MISSING FUNDAMENTAL STRATUM OF THE CURRENT FORMS OF THE REPRESENTATION OF CONCEPTS IN CONSTRUCTION

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ABSTRACT: The generation of concepts in the construction industry involves the interpretation of syntactically defined symbolic notations, such as logic, frames, semantic networks, natural language, and of other forms such as visual representations. These notations are deliberately organized to define concepts. Models as forms of representations are based on symbols that are aimed at referring to some entities of the world with properties and relations apprehended within them. Models involve grouping a set of relations, which characterize concepts, with the purpose of sharing and understanding these concepts by members of the community. However, models suffer the limitations that logic and the symbolic notations bear, because they cannot capture the richness of the phenomena of the world in their syntactic notation nor other intentionality features. Other forms of representations such as visual representations suffer the same limitations.

An analysis of the nature of the representations employed in the construction industry suggests the inclusion of the actor's role in a new stratum for generating representations of construction concepts. This actor, who manipulates or generates the representation for communicating concepts, is committed to the intentionality aspects of the represented concept that are not captured in current forms of the representation. The inclusion of these and other phenomenological aspects concerning the nature of the representation are intended to generate representations for accurate interpretations. The modus operandi with these representations indicates a subsequent interpretation by other actors or project participants. The inclusion of this stratum promises a significant progress in creating efficiency in interoperability on construction projects. The assumption is that the representations are cognitive manifestations of common, shared concepts employed by the construction industry community. This analysis is supported and developed through the semiotic theory which addresses the nature of the representations through signs and the role of agents with the representations and with the external physical domain.

This study attempts to approximate 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.

KEYWORDS: semiotics, construction concepts, representations, interpretation.

1 INTRODUCTION

This investigation searches for the understanding of the forms of representation employed in the construction industry 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 interpreter's role, and the extent of their ability to capture the richness of the construction domain. A clear distinction between the nature of representations, their semantics, and the role of their interpreters is suggested. A close analysis of these elements indicates a missed stratum where the semantics of the representations that articulate the actor's interpretations can take place. The suggested approach consists of a study of the fundamentals of forms of representations employed in construction industry.

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 research. The analysis of the systematic, common forms of symbols, and particularly those from the semiotics experience of the representations are put into consideration within this approach in order to question the current employed forms of representation in their ability to express meanings in interoperability. Sharing concepts among the construction industry community is limited to the captured content in the representations producing errors and misinterpretations in these operations. The suggested approach consists of the study of the rela-

tionship between concepts and their associations to a more primitive sense of signs, i.e concepts and systematic, common forms of symbols that can be embedded in models or in computers, and of the role of the agents with the representations of concepts and the domain.

2 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 on 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 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 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 schematic order when the actions 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.

2.1 *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 nonacknowledgment of the captured features which have been explicitly described in the representation.

2.2 *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 within 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 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.

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 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.

2.3 *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 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 for 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 interpretating 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.

3 MODUS OPERANDI

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 presented 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 illustration is to clarify fundamentals of the relations between the representations and the construction project participants as cognitive agents. This relationship is central for 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 (Mutis and Issa 2007a; Mutis and Issa 2007b). This analysis facilitates the detection of the additional forms of knowledge representation proposed within this approach.

The examination of the *modus operandi* particularly addresses the perception, and interpretations of the representations and their constituents that depict concepts from the domain. The relationships between concept representations and the actor's interpretation are based on the actor's sensory experience, the actor's internal conceptual role, and the use of representations as existing methods to communicate construction concepts among the community. This analysis exposes the role of the actor with the representation through a sensory experience.

3.1 *Sensory experience and its role on concept interpretation*

The perception and interpretations of *modus operandi* are in their simplest form a sensory experience and a cognitive process. The general aspects of the dynamics of the sensory experience and cognitiveprocess can be deemed as self-explanatory by the reader. This triviality is borrowed from an ordinary commonsensical perspective that ignores the fundamental nature of representations and the complexity of cognitive processes. The analysis approach in this study 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 implies that concept structures and linguistic structures are shaped by the peculiarities of our perceptual structures 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 interprets an internal representation of external stimuli through a set of inter-related concepts learned by experience. The internal representations resemble other representations 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 about 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.

Figure 2(a) illustrates an interpretation of a visual representation by two actors working on the same 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 performs. It can be noticed that a 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 their meanings.

3.2 *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 2(b) shows the generation of a concept by an actor on a construction project and its communication to another actor. The assumption in Figure 2(b) is that the representation is the only means for sharing information between the actors. The actor *correlates* internal forms of representation: 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 the Figure 2(a), 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 2(a), the resulting differences in the internal, conceptual roles are represented through the semantics differences, by color of the compo-

nents 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.

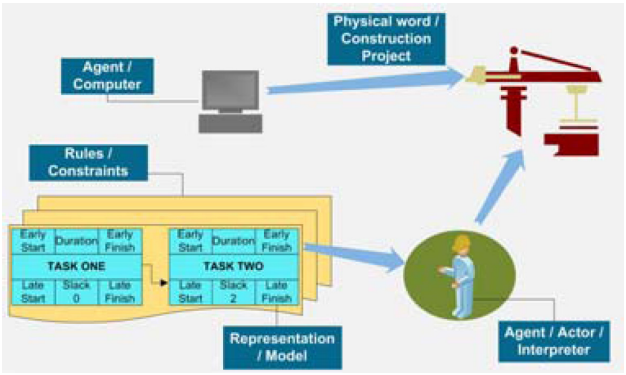


Figure 1. Representations, agents, and domain relationships.

(a) (b)

Figure 2. Modus operandi.

4 THE 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 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 1991). 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, of markers that are used to represent natural language, among other possible representations, such as the collection of hexadecimal numbers. In this analysis, the language that previously was used to describe *symbols* is changed by the terms used in semiotics as *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*.

4.1 *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 3 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 rom 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.

4.2 *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 4 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 4 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*.

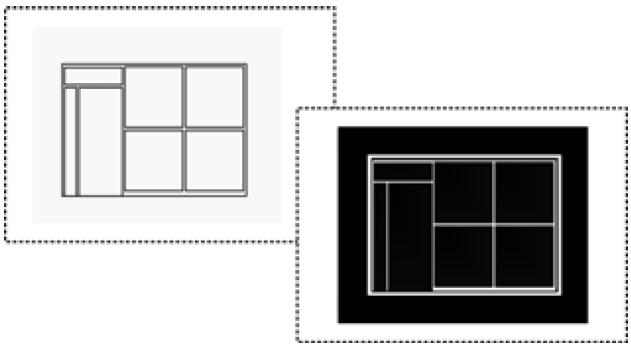


Figure 3. Visual experience as *qualisign.*

4.3 *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 reasonings about the meaning of the perceptions, identifies that the representation 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 a window in the agent's mind. In the example (see Figure 5), 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 5(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 5(b) illustrates the hypothetical internal representations for a certain agent that stands for the concept that resembles the a priori learned concept of windows.

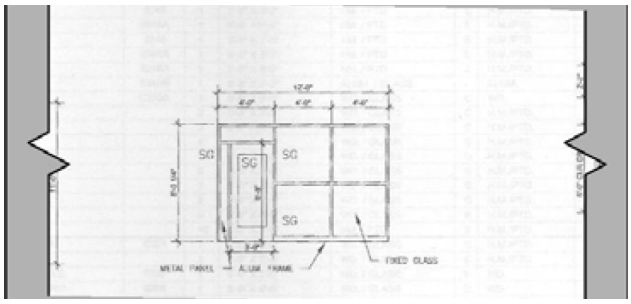
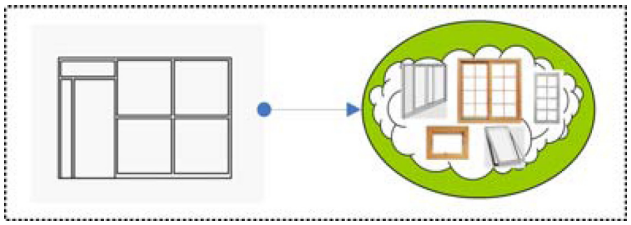


Figure 4. Sinsign

4.4 *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 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.



(a) (b)

Figure 5. Legisign.

(a) (b)

Figure 5. Icons, and the resembled concept.

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 6(a) shows an example of a representation that it is visual. The form of the representation resembles a concept the reader is already familiarized with and which is depicted in the Figure 6(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.

4.5 *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 no 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 resides 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 nonsolipsistic character and its nature is not imaginary.

Although, Peirce suggested that *indici* 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 is based on *similarity* relations. In Figure 7, 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.

4.6 *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 resulting 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 8 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 represention 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. 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 on the drawings.

4.7 *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 features of 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 (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.

4.8 *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 resides 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.

4.9 *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.

4.10 *The semiotics experience and its implications in construction industry*

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, 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.

As a further illustration, consider the following interoperability situation in order to highlight the implications of the semiotic experience analysis with common practical problems. 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 the Figure 9.

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.

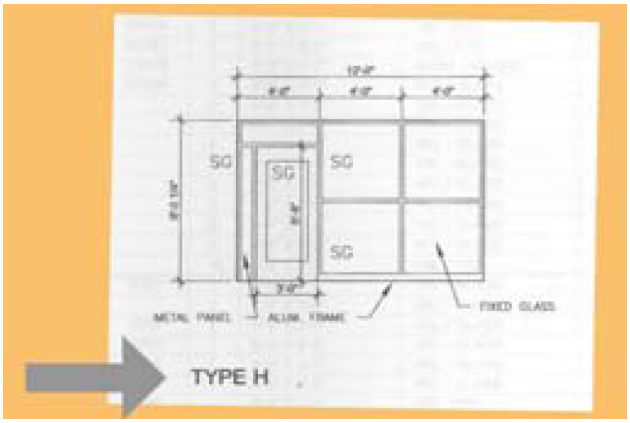


Figure 7. Index.

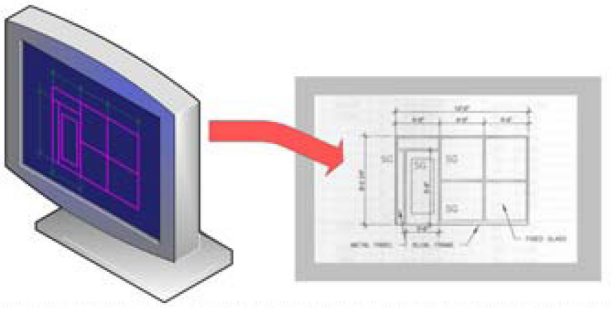


Figure 8. *Symbol* on a computer screen.

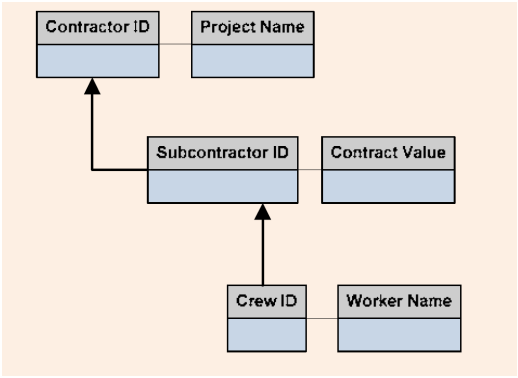


Figure 9. Meta-Level representation.

5 CONCLUSION

Misinterpretations, errors, rework among other typical construction problems are the resulting, hindering factors that affect the effectiveness of sharing, exchanging, and integrating of information in construction projects. The effective communication of the information is the goal during their *modus operandi* on the construction projects. This 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. This research explores the nature of signs and intentionality through a semiotics 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.

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