Architectural reconstruction of 3D building objects through semantic knowledge management

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Abstract—**This paper presents an ongoing research which aims at combining geometrical analysis of point clouds and semantic rules to detect 3D building objects. Firstly by applying a previous semantic formalization investigation, we propose a classification of related knowledge as definition, partial knowledge and ambiguous knowledge to facilitate the understanding and design. Secondly an empirical implementation is conducted on a simplified building prototype complying with the IFC standard. The generation of empirical knowledge rules is revealed and semantic scopes are addressed both in the bottom up manner along the line of geometry → topology → semantic, and a vice versa top down manner. Concrete implementation is on the platform of protégé with Semantic Web Rule Language (SWRL).**

Keywords- semantic; knowledge management; formal; epistemology; cognition

I. INTRODUCTION

The technical survey of buildings (asset entry on site) is a long and costly process. 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 an architect. They will correct the inconsistencies of the digital mock-up.

Over the past ten years, the DWG has shown these limits at the onset of new needs in the field of facility management. The modeling of a building as a set of vectors is not sufficient if one wants to digitally manage the lifecycle of the building. For example, how to calculate the impact of the renovation of a building element on other related items. Moreover, 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 ten 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. It is necessary not only for the architect to recognize a wall on a map, but also for the system to recognize the walls and other building objects on the mock-up. In the Achi3D research project, 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.

Reconstruction of 3D objects from 3D point clouds has been investigated as a topic of computer graphics researches in [2], [3], [8], which progress from large earth terrain towards precise building parts, etc. With the popularization of 3D laser scanning equipment and technologies, more and more focus is shifted on related very promising researches and applications. Most works [6], [7], [10], [20] on 3D point clouds gained from laser scanning focus mainly on the 2D or 3D visualization and geometrical segmentation aspects. Some of the earliest works on 3D point clouds [18], [19] have investigated the construction of geometrical shapes for a long time. Later semantic [2], [3] has been introduced to the process for improvement on automation, accuracy, efficiency and goal-directed applications from the knowledge engineering and artificial intelligence areas [9], [28]. We agree with the assumptions that there are different understandings on semantic segments in terms of meaning [12] or interpretation [25]. While in practice, semantic classifications succeed for that they are simple for the users to understand and participate with their knowledge [11], and ontology could capture intrinsic structure of 3D shapes to achieve shape characterization with high probability in both general backgrounds and a specific domain [11].

The goal of Archi3D is to facilitate the reverse engineering process from an existing building to obtain a normalized semantic and 3D digital model. To reach this goal, we have defined an Ontology describing the knowledge of the domain (section II). This ontology is derived from the IFC norm and it is created on the platform of protégé with Web Ontology Language (OWL) [14]. We have completed this modeling by adding semantic rules developed with Semantic Web Rule Language (SWRL) [26] (Section III). The reasoning is performed with SWRL Jess Tab which is based on Jena [33]. Business rules used during the technical survey of buildings are translated into semantic rules to help the system in the semantic definition of 3D shapes detected. Section IV compares the proposed approach with other technical procedures. Finally, Section V summarizes the expected contributions and concludes this work in progress with future works.

II. ONTOLOGY OVERVIEW

In this section, the concepts used in this draft are introduced which are mainly derived from Industry Foundation Classes (IFC) [29]. In addition, building element concepts will be described with the syntax which is similar to semantic of description logic (DL) [30] 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 [15] and DL (Description Logic) [21] related expressions [5] by default.

A. *Classes*

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 $I = (\triangle^I, \cdot^I)$ [5]:

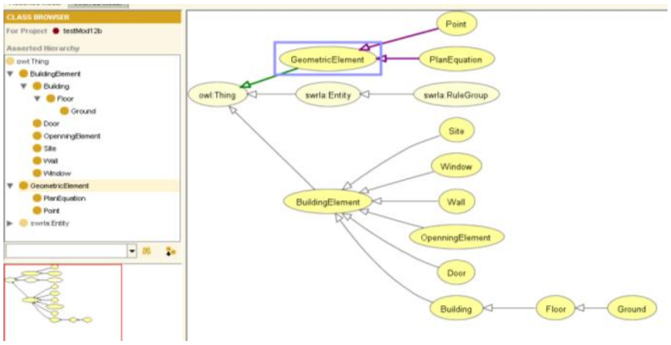


Figure 1. Classes of Archi3D .

Thing is a ZFC set.

$$\text{Thing}^I \subseteq \triangle^I$$

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.

B. *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:

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

III. SWRL RULES OVERVIEW

SWRL Rules take the form of an implication "→" between an antecedent and a consequent. It is read as that if conditions specified in the antecedent hold, then conditions specified in the consequent hold.

At semantic view, top down implementation of the knowledge involves mining semantic relying relationships from semantic view towards topological view and geometrical view [22]. Figure 2 illustrates the structure of the knowledge rules which span across three views of semantic, topological and geometrical. The knowledge organization modes are illustrated with arrows at the right side of Figure2 as 3 manners of top down and bottom up respectively.

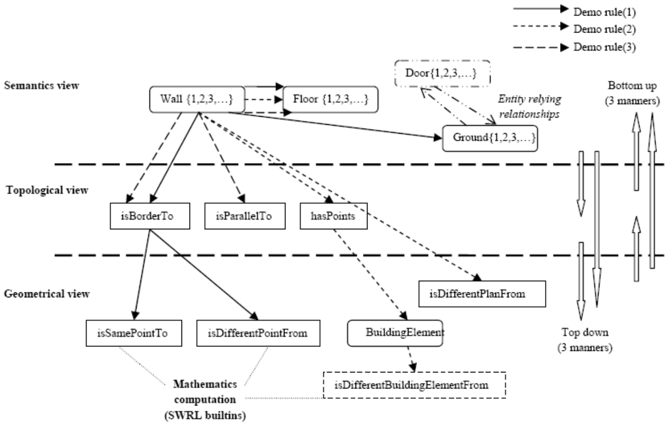


Figure 2. Exposition of the structure of the knowledge rules

A. *Top down reasoning*

We are going to explain how knowledge rules are employed for reasoning in a top down manner.

1) *Refine semantic levels towards topological levels*

In Figure 2, the identification of a semantic object of Wall may use some of the possible rules which might be Rule of demo (1), Rule of demo (2) and Rule of demo (3), etc.

Rule of demo (1): isBorderTo(?x, ?y) ∧ Floor(?y) ∧ isBorderTo(?x, ?z) ∧ Ground(?z) → Wall(?x)

In this rule, a Wall is identified by the relative bordering relationship with a Floor and a Ground. All directly required elements for this reasoning are either at the semantic level as Floor and Ground, or at the topological level as isBorderTo. This rule only realizes one of several possible situations of identifying a Wall.

Rule of demo (2): BuildingElement(?a) ∧ hasPoints(?a, ?ap1) ∧ hasPoints(?a, ?ap2) ∧ isDifferentPointFrom(?ap1, ?ap2) ∧ pz(?ap1, ?ap1z) ∧ pz(?ap2, ?ap2z) ∧ swrlb:notEqual(?ap1z, ?ap2z) → Wall(?a)

This rule represents the partial knowledge which identifies a not horizontal building object as a potential Wall. This can be used at the early phase of an identification process to initially exclude horizontal building objects from potential wall. In this rule, all directly required elements for reasoning Wall are either at the topological level as hasPoints or at the geometrical view such as isDifferentPointFrom and mathematical computation from SWRL builtins, etc.

Rule of demo (3): isBorderTo(?x, ?y) ∧ Floor(?y) ∧ isBorderTo(?x, ?z) ∧isParallelTo(?y, ?z) → Wall(?x)

This rule is an alternation of knowledge of Rule of demo (1). The section "…Floor(?y) ∧isParallelTo(?y, ?z)…" of Rule of demo (3) is enough to identify z as a horizontal building object of either a Floor or a Ground. The knowledge here is more general than that of Rule of demo (1) where the identification is specifically restricted to a Ground. In this rule, all directly required elements for reasoning Wall are either at the semantic level as Floor or at the Topological level as isBorderTo and isParallelTo.

From these three rules, we summarize semantic characteristics of involved knowledge as follow:

(i) The knowledge supports either final decisions or intermediate decisions in a process.

(ii) The expression scopes of the knowledge may overlap in part. There is possibility that some rules can be replaced by others if both expressiveness and efficiency are not weakened. The empirically employing all these rules may benefit for practical situations where the integrity of the whole knowledge is not strictly guaranteed or is difficult to reach. We will investigate difference of the computation efficiency and propose optimization at next stage of the research.

2) *Refine topological levels towards geometrical levels*

The semantic level identification of a Wall in Rule of demo (1) and Rule of demo (3) may require the topological level knowledge of "isBorderTo" which might be implemented as:

hasPoints(?x, ?px1) ∧ hasPoints(?x, ?px2) ∧ isDifferentPointFrom(?px1, ?px2) ∧ hasPoints(?y, ?py1) ∧ hasPoints(?y, ?py2) ∧ isSamePointTo(?px1, ?py1) ∧ isSamePointTo(?px2, ?py2) → isBorderTo(?x, ?y)

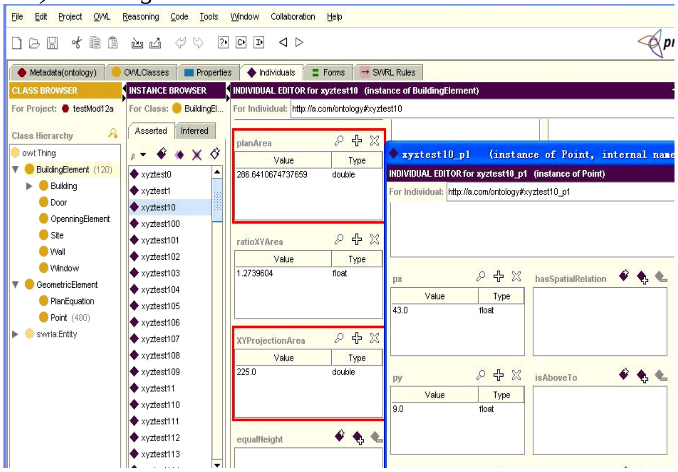
This implementation of "isBorderTo" is only one possible situation of several situations of "isBorderTo". It states the strict situation where two edges of objects x and objects y overlap. More situations can be discovered, validated and added as independent supplement to existing knowledge rules. The computation complexity and optimization is not taken into consideration at this stage of knowledge rules collection.

Similarly the implementation of Rule of demo (2) relies on "isDifferentPointFrom" and "isSamePointTo" which rely on SWRL built-ins. All of these rules are shown here for gaining an intuitive view of potentially knowledge implementations.

B. *Bottom up reasonning*

We are going to explain how knowledge rules are employed for reasoning in a bottom up manner.

1) *From geometrical to semantic levels*



CLASS BROWSER

For Project: testMod12a

Class Hierarchy
- owl:Thing
  - BuildingElement (120)
    - Building
    - Door
    - OpenningElement
    - Site
    - Wall
    - Window
  - GeometricElement
    - PlanEquation
    - Point (480)
  - swrla:Entity

INSTANCE BROWSER

For Class: BuildingEl...

- xyztest0
- xyztest1
- xyztest10
- xyztest100
- xyztest101
- xyztest102
- xyztest103
- xyztest104
- xyztest105
- xyztest106
- xyztest107
- xyztest108
- xyztest109
- xyztest11
- xyztest110
- xyztest111
- xyztest112
- xyztest113

INDIVIDUAL EDITOR for xyztest10 (instance of BuildingElement)

For Individual: http://a.com/ontology#xyztest10

planArea

Value	Type
286.6410674737659	double

ratioXYArea

Value	Type
1.2739604	float

XYProjectionArea

Value	Type
225.0	double

equalHeight

xyztest10_p1 (instance of Point, internal name

INDIVIDUAL EDITOR for xyztest10_p1 (instance of Point)

For Individual: http://a.com/ontology#xyztest10_p1

px

Value	Type
43.0	float

hasSpatialRelation

py

Value	Type
9.0	float

isAboveTo

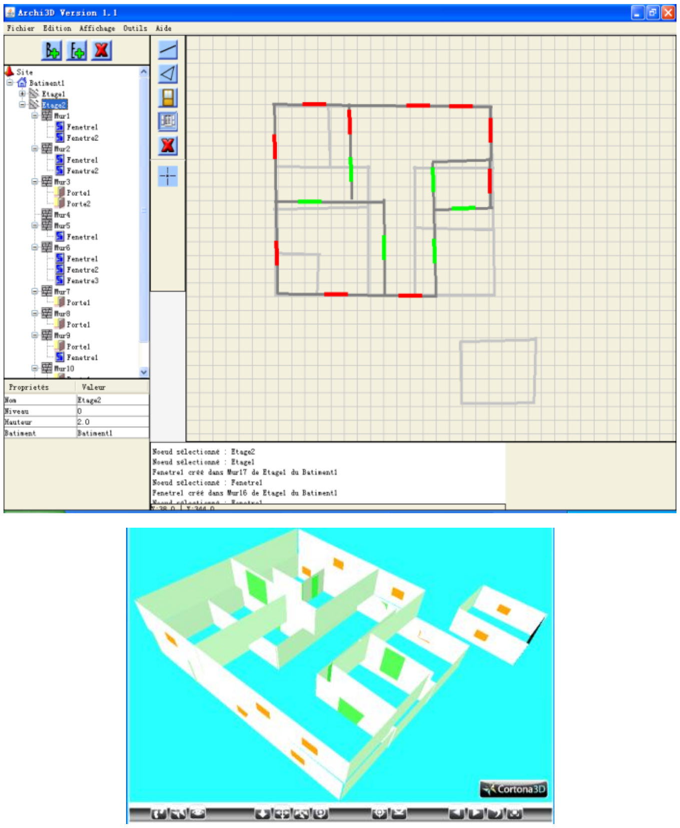
Figure 3. Individual building plans

Figure 4. (a) 120 randomly generated builing plans; (b) initially identified parts of walls and floors in a bottom up manner

The bottom up generation of walls and floors from geometrical to semantic levels are intuitively shown as in Figure 3 and Figure 4. It is proposed to use geometrical knowledge to identify parts of semantic objects of Walls and Floors from random generated building parts. For example, rules compute the ratio of a building plan's projection areas to decide whether a building plan is a potential Wall or a potential Ground among many unidentified plans. Examples of the individual building plans are shown in Figure 3. (a) of Figure 4 shows 120 random generated building plans expressed with Virtual Reality Modeling Language (VRML). By applying

SWRL knowledge rules, a reasoning from the geometrical level to the semantic level will identify the potential Walls and Floors. The identified Floors and Walls as the output are intuitively shown in (b) of Figure 4. The result includes 2 parts of horizontal Floors which are colored with blue and 5 parts of vertical Walls which are colored with red.

2) *From topological to semantic levels*



Proprietés	Valeur
Nom	Etage2
Niveau	0
Hauteur	2.0
Batiment	Batiment1

```
Noeud sélectionné : Etage2
Noeud sélectionné : Etage1
Fenetre1 créé dans Mur17 de Etage1 du Batiment1
Noeud sélectionné : Fenetre1
Fenetre1 créé dans Mur16 de Etage1 du Batiment1
```

Figure 5. (a) creation of topological coarse model with Archi3D; (b) result of bottom up identification from topological to semantic levels

A topological level to semantic level processing example is shown as follows. Firstly a coarse model[3] generation tools called Archi3D is employed for drawing a building group composing of a two-floor multiple room building and an one-floor single room with windows and doors. It is shown in (a) of Figure 5 where walls are colored with grey, doors are colored with green and windows are colored with red. Thereafter it is exported out as topological 3D building elements composing of geometrical 3D points in OWL file format. After importing the OWL file into Protégé, reasoning with SWRL Jess Tab is performed using topological to semantic level reasoning rules to detect the Wall, Floor, Window, and Door, etc. The reasoning process involves several human interactions for organizing relative rule groups for specific reasoning goals. A glance of the final result of the identification can be gained from (b) of Figure 5 where walls are colored with white, doors are colored with green and windows are colored with orange.

C. *On going reorgnization and classification for optimaztion*

The management of the knowledge for 3D building objects reconstruction is a huge and interesting topic which deserves much more efforts. The knowledge could require the mix of bidirectional and relative knowledge rules. Bidirectional rules cover both top down and bottom up manners. Relative rules involve 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.

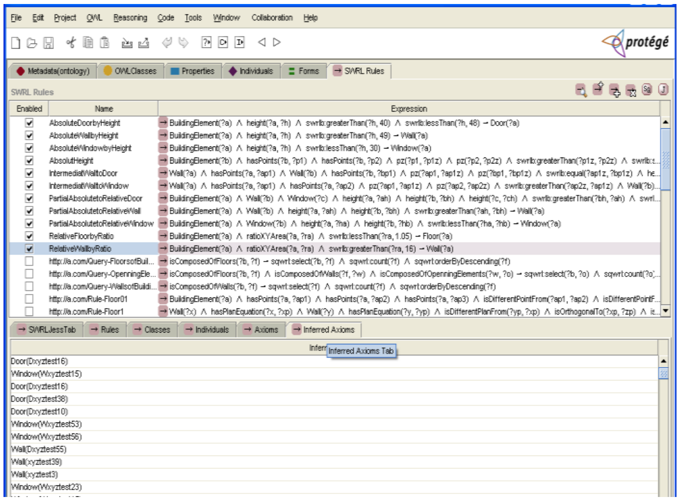
From a systematic and process oriented view of software engineering, much more situations could occur which could demand new types of knowledge and knowledge rules include rules which are used for identifying intermediate relationships or conceptual entities, rules which are used as redundant rules for validating other rules.

TABLE I. ILLUSTRATION OF ORGANIZATION OF RULES AS (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)

For a correct usage and effective optimization on the knowledge represented by the knowledge rules, we believe a good classification is fundamental. We are working on re organization of rules. An initial version is as (absolute vs. relative) vs. (partial vs. whole).

Absolute: the decision is strictly based on the threshold which relies on the parameter which is input manually. Absolute rules refer to rules which rely on the geometrical data, e.g. height value, directly for achieving a conclusion. Relative: the decision is based on the relative ratio differed by {"="/equal, ">"/greater and "<"/less}, etc. Relative rules refer to rules which rely indirectly on geometrical data, e.g. ratio value or the relative topological/semantic relationships, for achieving a conclusion. "partial" characters a rule as not exclusive to the existence of not identical rules for identifying the same target. “whole” characters a rule as exclusive to the existence of not identical rules for identifying the same target. Otherwise than explicitly claimed as “partial”, the rules are taken as “whole” by default. To distinguish the rules which contribute only for intermediate processing at a process from those which conclude as final results, we also introduce “intermediate” as a prefix. A glance of the classification can be gained from Table I. And reasoning process can be viewed from Figure 6.



Enabled	Name	Expression
☑	AbsoluteDoorbyHeight	BuildingElement(?a) ∧ height(?a, ?h) ∧ swrlb:greaterThan(?h, 40) ∧ swrlb:lessThan(?h, 48) → Door(?a)
☑	AbsoluteWallbyHeight	BuildingElement(?a) ∧ height(?a, ?h) ∧ swrlb:greaterThan(?h, 49) → Wall(?a)
☑	AbsoluteWindowbyHeight	BuildingElement(?a) ∧ height(?a, ?h) ∧ swrlb:lessThan(?h, 30) → Window(?a)
☑	AbsolutHeight	BuildingElement(?b) ∧ hasPoints(?b, ?p1) ∧ hasPoints(?b, ?p2) ∧ pz(?p1, ?p1z) ∧ pz(?p2, ?p2z) ∧ swrlb:greaterThan(?p1z, ?p2z) ∧ swrlb:s...
☑	IntermediatWalltoDoor	Wall(?a) ∧ hasPoints(?a, ?ap1) ∧ Wall(?b) ∧ hasPoints(?b, ?bp1) ∧ pz(?ap1, ?ap1z) ∧ pz(?bp1, ?bp1z) ∧ swrlb:equal(?ap1z, ?bp1z) ∧ he...
☑	IntermediatWalltoWindow	Wall(?a) ∧ hasPoints(?a, ?ap1) ∧ hasPoints(?a, ?ap2) ∧ pz(?ap1, ?ap1z) ∧ pz(?ap2, ?ap2z) ∧ swrlb:greaterThan(?ap2z, ?ap1z) ∧ Wall(?b)...
☑	PartialAbsolutetoRelativeDoor	BuildingElement(?a) ∧ Wall(?b) ∧ Window(?c) ∧ height(?a, ?ah) ∧ height(?b, ?bh) ∧ height(?c, ?ch) ∧ swrlb:greaterThan(?bh, ?ah) ∧ swrl...
☑	PartialAbsolutetoRelativeWall	BuildingElement(?a) ∧ Wall(?b) ∧ height(?a, ?ah) ∧ height(?b, ?bh) ∧ swrlb:greaterThan(?ah, ?bh) → Wall(?a)
☑	PartialAbsolutetoRelativeWindow	BuildingElement(?a) ∧ Window(?b) ∧ height(?a, ?ha) ∧ height(?b, ?hb) ∧ swrlb:lessThan(?ha, ?hb) → Window(?a)
☑	RelativeFloorbyRatio	BuildingElement(?a) ∧ ratioXYArea(?a, ?ra) ∧ swrlb:lessThan(?ra, 1.05) → Floor(?a)
☑	RelativeWallbyRatio	BuildingElement(?a) ∧ ratioXYArea(?a, ?ra) ∧ swrlb:greaterThan(?ra, 16) → Wall(?a)
☐	http://a.com/Query-FloorsofBuil...	isComposedOfFloors(?b, ?f) → sqwrl:select(?b, ?f) ∧ sqwrl:count(?f) ∧ sqwrl:orderByDescending(?f)
☐	http://a.com/Query-OpenningEle...	isComposedOfFloors(?b, ?f) ∧ isComposedOfWalls(?f, ?w) ∧ isComposedOfOpenningElements(?w, ?o) → sqwrl:select(?b, ?o) ∧ sqwrl:count(?o)...
☐	http://a.com/Query-WallsofBuildi...	isComposedOfWalls(?b, ?f) → sqwrl:select(?f) ∧ sqwrl:count(?f) ∧ sqwrl:orderByDescending(?f)
☐	http://a.com/Rule-Floor01	BuildingElement(?a) ∧ hasPoints(?a, ?ap1) ∧ hasPoints(?a, ?ap2) ∧ hasPoints(?a, ?ap3) ∧ isDifferentPointFrom(?ap1, ?ap2) ∧ isDifferentPointF...
☐	http://a.com/Rule-Floor1	Wall(?x) ∧ hasPlanEquation(?x, ?xp) ∧ Wall(?y) ∧ hasPlanEquation(?y, ?yp) ∧ isDifferentPlanFrom(?yp, ?xp) ∧ isOrthogonalTo(?xp, ?zp) ∧ is...

Door(Dxyztest16)
Window(Wxyztest15)
Door(Dxyztest16)
Door(Dxyztest38)
Door(Dxyztest10)
Window(Wxyztest53)
Window(Wxyztest56)
Wall(Dxyztest55)
Wall(xyztest39)
Wall(xyztest3)
Window(Wxyztest23)

Figure 6. Reasoning result of the rules “((absolute vs. relative) vs. (partial vs. whole)) vs. intermediate”

Further investigation will detail many practical problems such as that “partial” could be extended as “partial vs. fuzzy” for situations of which the knowledge by itself can be partially true but not sufficient, or need more specific context to justify. We plan to investigate a formal classification in the back ground of CWA (closed world assumption) vs. OWA (open world assumption) [22], [27], [36].

Here we analysis 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.

Also we would like to explicitly explore the dynamic aspect of the semantic: the conversion from absolute computation to relative computation, which is implemented implicitly in the previous description of both top down and bottom up reasoning.

IV. COMPARISON ON TECHNICAL PROCEDURES

Most works which deal with the point cloud gained with 3D laser scanning focus on achieving the visualization related issues ranging from various surface interpolation of creating mesh representation to post-processing operations of smoothing and texturing, etc. A systematic review on the surface reconstruction and visualization problems and solutions from either measured point cloud of photogrammetry or unorganized point clouds toward 3D polygons and shapes are reviewed in [17].

Some semantic processing projects do not relate their works to the processing of 3D point clouds. The closest work to Archi3D which explicitly adopts semantic for scene interpretation and object detection of building semantic maps is described in [2]. Firstly a method called 6D SLAM [2] which compose a Iterative Closest Points (ICP) algorithm and heuristics to register the data of the point cloud from multiple scanners in a consistent manner. Then plane extraction on the point set proceeds with RANSAC (Random Sample Consensus) algorithm [39] with ICP optimization. Labeling is performed with background knowledge which is represented in a constraint network [1]. The constraint network contains mainly relative and transitive binary relationships which are mainly geometrical between two objects. Prolog is used to implement the constraint network solver with unification and backtracking. During this stage, basic building elements are labeled out. After this stage, the 3D range and reflectance data is transformed into 2D images by off-screen rendering for detecting and localizing objects with a contour based approach [38] and cascade classifiers [37], e.g., Support Vector Machines (SVM), with the help of sensors.

Archi3D bases the plan extraction on a least squares estimation algorithm. Compared to the work [2], Archi3D does not limit the attainable knowledge to the scope of geometrical. Instead, it makes full use of the semantically expressiveness of NL terms and DL to integrate all kinds of knowledge and properly deploys/organizes them for civil reconstruction purposes. Based on an OWL ontology and SWRL rules, the processing of Archi3Dcontains not only bottom up [2] processing from point cloud to planes and objects subsequently, but also the top down [21] supports from objects to planes with the aid of a pre-drawn parameter-less coarse model (CM) [3]. The CM contains not only labeled features but also part of the objects definition information. The top down direction adopted by Archi3D coincidences with the future direction claimed by [2] as mostly unexplored “main direction of the work ahead”. The semantic reasoning supports both classes’ level and instances’ level as what is proposed in [2]. Work [2] has also argued and demonstrated the relative advantage of semantic feature based labeling in contrast to direct labeling from point cloud such as in [40].

V. CONCLUSION AND FUTURE WORKS

This paper presented an innovative solution to perform the technical survey of a building using a 3D scanner to obtain a digital model in IFC format. This solution is based on detection algorithms of building elements and semantic rules to characterize the detected elements and to drive the research of new objects from the point cloud.

This work concerns both the image processing domain and the semantic Web domain. These two domains are combined and the semantic definition of coarse model drives the geometrical analysis of the point cloud. When objects are identified, semantic rules are used to drive a new analysis of the point cloud to detect other existing objects connected to the previous one.

Now our proposal is limited by the definition of bounds between identified objects. For example a windows detected by the image processing algorithms can be inside a wall or inside a door. This knowledge doesn’t change the nature of the wall but could change the nature of the door which becomes a patio door. We hope to resolve these problems in the next 6 months.

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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