A Virtual Reality Interpreter for Aiding the Reconciliaton of Construction Concepts

Ivan Mutis, Raja R.A. Issa, Ian Flood
Rinker School of Building Construction
University of Florida
Gainesville, FL 32611
{imutis,raymond-issa,flood}@ufl.edu

Abstract

Construction project participants such as designers and contractors, rely on drawings and specifications as sources of information to specify building components and to interpret how to build them. The specifications are text-based descriptions of construction concepts, which define building components, parts of components, relationship with other components, and processes among others. Drawings are visual forms to represent construction concepts.

These representations are semantically poor and do not fully explain the intent behind the information, and the conditions are ambiguous and do not represent how the building evolves and progresses through the various construction stages. These information gaps force a construction participant to interpret the specifications based only on their own experiences and perspectives and to make incongruous decisions in the advancement of the activity, which tend to be error prone and inefficient. Accordingly, there is a need in the industry to develop interoperability systematic approach that helps construction participants in identifying the potential inconsistencies.

This approach uses conceptual formalization procedures by developing ontology in order to obtain explicit information. As a result of the ontology development, this research proposes a tool named 'Virtual Reality Interpreter' to help construction participants to perform accurate interpretations with the purpose of aid the reconciliation of two sources of construction concept representations.

Keywords

Construction Representation, Semantic Interoperability, Ontology Categories, Construction Concepts

1. INTRODUCTION

Construction participants must be able to operate in conjunction, or interoperate. Multiple participants regularly and concurrently interoperate during the project life cycle. Interoperability occurs at any time on demand during any construction activity, such as utility installations, site work, or roof installations.

Multiple efforts have been exerted to overcome the lack of interoperability in the construction industry by the research community. However, these efforts on finding methods of exchanging, sharing, transferring, and integrating of information from distributed sources have not been successful.

In the following sections, this paper briefly examines the limitations of these efforts and outlines a novel approach, which is based on the analysis of the semantic layer of information, and which recognizes the need for human intervention in any attempt to integrate, merge or share information.

1.1 Limitation of current information representations for interoperability

The construction industry information that contains processes, products, and documents is exchanged, shared, and transferred in either paper-based or computerized forms. The tendency is that contractors, subcontractors, suppliers, and other participants to interoperate their information by describing their processes, products, and documents within forms able to be represented and manipulated by computer systems. For example, products are represented in digital libraries, or construction schedules, which are part of the documentation in construction projects, and are elaborated through problem-solving software that is aimed at the optimization of time and resources.

The supposed benefits of describing the information through computer systems rather than paper-based formats are the facilitation of elaboration in construction participants' systems, fewer inconsistencies and errors, and the easy manipulation for storage, reproduction, sharing, distribution or exchanging. However, the description of information through representations in computational systems does not guarantee a continuous information workflow among construction project participants. The information is "displayed" by computers. However, this fact does not indicate that the information could be processed within other construction participants' systems. The manipulation of information is limited to storage, reproduction, sharing, distribution or exchanging, with the objective of that information being "displayed" in each of the construction participants' own systems.

Other more frequent problems encountered in interoperability are lack of coordination, inconsistencies, errors, delays, or misinformation. These problems were analyzed in a recent labeled domain, construction informatics (Turk 2006). We recognize multiple sources for the problem of creating the effective exchanging, sharing, and transferring of information. Roughly, these sources are different methods used to represent information (Partridge 2002), different levels of specification of the concepts in the domain, and the various levels of systematization or sophistication of the construction participants' systems. The consequence is a reduction in the productivity and efficiency of current interoperability activities.

1.2 The Integration Challenge

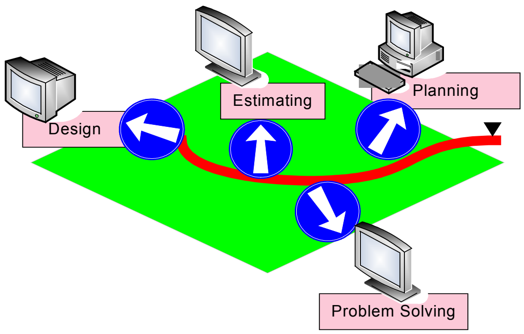
The processing of the information into others actors' systems is known as *integration*. This *integration* is a process used to support many activities in current construction projects that employs information represented in computer forms. However, this process is a big challenge that cannot possibly be performed without intervention by human resources. 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, without the interpretation and re-elaboration of the other party's schedule. Construction participants need to interpret the "displayed" information and rebuilding the required components of the "displayed" information in order to process them in their systems. The research community has recently made major efforts in providing an understanding of the information integration problem. Their efforts are addressed to support many forms of communication and collaboration on all projects with the purpose of aiding processes involved with computerized systems, or Information Technology (IT) (Amor 2000).

1.3 The interpretation step

Evidently, there is a gap in the interoperability process itself that delays or interrupts the continuity of the information workflow. Each participant creates information independently rather than in a collaborative environment. The absence of collaboration, coordination, and agreements produces the gap. This gap is reflected when participants must perform an interpretation step of the information that was obtained from multiple sources. This problem of interpretation is designated as *semantic interoperability*, which stands for the understanding of what is represented within the information by other actors' domain agents. Clearly, before any *integration* there should be an *understanding* of what is going to be added, processed, or manipulated. Inconsequently, the construction industry seems to be focusing on finding strategies for '*integration'* rather than strategies for '*understanding'* the information from other construction participants. For example, huge groups of researchers have been formed to address integration through the modeling paradigm during the construction life cycle (IAI 2005).

Thus, in our view, strategies for *integration* will not solve an interoperability problem without working first on strategies of '*understanding*' the information from other sources. The community assumption is that creating an *a priori* consensus over the content of what is described within the information will guarantee a clear path to interoperability. Unfortunately, as will be further analyzed in this paper, there are issues concerning the nature of knowledge representation *per se* that have yet to be solved regarding the representation of the real world through the use of computers by the computer science community. The *a priori* consensus assumption has made the construction community find solutions via the *integration* paradigm. The pressure of encountering rapid, applicable solutions has created an avoidance of the '*understanding*' of the content of information. The study of the '*understanding*' and the meanings of the components is part of the semantics arena and it moves our analysis to inquiries concerning how a construction participant sees the real world or how he or she maps the views of the world into information represented in computers.

This paper further outlines current limitations for interoperability in order to propose an additional overlooked step, which is based in a novel way to see the problem based on a semantic layer of representation of information in construction. The objective is to have a better understanding of the role of semantics through representations within information, and to place the analysis to visualize the semantic representations upon ambitious challenges like integration or collaboration. The results of this



analysis is the development of a proposed tool named 'virtual interpreter' to help construction participants perform accurate interpretations of construction concepts, which are represented in plans and specification.

1. THE EVIDENCE OF THE DIVERGENCE

In the last two decades, the industry has rapidly jumped into searching for solutions by pursuing the automation of construction tasks with the use of information processed by computer systems. The main purpose is to expedite the specialized industry practices and to look for efficiency in their operations. For clarity, the information processed by computer systems, which includes programs and data, is shortly labeled as software. The 'jump' into finding solutions has created highly specialized operations and has produced what is named 'islands of automation'. Part of the this trend could be explained by the higher levels of sophistication of the construction processes that demand high levels of human specialization that go along with the division of labor in the construction projects.

The solutions that use information processed by computer systems are divergent from any form of integration. The final outcomes of such solutions are focused on a particular process and phase during the construction projects, and the products are not even attempting to share common aspects with solutions of other construction processes. Figure 1 illustrates this divergence of the software solution created to meet the user needs in particular construction project processes, although they limit their applications to specific construction problems (see Figure 1). For example, the design stage has its own specialized solutions such as those found in Archicad 10 (Archicad 2006), a popular design software. In processes such as planning and scheduling, there are multiple software manufactures that formulate solutions for the optimization of time and resources together with other problem solving strategies and helpful algorithms; Primavera is one of the most successful in this arena with its Project Planner software (Primavera 2006).

At the estimating stage, which is a more specific domain process, there are tools in the market such as Timberline Precision Estimating (Timberline 2006) that help users through libraries and other knowledge base components to produce project cost estimates. Other solutions for analysis of information for decision support, known as decision support system (DSS), i.e. Cognos (Cognos 2006), enables the project team to evaluate alternatives in specific contexts of the project such as logistics, and procurement, among others.

Figure 1. Computer System Solutions Divergence

The divergence is the first challenge for the construction community that pursues interoperability with other actors in construction projects. There is no articulation within these solutions. The articulation is more difficult with the proliferation of solutions that have permeated the industry for specific users and for particular needs, but, paradoxically, was created for shared construction processes, which construction participants intervene. Within this divergence, the automation of the specific processes has attempted to reach efficiency, but done so at the expense of failing to achieve interoperability by overlooking the integration of information among construction project agents and thus overlooking as well the efficiency of the whole construction project.

A second challenge is how the level of specialization that these solutions exhibit can achieve *collaboration* for interoperability. Multiple solutions produce multiple sources of information, and in a context where multiple construction participants intervene within a construction operation; the multiple solutions become a cause of a major complexity for *collaboration*. Even when considering a narrower case for collaboration such as simple *communication* acts, it is difficult to succeed when the multiple sources of information are created at different levels of specializations. The use of information at different levels of knowledge specializations requires professionals in the industry that suffice in their level of knowledge of the multiple specializations to succeed in the construction operation, but with high costs on human resources and high risks of conflicts among participants.

2. SEMANTIC INTERPRETER

Integration through consensus is not possible, but it is possible to address construction concepts and their semantics. We envision the use of the semantic interpreter as a basic tool to enable construction participants to anticipate undetected or unknown details and situational conditions of a construction concept. The use of the proposed tool will facilitate construction participants' reasoning concerning correct interpretation of representation of construction concepts within an interoperability activity.

As was explained previously, interoperability with representations derived from solutions from different construction participants cannot be performed automatically. Parts of the interoperability process call for human intervention. This step consists of an interpretation of such representation. For example, the interpretation of the design representations of a door represented by a series of lines in a CAD solution, is a semantic interoperability activity performed by an agent. In this case, the interpreter or construction participant plays the role of a cognitive agent.

We envision the semantic interpreter as a tool that aids the process of interpretation of the representation that is going to be integrated or exchanged from different sources (see Figure 2). Several construction participants interact in the construction process and exchange information that represents a set of construction concepts in order to be integrated in their computation systems.

The semantic interpreter should contain the conceptualizations of construction products, processed according to the construction participants' roles in the organization. Then, the tool will help in an analysis of the interpretation process through the intentionality of the cognitive agent. The tool should recognize the social role of the construction participant and additional relations to the state of affairs of a product or factors that influence a process. For example, the estimator is mainly concerned with the quantification of products. Thus, the semantic interpreter should associate the estimator's social role and, therefore, aid the estimator in finding additional semantics of the components that are being quantified. The tool should present the 'sufficiency' to perform interpretations at a certain level of details of the component to the estimator. Considering the same example, if the estimator receives from the designer pieces of lines in the drawings with poor definition due to text based representation on the drawings schedule, the tool will aid by enriching the semantics of such a component. Therefore, practical errors such as misinterpretations or a lack of understanding or familiarity with the components will be reduced.

The semantic interpreter will complement the semantic deficiencies of the representations. This tool attempts to satisfy the cognitive agent's lack of knowledge concerning a construction concept in order to aid him in performing an accurate interpretation.

3. 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 relationships to the other concepts are not taken into account. These relationships are termed contextual relations.

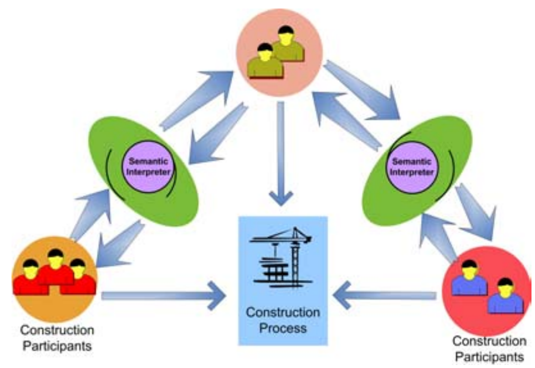


Figure 2. Semantic Interpreter Tool for Information exchange

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. This research takes contextual relations in consideration of a valid construction participant's interpretation. In the construction industry, typically the details and conditions are form of expression used to define characteristics of any construction concept used in a construction project by the industry community. A concept is commonly represented in two forms either as a physical construct or as an abstract expression. The reader is reminded that concepts are abstract, universal notions, of an entity of a domain that serves to designate a category of entities, events, or relations. A concept that is used in the construction community comprises geometric features, components or parts, additional or assembled items, and functional characteristics.

Concept details are modes of describing a concept with features (e.g. geometrical) and ontological aspects (e.g. dependency relations). For example, the concept details that describe the component 'hung' of an entity 'window' are part of the entity 'window' and have functional characteristics which can not exists independently; 'hung' needs a 'window' to perform the locking and handling functions necessary that allow an agent to open or close the 'window'.

This research addresses semantics to determine how an entity, which is an abstract, universal notion, is related to others. The semantics takes into account additional relations such as situational conditions. The conditions identify a separate piece of 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 situation 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).

Situational conditions help the analysis handle states of affairs and context relations. As an illustration, Figure 3 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). Figure 3 sketches the construction concept context relations and indicates the state of affairs of this particular entity.

For example, in Figure 3, '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.

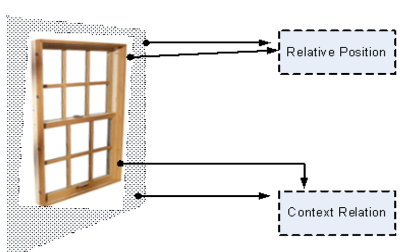


Figure 3. Visual representations of *situational conditions* of 'Wood Frame Window' concept

3.1 Representation of Construction Concepts

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 it to interpret the design intent.

The specifications are text-based data that are intended to describe construction concepts. The specifications are based on general regulations, project documents, or owner's requirements. In other words, this description of construction concepts is embedded into regulations and other project documentations. However, the description is semantically poor and does not fully explain concept *details* and *situational conditions*. In addition, the description of the product *conditions* is ambiguous and does not represent the evolvement and progress of such construction concept.

This lack of semantics forces construction participants to interpret representation of the cons pets based on their own perspectives and experiences. Accordingly, there is a need in the industry to develop a systematic approach that helps construction participants in identifying the potential inconsistencies in their interpretations of the representation of construction concepts. The right interpretation should lead construction project actors to make decisions in full compliance with the intent of the concept and with less potential conflicts.

3.2 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 would be the semantic relations that the observer can 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 relation 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 affect the interpretation but also non-observational factors. A good balance of these two factors will aid in performing better interpretations.

3.3 Interpretation as a cognitive process

Interpretation is a cognitive process that involves mappings of representations of 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.

The *intension* or the *sufficiency* of the set of properties, details, and conditions give and apply meaning to a concept. When the *intension* is 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 4 shows a sketch of mapping representations described within three layers: regulations, drawings, and document specifications. In Figure 5, 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).

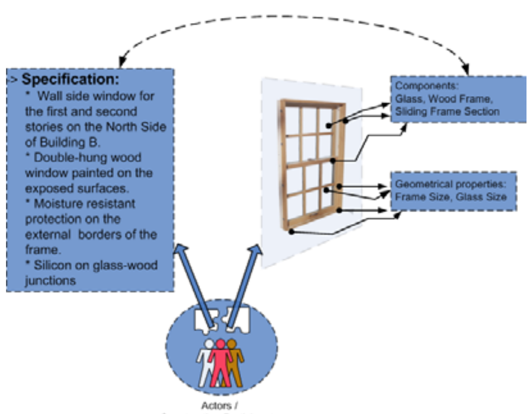


Figure 4. Mapping representations (layers) that describe the same concept

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 4 shows the construction participants' mappings of the visual representation's components with textual representation components of the construction documents. They map the visual representation (Wood Frame, Double Hung Frame') to the text-symbol ('Double-hung Wood Window') from the specification documents.

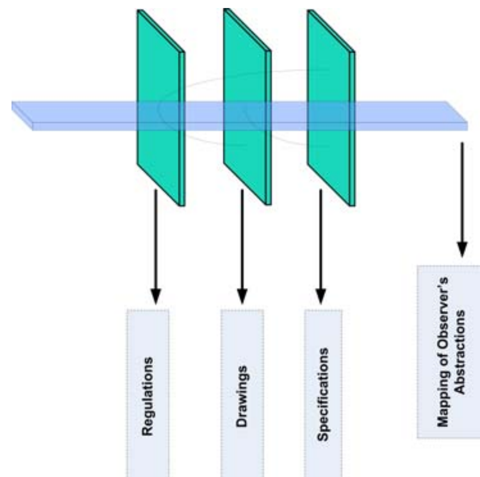


Figure 5. Relations between visual and text-based symbol

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 motivated by the cognitive agent purpose. In other words, the actors find correspondences according to their intentions that they have with the representations. As the reader can infer from the above explanation, the mappings or semantic relation include a reasoning process. This reasoning process will be illustrated in the next section.

3.4 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 his body of knowledge), to the *extension* of that concept. Figure 6 illustrates the relationships of the ure 6 illustrates the relationships of the abstractions among physical constructs, concepts, and representations in the popular *Meaning triangle* (Ogden and Richards 1989). In Figure 6, 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 the semantic relationships of the representations and to show how the relationships occur during the cognitive process within the actor's world.

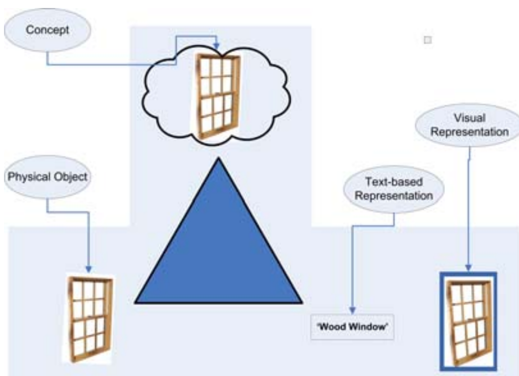


Figure 6. The Meaning Triangle

The reasoning process for interpretation can be described by the following steps: 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.

It is important to clarify that a concept can have several representations but only one referent, i.e. the thought or idea that a symbol, word, or phrase denotes. Different representations that describe the same concept are said to have the same reference. A referent designates an instance or an extension of the construction participant's world and an instance is the extension of the concept within its world (e.g. Door 34 of RNK Hall). The referent determines what type of entity, or set of entities it refers to (Sowa 1999). A classical example of extensions that have the same referent are Frege's statements: "I believe Venus is the Evening Star", and "I believe Venus is the Morning Star", by anticipating the referent "The Morning Star is the Evening Star" (this account of Frege is based on Appiah's citation (Appiah 2003). The referent can designate a specific instance by pointing to it, such as a locator (e.g. a specific door from a building: door type 2nd floor of building xx), or it can describe what a concept represents within the actor's world (e.g. there exists a set of doors of a type A). The designation is done through the use of syntax, which helps identify and locate a referent or, in other words, through the use of symbols, which are means to specify how a referent may be found. Numbers or code characters which are indexical in catalogs, or key codes in drawings are possible examples of this.

As an illustration, consider the following steps of 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. 'slide 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 'slide 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.

4. DEVELOPMENT MECHANISMS

This research proposes to build an ontology that will formalize the *Details & Conditions* of a particular construction concept. This ontology will yield formalized information that can be used to build computer software applications. This software will be able to extract explicit information about the particular construction concept. The information will be the result of the formalization of the representation of the construction concept.

4.1 Ontology for conceptualizations

The proposed ontology will be used as a mechanism to formalize and represent knowledge explicitly (Guarino 1997). This ontology has two category sources: observation and reasoning. The observation provides information of the physical world, and reasoning makes sense for observed features using a specific framework. The ontology is inducted by observations from an expert and it is structured by conceptualizations through reasoning concerning a particular construction concept.

The first step of this strategy is the identification of the need for interpreting a representation of a construction concept that is required by any construction process or activity in a project. The agent, then, identifies the representation (e.g. a representation in natural language, say "rolling doors" in the construction documents). The next step is circumscribed by the framework scheme, which is shown in Figure 7. In this step, there is an attempt to ontologically categorize the concept and to addresses the intention of the agent through the cognitive agent's role (e.g. inspector contractor, superintendent). The last step is the analysis of the information in order to derive an interpretation through the use of the proposed 'virtual interpreter tool'.

The step concerning the needs for interpretation of representations has been introduced and explained in previous sections. When a cognitive agent needs to interpret the representation, the agent recognizes the representation itself by identifying a concept to be represented, and by finding semantic relationships through contrasting *details* and *situational conditions*. This section exemplifies and illustrates the framework scheme step.

The scheme in Figure 7 contains aspects from the work of Zachman and Sowa (Brachman 1979; Guarino 1993; Sowa 1999; Zachman 1987), who proposed a framework to define knowledge for information system architectures, as well as from Brachman's and Guarino's suggestions concerning levels of representation (Brachman 1979; Guarino 1993). However, this scheme is intended to approximate the observer's or cognitive agent's world close to the representation of the construction concept.

The scheme represents a methodology that classifies concepts ontologically. It is critical to highlight how ontological categories back this framework and how different levels of representations intercede in the scheme, see Figure 7. These relations are reflected when the cognitive agent needs to interpret the representation. The agent recognizes the concept representation itself, finds semantic relations, and identifies ontological aspects of the concept (e.g. the cognitive agent's *role*, in the schema of Figure 7). In the scheme 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 ontological specification of the concept.

Figure 7 shows on first level the top ontological categories that are associated with each of the guidance or indicators of course of action ('*what*', '*how*', '*where*', '*who*', '*when*', '*why*') within the scheme. An analysis of a concept through the scheme must at least be defined by the categories showed. Although the purpose of this research is not to design a methodology for concept ontological analysis, this investigation does suggest that this framework must follow a systematic analysis of concepts. Other valid ontological analysis meth-

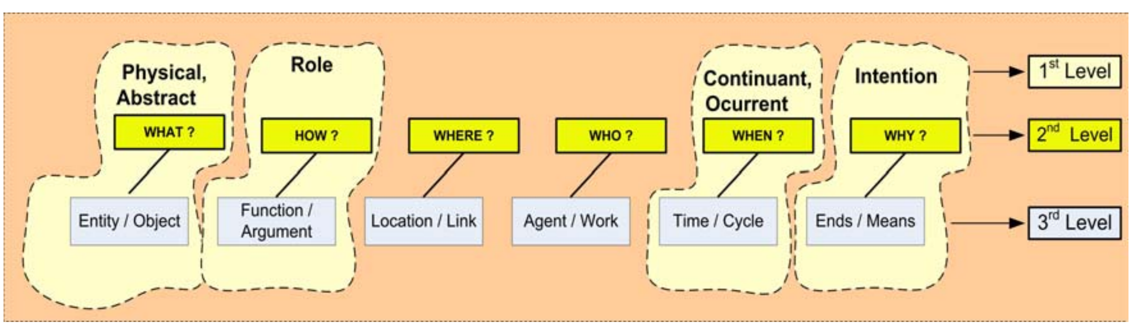


Figure 7. Framework Scheme

ods, which define top ontological categories (Guarino and Welty 2002; Sowa 1999), can be applied to the framework. This research does not recognize universal methods to define top ontological categories, but emphasizes a systematic conceptual analysis. Figure 7 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 second level of the scheme, shown in Figure 7, has the indicators of course of action expressed as questions ('*what*', '*how*', '*where*', '*who*', '*when*', '*why*') that help the cognitive agent query and address the description of the analyzed construction concept. As was explained previously, the first level indicates a direct description of the top ontological categories. In addition, the boxes, which correspond to the third level of the scheme, of each indicators of course of action have examples that help the readers analyze the concept.

The '*what*' indicator in Figure 7 conceives the description of the concept as a *physical object* or as an abstract *scheme*. An abstract *scheme* is a pattern (e.g. geometrical forms, syntactic structures), that describes or instantiates visual representations such as an object 'symbol' or object's topology, or a text-based phrase 'symbol' which is described by symbols used in natural language. A close analysis of this '*what*' indicator leads to <u>*contrasting*</u> the analyzed concept to others from the observer's knowledge or experience. This is a basic step of rationalization of *what* a concept is. In this step, the observer is able to identify a concept based on their own experience or knowledge by contrasting the *relations* between the analyzed concept and their knowledge or experience. The relations are essential for further analysis in the framework. The box that is on the third level of the scheme below the 'what' guidance contains examples of the possible *form* in which the concept is represented. These examples also will guide further analysis concerning computational aspects and the analyzed concept.

The '*how*' guidance conceives the function of the analyzed concept, and, if it contains components or parts, how the parts are organized for a given function. When the concept contains parts, the category can define one or more functional relations among them. The functional relations describe the role of the concept to others within the concept's space-time region. The role of the concept is to describe ontologically the functionality of the concept itself. The analysis of relations can be extended to other concepts when it is performed on functional aspects.

The '*where*' guidance describes the physical relations in which the analyzed concept is found. 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*. The reader is reminded that a concept can be instantiated having a unique reference in the world. This guidance situates the concept when the relation about a specific place or location is instantiated for that concept. For example, the concept "Rolling door" is instantiated, i.e. to the location first floor of the A39 platform in UF building 272.

Although, specific references are important in the analysis, this research intends to construct and consolidate a framework, which will not limit the generality of the ontological specifications. Thus, it is anticipated that specific referents will not be taken into account due to the restrictions and distortions that they will cause in the analysis. The analysis attempts to describe the generality of the concept through the *conceptual framework*, not through the descriptions of *unique* situations in the real world.

The '*when*' conceives the status condition of the concept during its life in the time-space dimensions. This is a specification of the stage of the concept (e.g. completed, installed, delayed) during its lifetime. It takes into account the process ontological category. It considers that an entity is either, in Sowa's top ontological definitions, occurrent or continuant. If the concept is seen within a different time scale, it could be considered as a process, part of a process, or a stable entity. Thus, the concept status is a view, which defines the entity at its unstable or stable state at a given period of a time scale. This situation is named by this research as *situational conditions*, specifically *status conditions*.

The '*why*' specifies the intention behind the interaction of the concept with other concepts. It defines a purpose or reason category. The purpose is dichotomy of the cognitive agent's intention. The '*why*' indicator is the first attempt to associate the intention of the cognitive agent with the concept by listing the intentions by employing the '*why'* form of inquiry. An example could be why the concept "Rolling Door" is relevant to the project manager. The '*why*' also specifies the purposes of the interaction with other concepts in relevant situations (e.g. 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).

5. CONCLUSIONS

Interoperability through integration approaches is not possible without the aid of human intervention. This intervention is reflected in the construction participant's interpretation of information provided and elaborated by different agents or sources. The *interpretation* is an overlooked step during interoperability. In this step, construction participants confront the lack of details that describe the information. This deficiency of details forces the agents to interpret the information based on their own perspectives and experiences. The information provided by other sources typically has poor semantics and this lack of semantics need to be replaced by the information proportioned by the experts.

This research outlines a novelty approach that investigates the overlooked interpretation step and the missing semantics of the information representations. This paper describes the theoretical accounts that explain the mechanism of the approach, which is based on exploring a semantic analysis of construction concepts.

A 'virtual interpreter tool' is suggested to help agents reduce misinterpretations, inconsistencies, delays or disruptions in construction processes, and other practical problems in interoperability. The tool is envisioned to help interpretations of the construction participant of construction concepts.

This is a systematic approach that is intended to help construction participants in identifying potential inconsistencies in interpretations of construction concepts. It is envisioned that the proper interpretation should lead construction project actors to make decisions in full compliance with the intent of the information provided by other sources.

6. ACKNOWLEDGEMENTS

This was supported by the National Science Foundation (NSF) grant ITR 0426886

7. REFERENCES

Amor, R.2000. "Integrating Construction Information: An Old Challenge Made New." *Construction Information Technology 2000*, Reykjavik, Iceland, 11-20.

Appiah, K. A. (2003). *Thinking It Through. An introduction to Contemporary Philosophy*, Oxford University Press, New York.

Archicad. (2006). "Graphisoft - Archicad 10." Budapest, Hungary, Design Software.

Brachman, R. J. (1979). "On the epistemological status of semantic networks." Associative Networks: Representation and Use of Knowledge by Computers, N. V. Findler, ed., Academic Press, New York, NY, 3 - 50.

Cognos. (2006). "Cognos 8 Business Intelligence." Burlington, MA, Decision Support Software.

Emmeche, C. (2004). "Causal processes, semiosis, and consciousness." Process Theories: Cross disciplinary Studies in Dynamic Categories., J. Seibt, ed., Dordrecht, Kluwer., 313 - 336.

Guarino, N.1993. "The Ontological Level." *Wittgenstein Symposium*, Kirchberg, Austria.

Guarino, N. (1997). "Understanding, building and using ontologies." *International Journal Human-Computer Studies*, 46, 293 - 310.

Guarino, N., and Welty, C. (2002). "Evaluating Ontological Decisions with Ontoclean." Communications of the ACM, 61-68.

IAI. (2005). "Industry Foundation Classes (IFC)." ifc2X, ed., International Alliance for Interoperability, International Alliance for Interoperability (IAI).

Kronfled, A. (1990). *Reference and computation. An essay in applied philosophy of language*, Cambridge University Press, Cambridge.

Luger, G. F. (2002). *Artificial intelligence : structures and strategies for complex problem solving*, Pearson Education Limited, Harlow, England.

Ogden, C. K., and Richards, I. A. (1989). *The Meaning of Meaning: A Study of the Influence of Language upon Thought and of the Science of Symbolism*, H. B. Javanovich, translator, Harvest Books, Orlando, Florida.

Partridge, C. (2002). "The role of ontology in integrating semantically heterogeneous databases." *05/02*, National Research Council, Institute of Systems Theory and Biomedical Engineering. (LADSEB-CNR), Padova - Italy.

Primavera. (2006). "Primavera Project Planner." Bala Cynwyd, PA, Planner / Scheduler.

Sowa, J. F. (1999). *Knowledge Representation: Logical, Philosophical, and Computational Foundations*, Brooks Cole Publishing Co, Pacific Grove, CA.

Thagard, P. (1996). *Mind: Introduction to Cognitive Science*, The MIT Press, Cambridge, Massachusetts.

Timberline, S. (2006). "Estimating. Sage Timberland Office." Beaverton, OR.

Turk, Z. (2006). "Construction informatics: Definition and ontology." *Advanced Engineering Informatics.*, 20(2), 187-199.

Yin, R. K. (2002). *Case Study Research. Design and Methods*, Sage Publications.

Zachman, J. A. (1987). "A framework for information systems architecture." *IBM Systems Journal*, 26(3), 276 - 293.