to be included as well. The 'fixed-aluminum windows' may be installed as the construction progresses or they may be slipped into the opening when the building has been completed.

CHAPTER 11
CONCLUSIONS AND CONTRIBUTIONS

Since fully automatic interoperation is not feasible, *human* intervention is necessary to accomplish interoperability activities. The *manipulations* on any form of representation, which are based on human intervention, are part of the interoperability process. The manipulations involve an *interpretation* step performed by the actor or construction participant. Therefore, one or more components of the interoperability process demand *human* intervention. For this purpose, this investigation considers *meditation as essential for interoperability.* A mediation mechanism should be established to aid the interpretation of any form of representation of a concept generated from other sources. Automatic interoperability by employing approaches that transform concepts into models, schemas, or conceptual models, operated by computers, without any form of mediation is not possible. The use of computers should be understood as a mechanism for mediation and as a device that translates a construction concept into other forms of representation, such as the translation from human readable forms to a computer readable form, and as a mechanism that performs calculations on the translated representation. Note that the representations are forms of knowledge representation that describe construction concepts.

The scrutiny of the *interpretation* action, which is performed by an actor as cognitive agent on the representations, indicates the quest for the understanding the involved, *fundamental elements*. The basic studied elements were the representation of construction concept in their *prima naturae* and in their *prima character*, and the relationship between the actor and the representations. The purpose is to bring into existence and to assemble a strategy that aids the actors reduce time, resources, and errors within their interpretation operations. The quest for *efficiency* as well as for *economy* of these operations is the motivation of the present research

efforts. The purposes of these efforts are the reduction of time, resources, and errors within the interoperability activities.

The interpretation step takes place when a relationship is established between a representations and an actor by observing the representation in sharing, exchanging, or integrating of information activities. Clearly, this research addresses a method to reduce the time and resources in this interpretation.

As a result of the analysis of the fundamental elements within an interpretation, this research develops a conceptual framework for aiding the interpretation action of a concept from the construction domain. This framework describes a mechanism or process that serves for semantic interpretation. The framework mediates between the representation and the actor in order to perform interpretations. The mediation is an alternative approach from that of the modeling paradigm which forces the actor to follow a previously prescribed set of rules, syntax, vocabulary, and conceptual model in order to perform the interoperability activity. The process defined in the conceptual is addressed to aid the interpretation according to the level of sufficiency for interpretation of the concept representation. The framework also considers the construction participants' roles in the organization, as well as to their intentionality upon the concept. Then, the conceptual framework helps in the analysis of the interpretation process and takes into account the intentionality of the cognitive agent.

One of the elements used by this framework is a knowledge representation structure named *'concept cluster'*. This knowledge base has the ability to store and to provide the semantic associations of the concepts. It semantically organizes concepts to facilitate the storing and retrieving of queries about a concept in construction. This knowledge structure is a mechanism that can be implemented as a metaclass for ontologies for computer systems.

The framework also recognizes the social role of the construction participant and additional relations such as the state of affairs and the physical location. For example, the estimator is mainly concerned with the quantification of products. Thus, the framework associate the estimator's social role and, therefore, aid the estimator in finding additional semantics of the components that are being quantified.

Our analysis of the fundamentals of sharing, exchanging and integrating information suggests that the concepts of 'sufficiency' to perform interpretations at a certain level of detail. This concept was taken under consideration for the framework design. Considering the case study, if the estimator receives pieces of lines from the designer in the drawings with poor definition of the concept on the drawings schedule, the framework provides a mechanism to aid the interpretation of the whole concept by finding semantics' associations to the concept that is observed and queried, and enriching the representation of such concept.

Therefore, practical errors such as misinterpretations or a lack of understanding or familiarity with the components are reduced. The framework addresses the enrichment of the semantic deficiencies of the representations. It attempts to satisfy the actor's lack of knowledge concerning a construction concept in order to aid the actor in performing an accurate interpretation.

As opposed to the current notion of *concept* within the construction industry, which implies the description of geometric features, components or parts, additional or assembled items, and functional characteristics, our research claims that concepts are manifestation of signs in the construction participant's mind. Following this claim, our research acknowledges the construction participant as a cognitive agent who uses his or her knowledge and experience for reasoning on any form of representation. In this study, the employment of metaphorical

reasoning is a valid strategy for the identification of construction concepts by the cognitive agents. The concepts are represented through forms of knowledge representation that have the character of signs. The signs are described on paper, such as ink markers or topologies on the drawings, or on human readable electronic forms. From the aforementioned proposition, the inclusion of the interpreter's role in the organization can be postulated for performing interpretations of concepts. Thus, the role of an actor within a construction project delimits the scope and the complexity for interpreting an observed representation. Our research concludes that the ability to accurately interpret a concept by observing explicit forms depends on the granularity level of the representation. This dependency is a relationship that can be plotted into an artificial graph (see Figure 5-1), which shows the relationship between the quantity of explicitly given information and the accuracy of its interpretation. The explicit information is directly related to the interpretation of a concept if the interpreter understands what is explicitly described. In this way, a level of explicit details is necessary until the interpreter is able to interpret what is explicitly described. This is the case for defining the border of sufficiency to interpret a concept. However, if the interpreter cannot reach a level for understanding what is explicitly represented, even though there are enough explicit details for such interpretation, then the interpreter's ability to interpret such a concept is deficient. This situation is delimited by the boundary of deficiency.

In summary, our research concludes that for understanding the information that is generated from other sources within a process of exchanging, sharing, and integrating information, a mediation mechanism should be included. The mechanism mediates through an ontological description of the information that is shared, exchanged, and integrated by the actors. In addition, our research claims that the information that is exchanged, shared, and integrated is

based on representation of concepts. These tend to be poor semantic representations of concepts that are translated from the actors' minds with the purpose of being communicated to other actors within the construction project. The accuracy for interpreting the representation depends on the level of granularity of the representation as well as the interpreter's a priori experience. Therefore, this claim contrasts to the modelling and to the standardization efforts on imposing the modeller's particular view of the world on the other actors on a construction project.

Contributions and Implications

A major contribution to the construction scientific community is the systematic study of the fundamentals on the interpretation of explicit information, which were employed for constructing theoretical propositions assembled in a conceptual framework. The framework articulates a strategy based on theoretical propositions in order to interpret forms of representation of a concept. The employment of the method devised in this framework, as a programmed tool as or as implemented process, should facilitate the construction participants' reasoning concerning accurate interpretations of representations of construction concepts within an interoperability activity.

Therefore, the first contribution is that this research furnishes a valid framework to manually interoperate with information provided from other sources. This framework provides assistance to the construction participant in interpreting an observed representation. The framework is based on operating and on working with concepts of the construction domain. In this framework, this research addresses fundamental aspects of the *interpretation* step of what is represented in paper-based or computer-readable forms. The exploration of these fundamentals significantly advances the understanding of the semantic interoperability paradigm, especially in the direction was made towards analysis of the relationship between the construction project

actor as cognitive agent and explicit forms of representations. This framework is a contribution not only in the mechanisms for organizing construction domain concepts, but also on the proposed *modus operandi* for interoperability. The conceptual framework is an outcome of the explanatory approach within the semantic interoperability paradigm.

An implication to the community is that the rethinking of the modus operandi of information through the employment of construction concepts is a revolutionary approach for manipulating information in construction projects. An increase in productivity and efficiency in interoperability is expected with the implementation of this approach in the projects. In other words, the construction project actor benefits from employing the strategy described in the framework by reaching efficiency as well as for economy of the interpretation operations. The implementation of this approach should result in a better use of the resources and to the reduction of time, errors, and misunderstandings on interpreting information provided from other sources in the project.

In addition, this framework will offer any domain actor support on theoretical foundations to develop computer applications. Thus, the reasoning that the framework provides will help system designers of the construction domain to have a better basis to explicitly represent construction products. In addition, concept clusters should give better insights to the designer in order to identify the components of concepts and concept practical accounts. Accordingly, the implementation of the proposed strategy systematically will help construction participants in identifying the potential inconsistencies in their interpretations of the construction concept representations.

Recommendations for Future Research

Since construction management is a practical discipline, any future research has to be focused on applications to the current problems continuously challenge the construction industry. Our research envisions the communication of representations of concepts which are shared, exchanged, and integrated by multiple actors on construction projects as a practical area of research, which falls within the interoperability and collaboration paradigms.

From the scientific point of view, our research envisions the use of the semiotic framework as a promising field for understanding the relationship between actors and representations and the relationship between the actors and the world. The semiotic framework studies signs and their interpretations. The introduction of the semiotic framework is a new strategy to find approaches within the interoperability paradigm and it is also new research within the construction management field. The applicability of this effort requires the development of tools that employ signs as a vehicle for meaning that aids the communication between construction project actors of observable and not observable signs. The purpose of these practical implementations is to significantly reduce errors within the interpretations of representations of construction concepts.

The scientific exploration of conceptual role semantics theory is a promising field for the understanding of meanings of representation of concepts which are generated from other sources. Future efforts should address the lack of methodologies to aid construction project actors in interpreting the representation of concepts. They will require the development of meta-ontologies to capture the meanings of representations generated from other sources. The practical purpose is to generate a new and innovative technique to communicate concepts that are translated into representation among construction project actors.

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BIOGRAPHICAL SKETCH

Ivan Mutis earned his PhD degree in construction engineering and management from the University of Florida, Gainesville, Florida. Ivan was honored with the Rinker Scholar Fellowship, the highest merit-based award for PhD students in the department, to support his doctoral studies. While working towards his degree, he worked at the Computer Science Department at the University of Florida where he collaborated with computer science colleagues in research on interoperability in construction.

Ivan holds a Master of Science in civil engineering from the University of Florida with an area of concentration in construction management. He also holds a Master of Science degree in Construction Engineering and Management from the Civil Engineering Department at Los Andes University, Bogota, Colombia, and a Bachelor of Science in Civil Engineering from the Pontificia Universidad Javeriana, Bogota, Colombia.

Ivan worked as an instructor at Pontificia Universidad Javeriana, and held positions as a project manager and graduate assistant at Los Andes University. After graduation, Ivan will continue his academic career as an assistant professor at the University of Southern Mississippi, at Hattiesburg, MS.