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An Upper Abstraction Layer for '*Reasoning*' on CAAD Tools – *Two interfaces*

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Abstract: New inventions and changes in technology and methodologies affect design activity frequently resulting in unpredictable effects on the final design solution, hence on the real outcome - unsatisfactory buildings. To avoid these consequences, it is necessary to store and exploit ever-growing knowledge and experiences that allow these problems to be overcome. An innovative 'Abstraction Layer' overlying existing application programs has been introduced to model a *Reasoner* that verifies the coherence of design solutions. This one has been developed by means of an entity class based on ontologies at semantic level, not data. This paper explains how the *Reasoner* prototype is linked with usual CAAD and BIM tools in order to demonstrate the insight. This research is mainly related with architectural and construction design - but can also be applied to many sectors.

1. Introduction – Sociality vs. Specialization in contemporary world

The present paper shows specific results referred to reasoning and logic rules applied on building knowledge entities, which represent a limited part of wider author's ongoing research on Collaborative design support tools.

First, an analysis of the evolving scenario in architecture and building design is presented, afterwards, a deep and focused approach on existing design tools is discussed presenting potential and limits of CAAD and BIM technologies.

In order to add an effective support tool and to overcome the limits of existing commercial design software an innovative '*Reasoner*' complementary to existing BIM and CAAD software is proposed.

The main objective of the '*Reasoner*' is to on-the-fly support designers allowing them to model constraints, to check Codes and to verify the design coherence related to stated needs. The '*Reasoner*' has been developed with two interfaces: for BIM (Building Information Modelling) and for CAAD (Computer Aided Architectural Design) ones.

The paper presents implemented algorithms and reasoning rules developed to validate the proposed approaches.

Nowadays people in developed countries live in better conditions than in the past due to the organization of society and technological evolution. On the other hand, sociality has been replaced by competitiveness, mainly because of increasing complexity and changing needs that require new approaches in all human activities in order to meet ever-growing needs [1].

Referring to Building Design Tools, the evolution from paper and pencil to CAAD 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 [2]. As a matter of facts, these methodologies and tools together with new social and architectural sensibilities

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influenced and in turn were influenced by current contemporary buildings and also by high performing ones as shown in architectural masterpieces of arch stars.

CAAD 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 component, 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 H.A. Simon: “Once a profession reaches the point where it takes 10 years to master, it tends to break up into specializations” [3].

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 sectorialization, 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 Level to existing BIM and CAAD software.

2. Objectives – Design Support Tools: limits and needs

Existing BIM software systems are evolving into Collaborative BIM environments: different domains are combined into single software or several connected software families; user interfaces are changing into domain-oriented GUIs that adapt to suit the target user.

Design activity is pervasive as it is increasingly expanding 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.

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 fulfil 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 *Reasoning Layer* is complementary to existing BIM (Fig. 1) and CAAD software in order to support on-the-fly designers, allowing them to model their respective constraints, verification algorithms and checking rules at different levels [4], [5]:

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, [6]; 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).

3. Methodology – A new "Mixed" System for Architectural Design

The present research bases on our vision of Collaborative Design systems [7, 8, 9]; the overall research leads to an innovative platform to reduce misunderstanding among different specialist actors involved in design process [10] and to promote an aware design by means of spreading appropriate explicit knowledge [11].

Continuing our research results the proposed Design Support Tool combines existing software tools with a system composed of developed routines and Structured Knowledge.

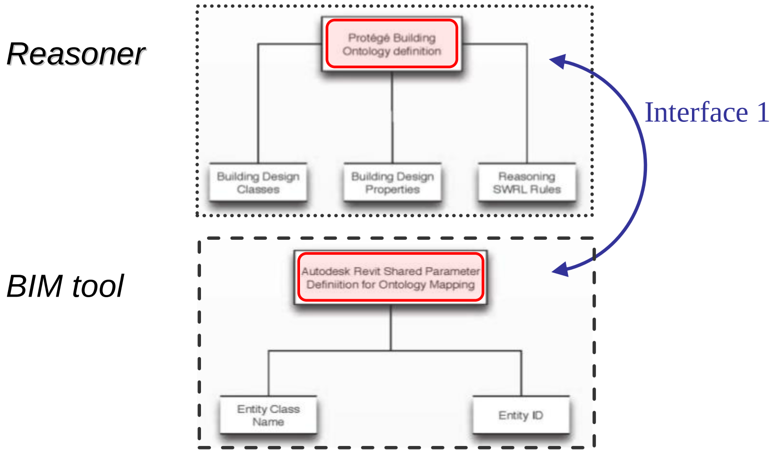

Figure 1: The Reasoning Layer *is Complementary to Existing BIM tools – Interface 1.*

The research analysed and tested several software(s), although the proposed system (prototype) 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 [12];
- Revit DB: a tool for Revit projects exported into a Database;
- Oracle MySQL: a relational database management system.

The accomplished research has been validated by means of developing ad hoc plug-ins, software add-ons and tools to connect Structured Knowledge (implemented in OWL) with Autodesk commercial software.

This link with CAAD 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 modelled 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.

4. Technology –Interface 1: Implementing a Semantic Layer over a BIM

4.1 Architectural Knowledge - its Model and Formalized Rules

In order to represent Building Knowledge Entities, a specific Design Ontology has been developed and implemented. It has been structured by means of a triplet "Meanings-Properties-Rules" template devised by authors and implemented by Protégé Ontology Editor [13].

Entities description, properties, relationships and hierarchical structure have been modelled by means of predicate logics [14] and of ontology formalization (data and metadata formalization); the Knowledge Representation allows queries and constraint verification by means of a specific *reasoner* and rules formalized 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 modelled both in terms of general entity Classes and testing instances (spaces and components) [15]; 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.

4.2 Developments 1 – The Architectural Design Process Implementation

The prototype concept has been conceived of – and afterwards modelled - as a sequence of necessary steps (Fig. 2) that are transparent to designers.

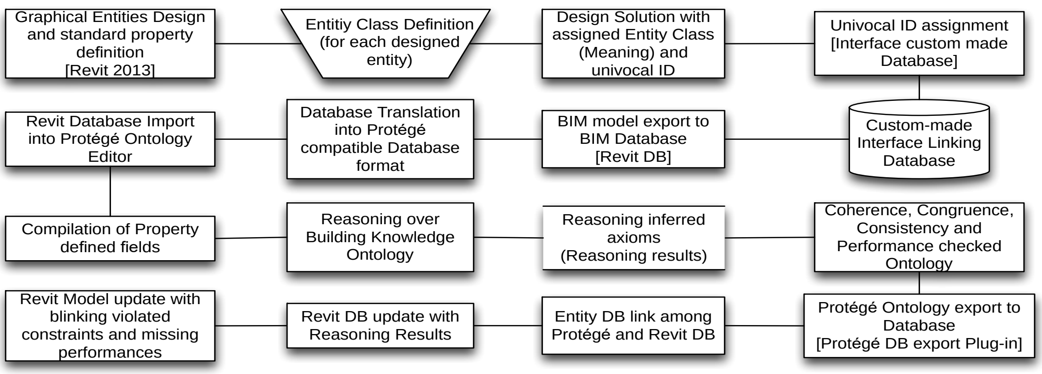

Figure 2: Building Design Process Flowchart

1. Designers 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 (Fig. 3);

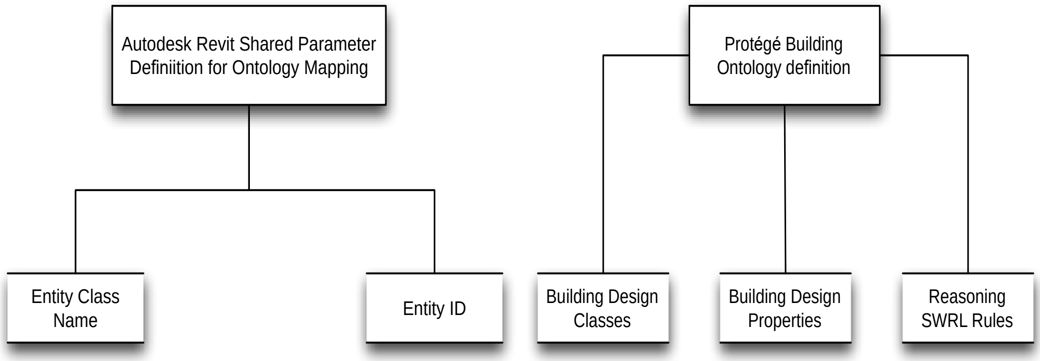

Figure 3: Autodesk Revit 2013 and Protégé OWL 3.4.8 (Frames) Customization

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 query 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;
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.

5. Technology –Interface 2: – Implementing a Semantic Layer over a CAAD

5.1 Architectural Knowledge - its Model and Formalized Rules

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

5.2 Developments 2 – The Architectural Design Process Implementation

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 (Fig. 4);

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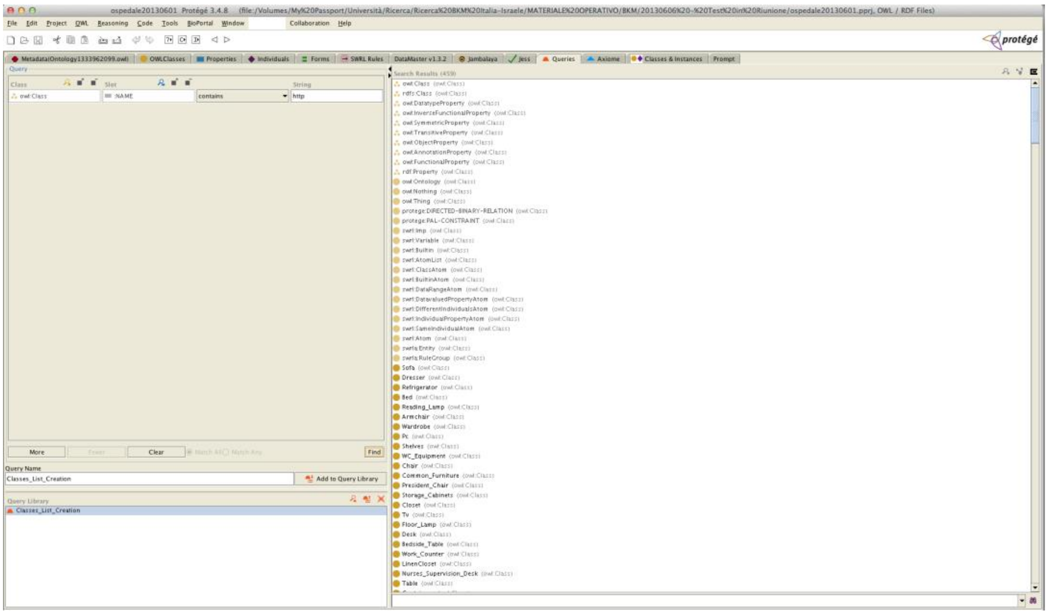

Figure 4: Protégé OWL 3.4.8 Ontology Editor: Query Tab Class List Result

3. Class List Export in a TXT file;
4. Autodesk AutoCAD Launch (tested on 2013, 2014 and 2015 versions);
5. AutoLisp implemented application launch for automatic Layer creation with layer name equivalent to class name (Fig. 5);

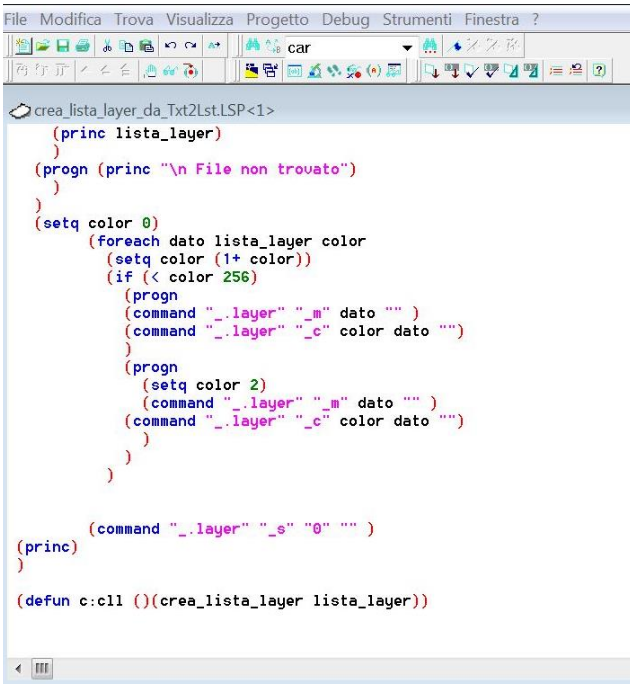

Figure 5: Autodesk Visual LISP Editor. Autodesk AutoCAD Layer Creation Script

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 y vertex coordinates;

9. In order to facilitate DB content management, the CSV files obtained are merged into a single Microsoft Access® DB, importing each CSV into a different table of the database;
10. ODBC DNS system link with the created DB;
11. Protégé and DataMaster v.1.3.2 Launch: allows the linked DB to be connected and the existing tables can then be imported into the existing ontology;
12. By setting Datamaster import under Thing, the system will automatically create as many instances as there are rows on each table as a subclass of related Class with name equal to the table name. As a result of the previous steps, the table name will correspond to the ontology class name so that instances will inherit knowledge properties and rules definition including also geometrical values obtained by AutoCAD® representation;
13. A testing Design Rule was implemented by means of SWRL in order to validate proposed system potentials. The testing rule checks all the Room instances and verifies whether the bounding windows area is greater than room area/8 (Fig. 6);

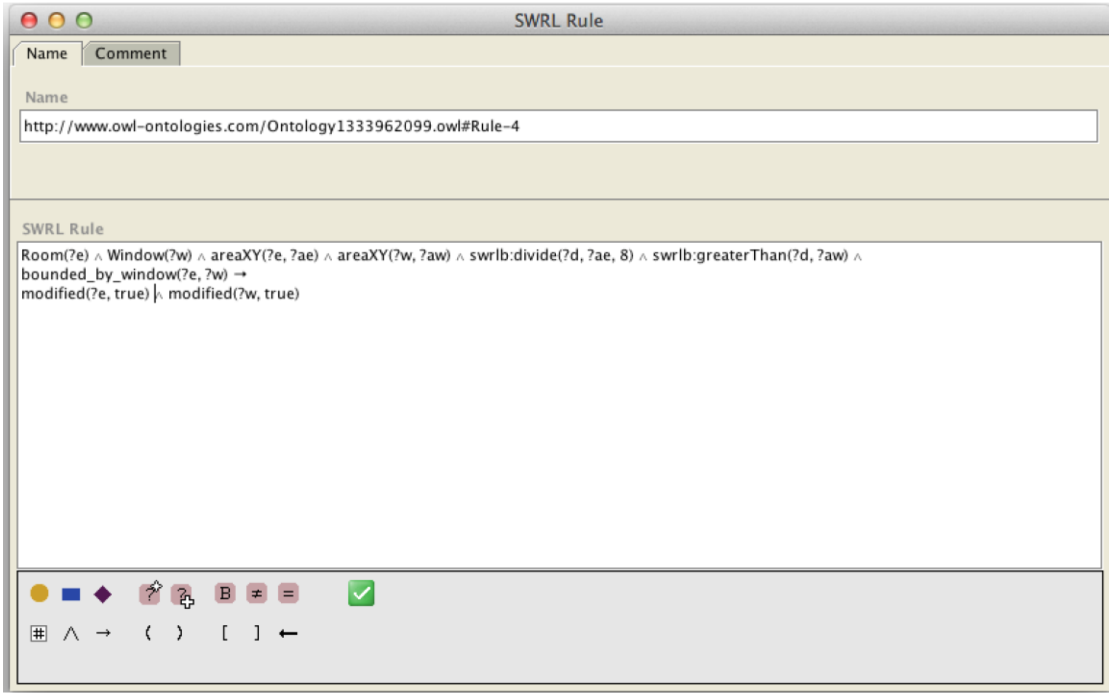

Figure 6: Protégé OWL 3.4.8 Ontology Editor. SWRL Testing Rule Definition

14. Reasoning rules are applied by means of the Jess Rules [12] reasoner and, according to rules definition, unverified instances will have the Boolean modified property set to true.
15. Query Tab launch: at this stage it is possible to search for all instances with modified Boolean property set to true;
16. It is then possible to export the modified Instances List as a txt file with handle property associated values;
17. By means of some other developed software, the system will check the previous created DXF file, compare it with exported txt file and modify the entities colours to Red if the handle in dxf is present also in the exported txt modified entities list.

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6. Results and 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, leverages existing commercial software, enhancing the definition and the modelling 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 modelled Architectural Design Structured Knowledge (ontology classes and properties) [11], 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 verifications on the design solutions.

Due to the proprietary nature of Revit®, first prototype implementation did not allow the Revit designed entity to be modified – interactively and on real-time: that is *Proactive design* - 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 CAAD 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 CAAD 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 Level*, which includes Specialist and/or Common Rules, expertise and Building Performance verifications.

Each involved Actor will then be able to model as many rules as he needs in the specific "on-the-fly" design check process:

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

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 for a new generation of Design Tools that allows further research development and deepening.

As far as its scalability is concerned, the 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.

Another field where the system can be applied is the academia one as students are forced to formalize their knowledge and then test it on a project together (or not) knowledge formalized by other students.

The ultimate aim of the presented knowledge-based system is to improve building design overall quality by enhancing design choice awareness: improving the process to improve the product.

At present the proposed general template has been implemented on a limited but sufficiently representative number of building entities by means of current ontology editing systems in order to be used, checked and verified into teaching courses.

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