

[Architectural] Reasoning over BIM/CAD Database

How to combine reasoning powered ontologies with BIM/CAD tools (and vice-versa?)

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Abstract. *Design activity is pervasive as it is increasingly expanding into all sectors and every day it is increasingly difficult to anticipate the often unpredictable changes resulting from new inventions and changes in technology, tools, methods and social customs using current design systems, and at the same time we need to preserve and store knowledge and experiences that can help facing aforementioned problems. The present paper illustrates an innovative Rule Layer overlying existing commercial software in order to model Reasoning and Performance verification Rules to be applied to design instances. The authors developed two different prototypes, one on BIM and one on CAD commercial software in order to validate the proposed approach. Results demonstrate the general system potentials opened up to further research development and deepening.*

Keywords. *Building ontologies; building design reasoning; BIM/CAD; collaborative design.*

INTERLEAVED WORLD

Comparing our “era” with the past, people in developed countries obviously live in better conditions than before due to the organization of society and technological evolution. On the other hand, sociality has been replaced by competitiveness, mainly as a result of increasing complexity and changing needs that require new approaches in all human activities in order to meet increasing demands (Einstein 2006).

The problems are mainly related to the ‘idea’ of science and science law we have. In the past, our general conceptual elaborations were based on Thirties period. That time all academic institutions

in the world completely absorbed what was elaborated from most advanced scientific and philosophy researches: the importance of science (also social) facts, of measurable quantities, referred to phenomena expressed in mathematical-analytical formulas.

Hence fundamental science courses were taught, on which ‘objective’ base the following disciplines were set up. This ‘functional’ logic characterized scientific as well as humanistic Schools.

In short: avant-gardes inquired into “first” principles until the First World War; afterwards, the results of these researches were applied to well limited scopes. It was usual to describe phenomena by

means of first order theories (superposition of effects) in application domains precisely defined (limit conditions).

However, in the middle of last century new studies and ever-growing specializations have led scientific communities to verify that many phenomena could not be explained by means of these two assumptions. We discovered that also apparently simple phenomena are interrelated with context so belong to the category of Complexity, the right approach to these studies is a multi- and cross-disciplinary ones and very often only Chaos theory can explain them. We passed from mathematical formulae expressed by means of multiplications and logarithms to system of integrals with not exact solution, but partial derivative differential equation solutions; lastly concepts can be computed thanks to performative computer systems.

Referring to Building Design Tools, the evolution from paper and pencil to CAD systems, to Object Oriented Systems and ultimately to BIM platforms has led, step by step, to new design methodology and consequently to different design results. As a matter of facts, these methodologies and tools together with new social and architectural sensibilities influenced and in turn were influenced by current contemporary buildings and also by high performing ones as shown in architectural masterpieces of archistars like Eisenman, Gehry, Toyo Ito, Fuksas, etc.

CAD systems and their three-orthogonal coordinates systems have certainly supported the design process in building representation but have also indirectly influenced generations of architects and designers as far as space configuration and overall building design are concerned. These systems were used to represent only geometry, 2D or 3D and sometimes tagged entities to specify space destination or specific entity meaning.

Object-oriented Systems and actual BIM platforms allowed another step to be taken towards Design and Process Support Tools: each represented entity has a recognizable tag linking it to a general concept and a set of properties that contribute to meaningfully defining the designed building com-

ponent, space, 4D and 5D design process.

In the contemporary world, which is increasingly linked to reduced distances in terms of space, language and, sometimes, even culture, humans are evolving (or counter-evolving) into users connected by emails, social networks, news and any other web-based sources.

All these social links among different users contrast with the exponential increase in specialization of professionals in their own domain: as stated by Simon: "Once a profession reaches the point where it takes 10 years to master, it tends to break up into specializations".

In Architectural Design processes, many different specialist domains are involved as well as several specialist designers in their respective fields. These are changing the twentieth century-related design approaches made up of functionality verification, client requirement checking, cost control and time scheduling, cross disciplinary expertise into increasingly narrow specializations and knowledge sectoralisation, under the effect of increasing technology complexity and discipline multiplication.

Nowadays buildings are evolving into "smart" buildings, control panels substitute light switches, sensors will ultimately allow program building services to adjust performance to suit changing environmental conditions, forms will change according to weather, climate or use functions.

However, resources are limited, costs are out of control in a blurred economic, technical and social context, and sustainability becomes a necessity, not just a possibility.

In order to allow different Specialists to collaborate in a Design Process in an effective and productive way, the present abstract presents a prototype structure for an innovative design tool, a *System* that adds a Reasoning and Performance Layer to existing BIM and CAD software.

BUILDING DESIGN SUPPORT TOOL

Existing BIM software systems are evolving into Collaborative BIM environments: different domains are combined into a single software or several con-

nected software families; user interfaces are changing into domain-oriented GUIs that adapt to suit the target user.

The actual design activity is increasingly being extended into all sectors and every day it is more and more difficult to try and foresee the often unpredictable changes resulting from new inventions and changes in technology, tools, methods and social customs using existing design support tools.

In addition, client needs, requirements and constraints are becoming more specific day by day (for instance, real estate societies) and designers have to continuously check out their own design solutions in order to fulfill certain domain expectations.

Each Specialist Designer with her/his own expertise uses 'personal reasoning rules' in order to develop her/his own design solution.

In order to verify specialist domain constraints and general overall design consistency, coherence and congruence, "on-the-fly" performance verification systems are needed.

The proposed Layer is complementary to existing BIM and CAD software in order to support on-the-fly designers, allowing them to model their respective constraints, verification algorithms and checking rules at different levels (Beetz et al. 2006; Fioravanti et al., 2012):

- Internal Domain Private Rule Verification: Actors model their own rules in order to check the on-going design solution in their own personal specialist domain;
- Internal Domain Shared Rule Verification: Actors check rules shared by other actors involved their own private design solution in order to check for possible conflicts with a different specialist domains;
- Collaborative Rule Verification: in the Shared Design Workspace (Loffreda and Fioravanti, 2009) performance/verification and checking rules shared by all the actors involved in the specific design process are performed in order to evaluate and check out the proposed design solution (with input needs and requirements).

PROPOSED SYSTEM STRUCTURE: A MIXED MODEL

Referring to previous research results (Fioravanti et al., 2011a; 2011b) the proposed Design Support Tool combines existing software tools with a system composed of developed routines and Knowledge Structures. The research analyzed and tested several software(s), although the proposed system uses the following components:

- Autodesk Revit 2013: BIM software for Private and Shared Design Workspace Interface;
- Protégé OWL 3.4.8 (Frames): Ontology Editor for Knowledge Modelling in terms of Hierarchy, Properties and Entity Relationships;
- Semantic Web Rules Language Plug-in: Protégé plug-in for Rule Modelling on Ontology Entity Representation based on predicate logic formalization;
- Jess Rules: an ontology reasoner for rule checking and verification [1];
- Revit DB: a tool for Revit projects exported into a Database;
- Oracle MySQL: a relational database management system.

In order to validate the proposed research, authors developed ad hoc plug-ins, software add-ons and tools to connect Knowledge Structures implemented in OWL with Autodesk commercial software.

This link with CAD software expresses proposed platform potentials and also opens up fresh discussion on future developments:

- Link with existing commercial software with its limits and constraints due to its proprietary nature;
- Enterprise system development including "ad-hoc" and/or open-source graphical representation systems.

Reasoning results could affect the geometrical aspects of the modeled entities, but due to the "proprietary" nature of Autodesk Revit 2013, it is not possible to interact with geometrical properties on built-in Families from external software, not even from the Database via the Revit DB Link.

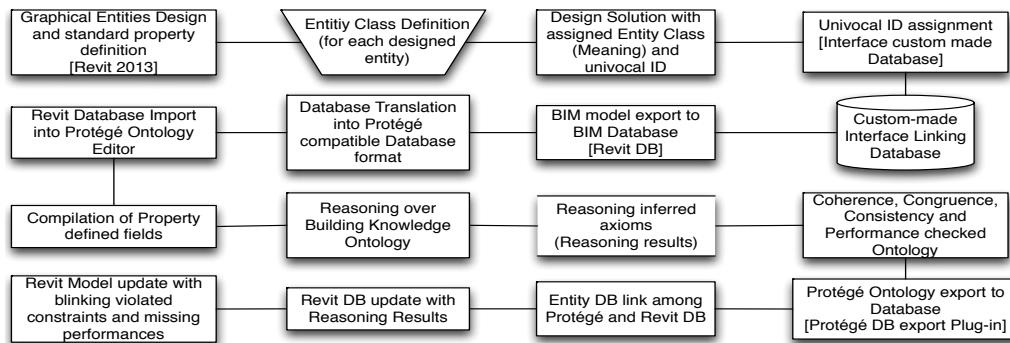


Figure 1
Design process Flowchart.

PROPOSED SYSTEM IMPLEMENTATION WITH BIM

Phase 1: Knowledge and Rule Modeling

In order to represent Building Knowledge Entities, a specific Design Ontology has been developed. It has been structured with reference to a Meanings-Properties-Rules Template devised by the authors and implemented by means of a Protégé Ontology Editor.

Entities description, properties, relationships and hierarchical structure have been modeled by means of predicate logics (Hofstadter, 1979) and ontology formalization [2]; the Knowledge Representation allows queries and constraint verification by means of specific reasoner and rules formalization in Semantic Web Rules Language (SWRL).

In order to interrogate Design Solutions, Ontology Rules have been implemented and tested on prototype instances of developed Ontology Classes: a hospital ward has been modeled both in terms of general entity Classes and testing instances (spaces and components) (Calvanese et al., 2008); moreover SWRL rules have been formalized to check specialist domain constraints:

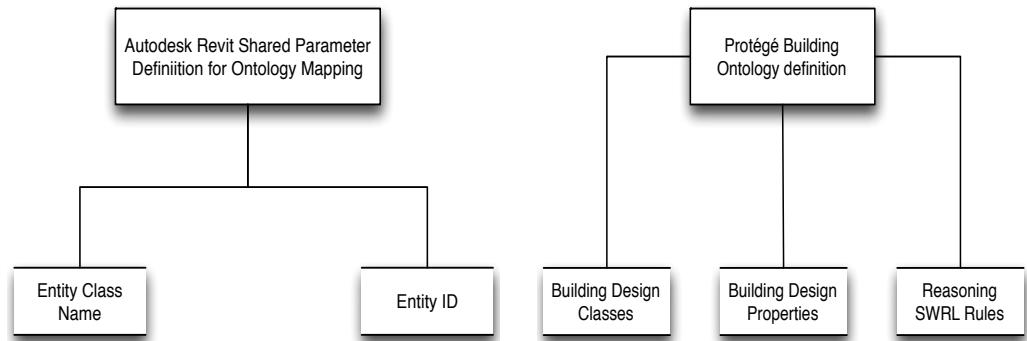
- Space configuration and topological relationships among spaces;
- Furniture and equipment provided for each building unit;
- MEP system, Structural elements and Space configuration compatibility.

Phase 2: Building Design Process workflow

The proposed prototype concept has been conceived of as a sequence of necessary steps (Figure 1) that are transparent to final users (designers).

1. Actors develop their own design solution by means of Autodesk Revit 2013;
2. Specific Revit shared parameters have been defined in order to specify Ontology Class and IDs for each designed Revit entity (Figure 2);
3. BIM Design Solutions include only BIM entities and properties; that implies: no space semantic definitions, no specialist domain properties, no rules;
4. BIM model is exported to a Database by means of Revit DBLink;
5. An open-source database MySQL is created in order to interrogate the exported database;
6. An ad hoc Linking Database has been created in order to connect exported Revit DB (Revit data) and Protégé Ontology Instances (Knowledge Entities);
7. Respecting Protégé Database exporting format, Knowledge entities are instantiated and property fields filled in with available values from Revit designed entities;
8. The DB obtained represents a combination of Knowledge and Graphical Entities in an Ontology query-able format;
9. By means of modelled SWRL rules, constraints, performance, consistency, coherence and congruence verification can be performed;

Figure 2
Autodesk Revit 2013 and
Protégé Frames 3.4.8 customi-
zation.



10. SWRL inferred axioms can be checked and verified by each Specialist Designer;
11. By means of Protégé “Export to Database” command, an inferred Entity Database is created;
12. The Revit Database is then updated with new values and definition from the inferred Entity Protégé Database by means of the developed Linking Database.

Due to the proprietary nature of Autodesk Revit, even if Reasoning Rules in Protégé may possibly affect geometrical properties modifying and/or adding values, Revit does not allow them to be changed because they are System Parameters and it is not possible to edit them out of Revit itself.

Due to this limitation, in order to validate the proposed system, the authors implemented plugins and add-ons for AutoCAD® which allows interaction with the DXF drawing format.

PROPOSED SYSTEM IMPLEMENTATION WITH CAD

Phase 1: Knowledge and Rules Modeling

Knowledge Ontology modeled by means of Protégé for the above-mentioned test has been modified in order to allow further prototype tests on the proposed system.

AreaXY property has been linked to Product class and its sub-classes and several has_xn (with n from 1 to 8) have been linked to classes in order to specify 2D geometrical instance definition.

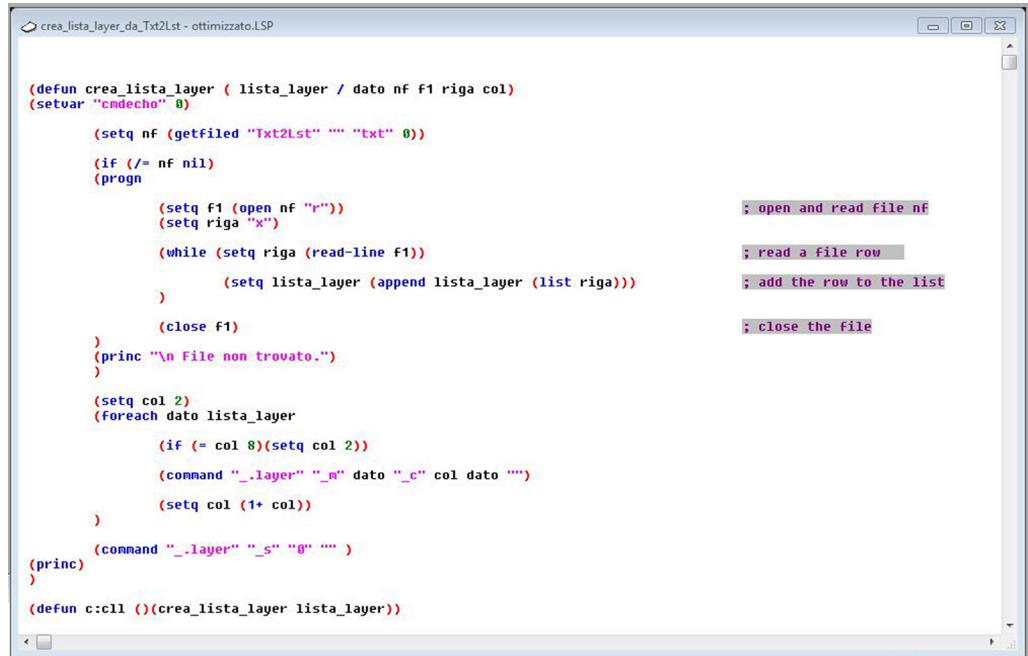
The CAD prototype refers to AutoCAD® for graphical representation and is limited to lines and 8-vertex polylines representation to suit the modeled knowledge structure.

Phase 2: Building Design Process workflow

The following workflow shows the step-by-step implemented prototype:

1. Launch Protégé Ontology Editor with classes, properties and rules definition;
2. Query Tab launch: classes list (Figure 3);
3. Class List Export in a TXT file;
4. Autodesk AutoCAD Launch;
5. AutoLisp implemented application launch for automatic Layer creation with layer name equivalent to class name (Figure 4);
6. Design solution representation by means of 2D lines and/or (at most) 8 vertex polylines;
7. Design solution saved as DXF format file;
8. A specific software has been implemented in order to parse the saved DXF file and then to create as many CSV files as the layers used. Each CSV file will contain as many rows as elements are present in corresponding layer in DXF file, separating the element features with a semicolon, for example sake:
 - Instance type: Line or LwPolyline;
 - Handle: unique AutoCAD® ID;
 - numVertex: number of instance vertex (only for polyline definition)
 - has_xn-has_yn: (with n from 1 to 8) x and

Figure 4
Autodesk Visual LISP Editor.
Autodesk AutoCad Layer crea-
tion program.



```
crea_lista_layer_da_Txt2Lst - ottimizzato.LSP

(defun crea_lista_layer ( lista_layer / dato nf f1 riga col)
  (setvar "cmdecho" 0)

  (setq nf (getfiled "Txt2Lst" "" "txt" 0))
  (if (/= nf nil)
    (progn
      (setq f1 (open nf "r"))
      (setq riga "x")
      (while (setq riga (read-line f1))
        (setq lista_layer (append lista_layer (list riga)))
      )
      (close f1)
    )
    (princ "\n File non trovato.")
  )

  (setq col 2)
  (foreach dato lista_layer
    (if (= col 8)(setq col 2))
    (command "_layer" "n" dato "c" col dato "")
    (setq col (1+ col))
  )
  (command "_layer" "s" "g" "")
  (princ)
)

(defun c:cll ()(crea_lista_layer lista_layer))
```

CONCLUSIONS

The system prototype illustrates an innovative approach to Building Design Support Tools by means of a mixed model using commercial application programs, ontology management systems and custom-made reasoning rules, database and interface tools.

A set of existing BIM software, Knowledge Representation systems and Database improves existing commercial software, enhancing definition and the modeling of building design.

In order to develop an innovative, powerful, scalable and useful design support system, the authors implemented an ad-hoc Linking Database interfacing previous modeled Design Knowledge Structures (ontology classes and properties) (Fioravanti et al., 2011) with Revit Entity Database. Afterwards SWRL Rules can allow the combined (Knowledge and Graphic) Database Ontology to be queried in order to perform consistency, coherence, congruence and performance verification on design solutions.

Due to the proprietary nature of Revit®, first prototype implementation did not allow the Revit designed entity to be modified even though the authors used specific Revit add-ons and extensions. According to these limitations and in order to validate theories and design process logic, the authors developed a second prototype based on CAD software.

This approach allowed a different design process workflow definition; plug-ins identification and specific program implementation help check constraints and design reasoning rule results affecting 2D CAD developed design solutions and demonstrating the overall system potentials.

Tests showed that it is possible to enhance existing commercial software by applying on top of them a Reasoning Layer which includes Specialist and/or Common Rules, expertise and Building Performance verification.

Each involved Actor will then be able to model



Figure 5
Protégé OWL 3.4.8 Ontology
Editor. SWRL Testing Rule
definition.

as many rules as needed in the specific “on-the-fly” design process checking:

- Personal Specialist Domain consistency and internal coherence;
- Other Domain Rules congruence;
- Overall Design Verification and Client Needs fulfillment.

This system represents an on-the-fly tool for Specialist Designers designed to suit Client needs and to correct the on-going design process according to performance and requirements goals.

The implementation of the system shows its potentiality in proposing a new generation of Design Tools that allows further research development and deepening.

As far as its scalability is concerned, the proposed tool is easily applicable to other Knowledge “Realms” aimed at improving different Design and Collaborative Processes in order to enhance knowledge sharing, innovation spreading and collaborative problem solving.

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