Semantics knowledge management for the 3D architectural reconstruction of building objects

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Abstract: This paper presents the framework of an ongoing semantics knowledge management practice. The practice combines geometrical analysis of point cloud and semantic rules to detect 3D building objects for the purpose of achieving computational correctness and efficiency. We assume that improvement in the form of well organized classification (CLA) and order (ORD) is a solution. Statically related knowledge is classified as definition, partial knowledge and ambiguous knowledge and formally revealed with transitions between CWA (closed world assumption) and OWA (open world assumption). To achieve the correctness, formalization is proposed for the validation of the rules through the mapping from Yes/No (Y/N) to True/False (T/F) and a further refinement of CWA/OWA flow. Dynamically a constructive model of knowledge rules organization is proposed to improve the controllability of previous empirically classified rules. A trade-off is illustrated to enable a quickly inheriting implementation.

1. INTRODUCTION

The technical survey of buildings (asset entry on site) is a long and costly process (Y. Duan, C. Cruz and C. Nicolle, 2010a and 2010b). This process aims to build a digital model in DWG format (vector) by geometric analysis of an existing building. By analogy to computers, we could describe this process as a reverse engineering process of a physical model to a conceptual model. In reality, this process requires a laser rangefinder controlled by an operator to acquire different points, connecting these points to construct lines and obtain forms which will be described by the operator (wall, windows ...). Recent commercial tools use laser rangefinders connected to PDAs to carry out this process. The geometric information is enhanced during the acquisition process with a basic semantic description of elements acquired. Then, the result DWG file is checked by a designer or architect. They will correct the inconsistencies of the geometric digital model.

The lack of semantic characterization of vector shapes has led to major problems of heterogeneity in the description of a building. To resolve this problem a new standard was developed over 10 years by the International Alliance for Interoperability (IAI). This standard called IFC, considers the building elements as objects that are defined by a 3D geometry and normalized semantic. Semantics (C. Cruz, F. Marzani, etc, 2007, C. Cruz, C. Nicolle, 2009, A. Nüchter and J. Hertzberg, 2008, and B. Kuipers, 2008) has also been used during the process of reconstruction of 3D objects from 3D point clouds for improvement on automation(A. Nüchter, H. Surmann, and J. Hertzberg, 2003), accuracy, efficiency and goal-directed applications from the knowledge engineering.

In the Achi3D research project (Y. Duan, C. Cruz and C. Nicolle, 2010a), we developed a complete process to perform the technical survey of a building using a 3D scanner to obtain a digital model in IFC format. This method is decomposed in four steps: 1/ Geometric characterization of the cloud of points obtained by the 3D scanner. 2/ The semantic characterization of geometric shapes detected. 3/ Automatic detection of objects of the building by logical rules combining geometric and semantic constraints. 4/ Production of an IFC digital model.

The goal of Archi3D is to facilitate the reverse engineering process from an existing building to obtain a normalized semantic and 3D digital model. In section 2, we have defined an Ontology describing the knowledge of the domain which is derived from the IFC norm and it is created on the platform of protégé with Web Ontology Language (OWL). Section 3 presents statically related knowledge organization including guide the correctness through mapping from Yes/No (Y/N) to True/False (T/F) and a further refinement of CWA/OWA flow. Section 4 presents a constructive model of knowledge rules organization from a dynamic view to improve the controllability of previous empirically classified rules. Finally, Section 5 summarizes and concludes this work in progress with future works.

2. ONTOLOGY OVERVIEW

In this section, the concepts used in this draft (Y. Duan, C. Cruz and C. Nicolle, 2010b) are introduced which are mainly derived from Industry Foundation Classes (IFC). In addition, building element concepts will be described with the syntax which is similar to semantic of description logic (DL) which is defined by interpreting concepts as sets of individuals/objects and roles as sets of pairs of individuals/objects. The definitions here are based on axioms of ZFC (Zermelo–Fraenkel set theory with the axiom of choice) set theory and DL (Description Logic) related expressions by default.

2.1 Classes introduction

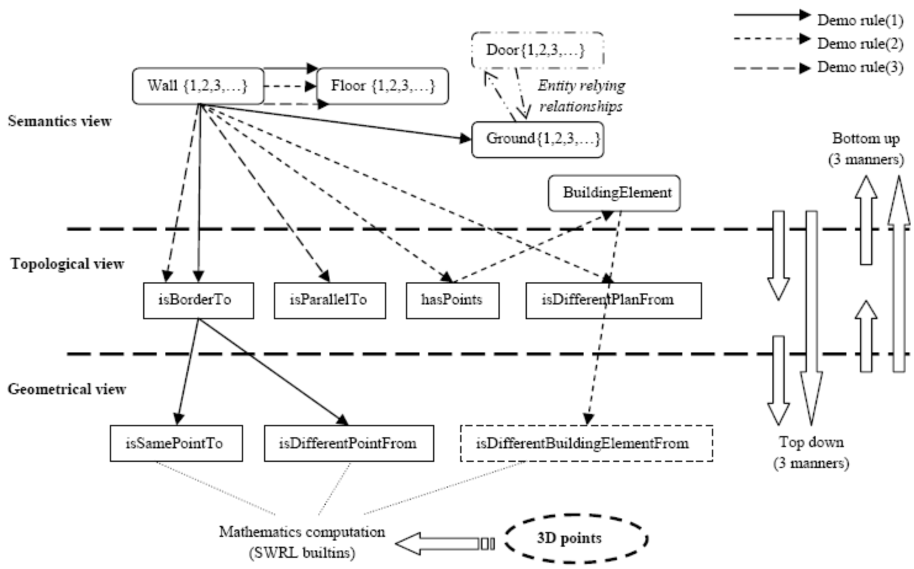


Figure 1. Exposition of the structure of the knowledge rules

Things for Achi3D project are initially proposed as “BuildingElement” which originates in IFCBuildingElement and “GeometricElement” which maps to geometries. Semantic given by means of interpretation $I = (\triangle^I, \cdot^I)$:

Thing is a ZFC set.

$Thing^I \subseteq \triangle^I$

The DL semantic of them which originate mainly in corresponding IFC elements and architecture is as follows.

BuildingElement = { Building, Wall, Door, Window, Ground, Platform, Site }

GeometricElement = {PlanEquation, Point}

A glance of the classes of Archi3D can be gained with Figure 1.

2.2 Properties

Properties for Achi3D project are classified as object properties which relate among Things and datatype properties which relate Things to datatypes. The DL semantic of them is as follows.

ObjectProperty = {hasGeometryElement, hasSemanticDescription, hasSpatialRelationship, hasPoints, isSamePointTo, isDifferentPointFrom, isBorderTo, …}

DatatypeProperty = {px, py, pz, ratioXYArea, height,…}

With a set of DL constructors, complex concepts and roles can be built with Classes and Properties. A classification of the composed semantic expression (CSE) is as follows:

$CSE^{I} \subseteq \triangle^{I} \times \triangle^{I} \times \ldots \times \triangle^{I}$

3. STATIC MODES FOR KNOWLEDGE CLASSIFICATION

We assume that the every semantic is bounded to a specific state. It is valid only for that state. For general description, usually this issue is not explicitly distinguished. It does not cause confusion for understanding as long as the context is provided in the form of structures which well preserve the information of CLA and ORD (Y.Duan, 2009a). We refer this expression mechanism as static.

3.1 Correctness validation through Y/N→T/F transition

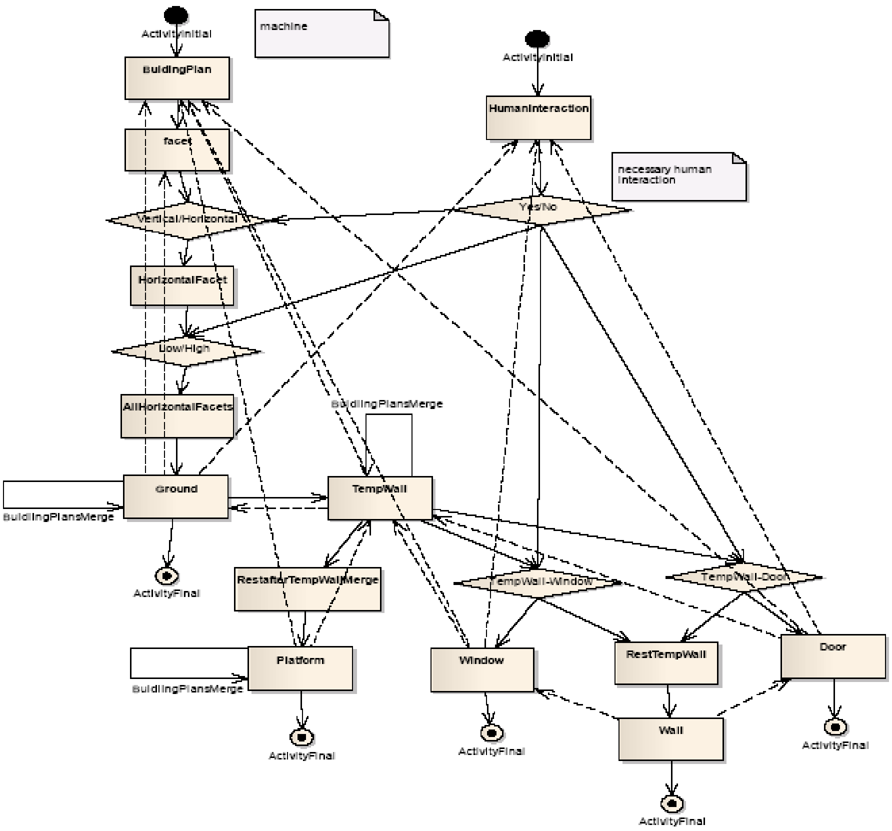
The main problem here is that we find out from the past experience that there are several problems limited to the informal characteristics of natural language expressions for potential knowledge.

- Implicit related incompleteness: we have identified that in natural language expressions, the expressed semantics could not always fully expressed the intended semantics which the speaker want to express. This could be caused by that there is some knowledge which is assumed by a speaker unconsciously. For example, when a speaker say that “on the left/right of a building element…”, it could be information transfer with incomplete semantics (Y. Duan, 2010c) since that the speaker’s view on the “left/right” is not explicitly transferred to listeners. Similar cases include usage of terms like “in front/behind”, etc.

- Partial knowledge related confusion: sometime a problem may arise from taking a partial knowledge as a complete knowledge. Or in terms of OWA vs. CWA, mistaking an OWA as CWA. For example, when a speaker put his/her view inside a room of a building, he/she might tender to use the expression of "inside/outside of the door…". This usage of "inside/outside" could be invalidated by just shifting his/her view into another room nearby. For the purpose of expressing independent knowledge rules (Y. Duan, 2010b), these kinds of mistakes could arise easily without notice.
- Lost with relative relationships: if the amount of empirically knowledge rules grows to exceed a certain scale, it is very difficult to maintain as long as the relative relationships of concepts could also explode.

Figure 2. Illustration of "(Yes/No)" control flow

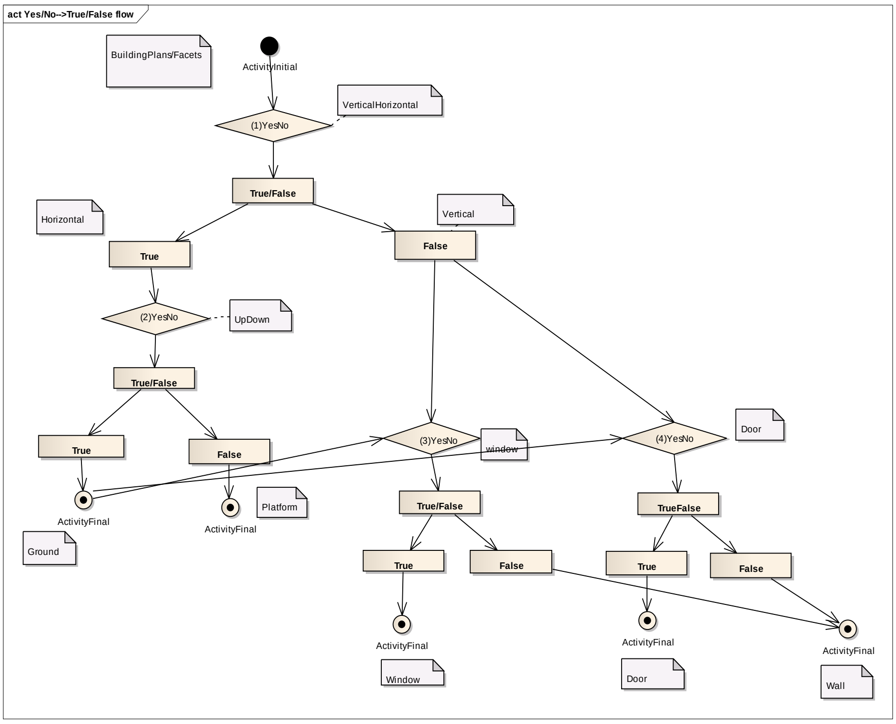
We summarize these situations as taking subjective (SUBJ) views of



Yes/No unconsciously as objective (OBJ) knowledge of True/False. There are many solutions available to remedy this situation. Here we proposed our solution in a static mode: (Yes/No)→ (True/False).

For example, decidability contained in our building ontology(Y. Duan, 2009b) could be revealed in the sense of Yes/No to True/False flow. And the CWA/“negation” can be also revealed. Figure 3 shows the example with this project which corresponds to the previous ontology. The Yes/No to True/False represent the transformation of information which is achieved subjectively are transformed to objective knowledge after it finishes the process of transferring from implicit human mind to explicit knowledge, such as the enforcement of “up vs. down”, “vertical vs. horizontal”, identifications of Doors and Windows, in Archi3D projects. After the necessary Yes/No→ True/False transformations, subsequent objective analysis can be extended, such as the Walls can be concluded as a negation relying on Doors and Windows, etc. The coherence of the revelation of the Yes/No→True/False flow can be viewed as a proof of the computability of a corresponding ontology and the project to be built with the ontology.

Figure 3. Illustration of “(Yes/No)→ (True/False)” flow



3.2 Refinement of T/F with CWA/OWA flow

The implementation of the True/False flow(Y. Duan, C. Cruz and C. Nicolle, 2010a.) by it self could be extended as several situations in consideration of the validation of the semantics of True and False separately and as a whole. The modes could be as follows: T/F→T, T/F→F, T/F→T/F, etc. In this session we would reveal the CWA/OWA (Y.Duan 2010b, Y. Duan, C. Cruz and C. Nicolle, 2010c) during the decision making process for a further refinement of T/F flow.

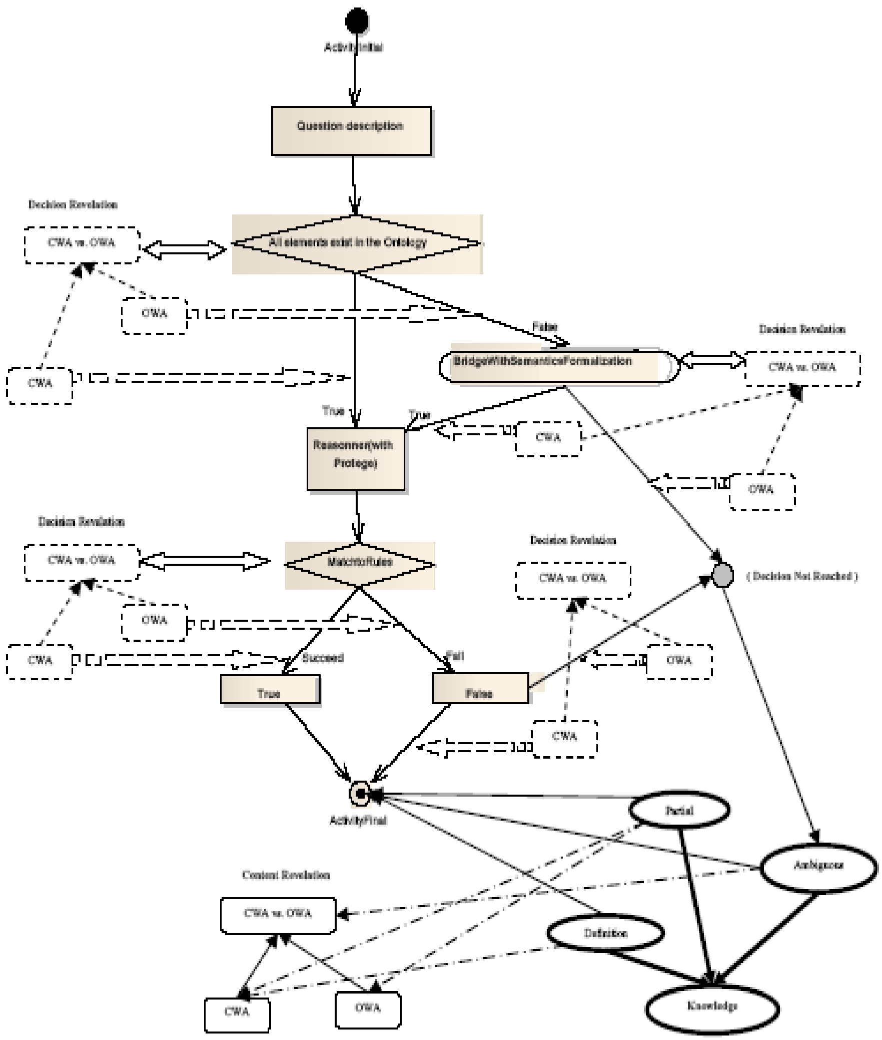


Figure 4. Demonstration of the CWA/OWA refinement of True/False decisions

Figure 4 demonstrates CWA/OWA extensions on an activity diagram of reasoning and validation processes for the SWRL rules in Archi3D investigation. The decision activity nodes can be mapped to “CWA vs. OWA”, and the specific decisions backgrounds can be revealed by relating to CWA and OWA respectively. After a question is presented, the semantics of its description is analyzed based on the matching of composing expression elements with the knowledge of an ontology. If the all elements can be mapped from the ontology, it proceeds to reason on Protégé. Here “all” requires a CWA confirmation/assumption. Otherwise semantics formalization extensions are demanded in the background of OWA. During the reasoning process, we classify the process to two states: with enough rules which map to CWA and without enough rules support which map to OWA. For this case, the content of intermediate analysis and final results can be mapped to the knowledge classification of Figure 1 indirectly. Mapping towards OWA and CWA could aid in achieving a complete and formal classification of SWRL rules also.

An intuitively case could be as follows:

Element_building(?x) ∧has_edge(?x,?a) ∧has_edge(?x,?b) ∧vertical_edge(?a) ∧ horizontal_edge(?b)∧Platform(?y) ∧has_edge(?y,?c)∧same_edge(?b, ?c) →Wall(?x)

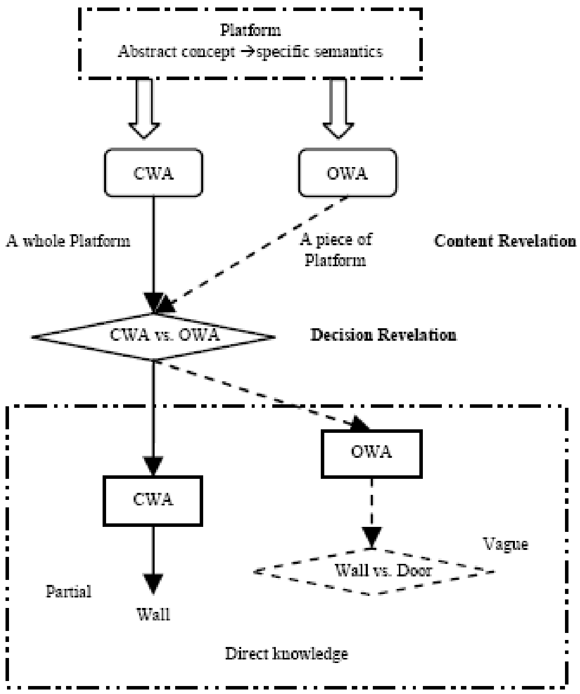


Figure 5. Illustration of “OWA/CWA→OWA/CWA” flow for Is_Wall

If a piece of a Platform is complete which is justified by a CWA based SWRL rule, the edge c will be a complete edge. Then the same_edge(?b, ?c) will help identifying the building element x as a piece of a Wall instead of a Door. If the Platform is identified by an OWA based SWRL rule as a piece of a Platform, this rule is not sufficient for distinguish between whether x is a piece of a Wall or a Door. In considerate the situations, we tender to use this rule as a form of vague knowledge by initially assigning the result as a piece of a Wall instead of a piece of a Door. A flow of "OWA/CWA→OWA/CWA" as is elementarily shown in Figure 5 (Y. Duan, C. Cruz and C. Nicolle, 2010a.).

4. DYNAMIC ORGANIZATION FOR RUNTIME IMPLEMENTATION

As we have stated in previous section our assumption is that every semantic is bounded to a specific state. Static expression use structures to preserve the necessary CLA and ORD while the complexity may grow out of control as the scale of the problem grows. We refer to the situation where specific states are considered and organized for runtime implementation purposes. In this section, we give a glance of our proposed dynamic solution scheme and also a glance of our scale control scheme.

4.1 Analysis of ongoing empirical organization

We have put continues efforts towards optimization on the organization of the knowledge especially in the form of reclassification and reorder the knowledge rules. The past efforts are limited by the limitations of static organization which actually rely on the introduction of "efficient" natural words, e.g., "partial, complete, relative, absolute…", etc.

For example, a version of our classification based on (absolute vs. relative) vs. (partial vs. whole) is shown as in Table 1(Y. Duan, C. Cruz and C. Nicolle, 2010b). The classification intends to cover bidirectional rules of both top down and bottom up manners, relative rules which are based on not absolute relative pure conceptual relying relationships such as relative relationships among Door vs. Window, Door vs. part of Wall, etc, absolute rules which rely on the geometrical data, e.g. height value, directly for achieving a conclusion, etc.

An example of partial knowledge with rule "PartialAbsolutetoRelativeWall":

height(?a, ?ah) ∧ height(?b, ?bh) ∧ BuildingElement(?a) ∧ Wall(?b) ∧ swrlb:greaterThan(?ah, ?bh) -> Wall(?a).

The background is CWA but the rules here are true (T) for the implicit assumption of "the ascending order of height for all building elements of {Wall, Window, Door, Floor} is: Floor→Window → Door → Wall. We implicitly assume the CWA of the category of building elements. Then if a building element is higher than a wall, it has to be a Wall.

Table 1. Empirical organization: (absolute vs. relative) vs. (partial/OWA vs. whole/CWA)

PartialAbsolutetoRelativeWall: height(?a, ?ah) ∧ height(?b, ?bh) ∧ BuildingElement(?a) ∧ Wall(?b) ∧ swrlb:greaterThan(?ah, ?bh) -> Wall(?a)
AbsolutHeight: hasPoints(?b, ?p1) ∧ hasPoints(?b, ?p2) ∧ pz(?p1, ?p1z) ∧ pz(?p2, ?p2z) ∧ BuildingElement(?b) ∧ swrlb:greaterThan(?p1z, ?p2z) ∧ swrlb:subtract(?h, ?p1z, ?p2z) -> height(?b, ?h)
AbsoluteWallbyHeight: height(?a, ?h) ∧ BuildingElement(?a) ∧ swrlb:greaterThan(?h, 49) -> Wall(?a)
AbsoluteWindowbyHeight: height(?a, ?h) ∧ BuildingElement(?a) ∧ swrlb:lessThan(?h, 30) -> Window(?a)
RelativeWallbyRatio: ratioXYArea(?a, ?ra) ∧ BuildingElement(?a) ∧ swrlb:greaterThan(?ra, 16) -> Wall(?a)
RelativeFloorbyRatio: ratioXYArea(?a, ?ra) ∧ BuildingElement(?a) ∧ swrlb:lessThan(?ra, 1.05) -> Floor(?a)
IntermediatWalltoDoor: hasPoints(?a, ?ap1) ∧ hasPoints(?b, ?bp1) ∧ pz(?ap1, ?ap1z) ∧ pz(?bp1, ?bp1z) ∧ height(?a, ?ah) ∧ height(?b, ?bh) ∧ Wall(?a) ∧ Wall(?b) ∧ swrlb:equal(?ap1z, ?bp1z) ∧ swrlb:greaterThan(?ah, ?bh) -> Door(?b)
PartialAbsolutetoRelativeWindow: height(?a, ?ha) ∧ height(?b, ?hb) ∧ BuildingElement(?a) ∧ Window(?b) ∧ swrlb:lessThan(?ha, ?hb) -> Window(?a)
IntermediatWalltoWindow: hasPoints(?a, ?ap1) ∧ hasPoints(?a, ?ap2) ∧ pz(?ap1, ?ap1z) ∧ pz(?ap2, ?ap2z) ∧ hasPoints(?b, ?bp1) ∧ hasPoints(?b, ?bp2) ∧ pz(?bp1, ?bp1z) ∧ pz(?bp2, ?bp2z) ∧ Wall(?a) ∧ Wall(?b) ∧ swrlb:greaterThan(?ap2z, ?ap1z) ∧ swrlb:greaterThan(?bp2z, ?bp1z) ∧ swrlb:lessThan(?bp1z, ?ap2z) ∧ swrlb:greaterThan(?bp1z, ?ap1z) -> Window(?b)
AbsoluteDoorbyHeight: height(?a, ?h) ∧ BuildingElement(?a) ∧ swrlb:greaterThan(?h, 40) ∧ swrlb:lessThan(?h, 48) -> Door(?a)
PartialAbsolutetoRelativeDoor: height(?a, ?ah) ∧ height(?b, ?bh) ∧ height(?c, ?ch) ∧ BuildingElement(?a) ∧ Wall(?b) ∧ Window(?c) ∧ swrlb:greaterThan(?bh, ?ah) ∧ swrlb:greaterThan(?ah, ?ch) -> Door(?a)

4.2 Proposed dynamic scheme

From a systematic and process oriented view of software engineering, it seems that much more situations could occur which could demand new types of knowledge and knowledge classification concepts in a static management approach. These rules could include rules which are used for identifying intermediate relationships or conceptual entities and rules which are used as redundant rules for validating other rules, etc.

Here we do not intend to deal with all this situations while staying in static description. What we intend is to shift our view to the cognitive level of entity instead of concept and try to reach some limit for rules organization in dynamic modes. The expected influence: help to reveal execution sequences of the rules, guide the rules organization for a proposal correspondingly, and validate the prediction of the rules from mapping to EID-SCE.

4.2.1 Dynamic knowledge management background

In essence, there are two main features which characteristic the complex phenomena of the related semantic knowledge management. One feature is that multiple semantic phenomena are all necessary to be organized dynamically for supporting a reasoning system. Another feature is that there seems to be semantics overlap and conflicts when these rules are put together simply. These two features actually demand a potential organization for the semantic knowledge. A basic semantic organization mechanism has been revealed in (Y. Duan, 2009a). For example, we use the CWA(closed world assumption) vs. OWA(open world assumption), and existence(E) and identification(I) .

CWA: it refers to the state that completeness is assumed in a formal manner, or the negation of logic connective is enabled.

OWA: it refers to the state that there are some CWAs which are either identified/(I=1) or confirmed to exist/(E=1) where we denote the confirmed and not confirmed with value "0" and "1" respectively, but are not all the CWAs are reached at the state of decision making. In consideration of the context for this project at this stage, we use an OWA based survey to denote the state to be identified. For example, if an absence/(E=0) of an identified exist/(E=1) composing the previous state is confirmed, the state will be changed to "E=0"from "E=1". The state transition from unidentified situations toward OWA can be modelled formally with Existence-Identification (EI) of CWAs as: EI(0/1, 0/1) → EI(0, 0/1).

4.2.2 Define the basic visibility of semantics knowledge

In the previous investigation on knowledge rules, we have shown that the correctness of an application of certain rules is partially determined by whether the knowledge expressed in these rules is semantically proper. By proper, it demands at least that the semantics of the knowledge are consistent.

Enlightened by our previous investigation on semantics formalization for mode driven engineering (Y. Duan, 2009a), we would like to reveal the abstract basic modes of semantics knowledge organization. These modes are supposed to be complete and consistent in a fundamental organized manner. They can be used for mapping related knowledge of rules accordingly to achieve completeness, consistency in a well organized manner.

We define a visibility of semantics expressions as containing all three of the following:

- Self independent: this assures an existence (E) of a target of this restriction, which can be expressed as E=1 of EID-SCE.
- Complete: this assures an identity (I) of a target of this restriction, which can be expressed as I=1 of EID-SCE.
- Meaningful or related for the expression purpose: this is not conflict to (a) as that all these restrictions are with the background of OWA .

4.2.3 The visible vs. invisible scenarios

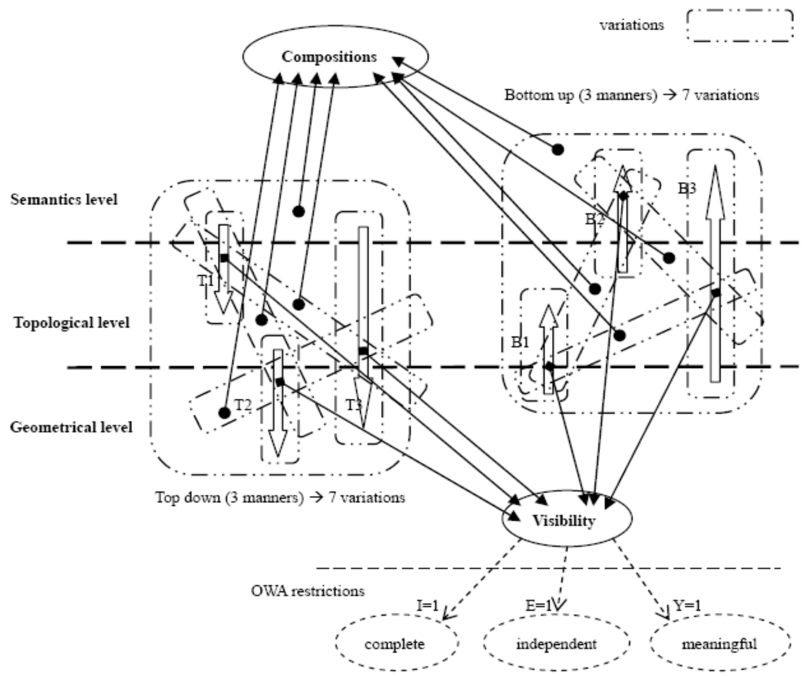


Figure 6. Revelation of the basic semantics phenomena with visibility

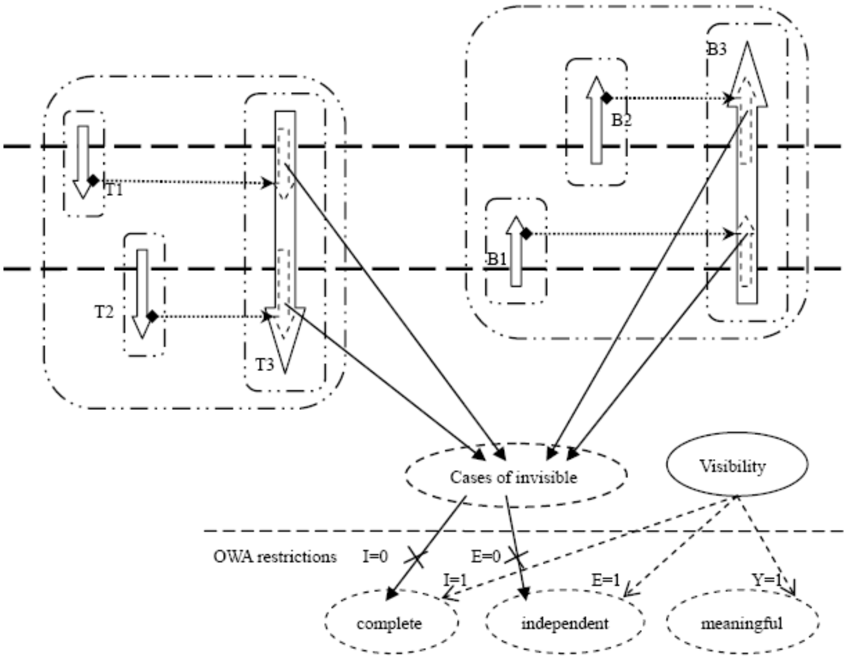


Figure 7. Cases of invisibility in contrast to visibility

These modes are illustrated by extending the 3+3 manners in Figure 1. The 3+3 manners of the semantics can be further explained/formalized according to EID-SCE (Y. Duan, 2009a) as follows:

The set of semantics variations of the 3+3 manners can be mapped to 7 + 7 semantics variations of which only 3+3 manners satisfy the restrictions of the definition of visibility. By satisfaction, it means the restrictions function on the phenomena in a manner of OWA instead of CWA. The specific cases of some semantics phenomena are extended as follows with special focus on each restriction: the existence of the independence of each phenomena or the exclusiveness among them.

The visibility 7+7 basic modes of “1+2+3” could be revealed in Figure with 3 layers of structures which corresponding to Figure 6. The T1, T2 and T3 represent the top down modes and B1, B2 and B3 represent the bottom up modes.

It is important not only to follow the right guideline to understand, utilize and realize the right semantics, but also to identify the possibility of fault semantics phenomena conversely to enhance the possibility of correctness of implementation. This Figure 7 extends cases of invisibility of semantics phenomena from the previous figure which reveals the visibility. For example, if the knowledge in the visibility of T1 is mistaken as inside T3 by mistake, it is not visible instead of visible anymore. For example, if T1 represents a partial knowledge rule of “a Buildingelement bordering 4 walls is a platform” and T3 represents a knowledge rule of “a Buildingelement bordering 4 walls which are orthogonally connected, geometrically simulated and measured as lowest is a ground”. They are rules which are not visible/used within the same semantics phenomena.

4.2.4 Further extension: apply four colour theory as a restriction

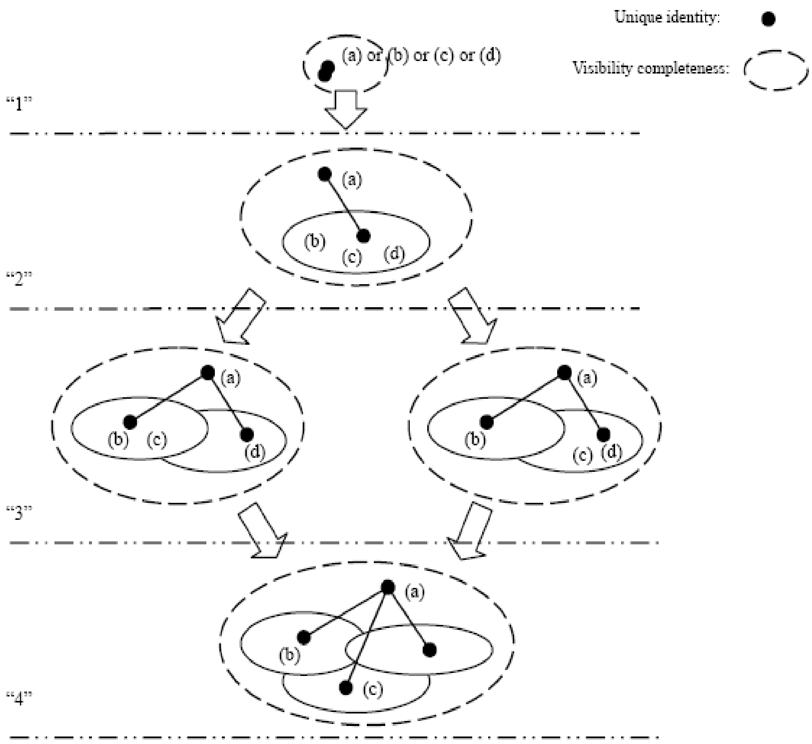


Figure 8. Hints for applying four colour theory as a restriction for efficient modelling

From the dynamic view, there are several elements of which the semantics validate for a specific state. To guide the control of the mount of the necessary and sufficient elements, we have seen a chance through applying the four colours theory (Y. Duan, 2010a,). Figure 8 gives a hint of our ideas. In general, the amount of necessary concepts which are needed can be mapped into no more than 4 unique identities. A full extension will detail the situations which map exactly for “1”, “2”, “3” and “4” identities which are initially shown as visible components in Figure 8.

5. CONCLUSION AND FUTURE WORKS

This paper presents a knowledge management framework to perform the technical survey of a building using a 3D scanner to obtain a digital model in IFC format. The solution is beneficial to semantics knowledge based characterization of the detected building elements, and driving new objects from the point cloud. The static modes propose solutions for enforcing explicit semantics formalization from subjective to objective at conceptual level through refinement transitions of Yes/No→ True/False and True/False → CWA/OWA. Dynamic modes initially propose solutions which could be beneficial to plan detailed runtime semantics organization in a systemic manner while avoiding mistakes. The dynamic modes are fundamental in that it is expected to be efficient from the modelling entity/elements in stead of from conceptual level. Much work is still left for us to validate the integration of the theoretical aspects and concrete empirical practices. More feedbacks from more projects are expected for modifying and improving these proposed structural description and dynamic implementation solutions. The project is conducted in cooperation with the I3Mainz Institute. In summer 2011 we will merge the first results of this project with the Active3D Project and its extension, the SIGA3D project (www.active3D.net). Active3D is already developed and industrialized. It is a web collaborative platform allowing actors of the lifecycle of a building to do facility management. Today, Active3D manages more than 61 Millions square meters of building represented with 3D and semantic objects (IFC format). The SIGA3D project is an ongoing Eureka project (European and private funds) which aims at extended the active 3D to the outside of the buildings for urban facility management.

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