An Ontology-based Knowledge Representation Model for Cross-Disciplinary Building Design

A General Template

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Abstract: *Process/product complexity is at present an unavoidable component of present building design approach that affects building product's quality. To overcome this problem, effective collaboration is required among all the actors involved in the design process. Data and information exchange is not sufficient to guarantee mutual understanding; to support effective collaboration among actors; it is required a proper knowledge formalization and management. This paper reports on an innovative structure for knowledge modeling in cross-disciplinary building design, that has been formalized in a general template. The proposed Knowledge Model has been, at present, implemented by means of available ontology editors and is going to be used into teaching courses to check its efficiency in collaborative building design classes.*

Keywords: *Building design; collaboration; knowledge modeling; knowledge management.*

The scientific context

Architectural Design is at present a complex activity as it involves numerous disciplines and increasing needs. It extends increasingly into all sectors involving the building artifact as it is necessary to try and foresee the often unpredictable changes resulting from new inventions and changes in technology, tools, methods and social customs: Design is horizontal and all-pervasive vis-à-vis the problems.

Building design process is directly affected by the increasing complexity and the quality of the building obtained through this type of process is too often unsatisfactory in terms of formal results, of the failure to achieve the technical and functional objectives, of excessive energy consumption, of unsustainable environmental impact, and of cost and time overruns. The inadequacy of the routine design methods and techniques used in the building sector, both in educational and professional context, makes it very difficult to correctly understand the information associated with the entities that make up the design solutions.

Collaboration among all the actors involved in a design process is considered to be the main road to solve these problems. A/E/C collaborative design can be supported by computing tools based on knowledge, namely related to the conceptual structure of the building organism, closely linked to the design process (Carrara and Fioravanti, 2002).

To be computed and shared, knowledge has to be machine and designer's use oriented, formalized and managed.

Several different research groups tried to improve collaboration among actors involved in the design process developing different building design support systems. The main result of this kind of researches pointed out the identification of the "core problems": 'how to correctly and effectively define knowledge modelling and management systems at all the different complexity levels of building objects' (Gero and Kannengiesser, 2004; Carrara and Fioravanti, 2007; Jeong and Trento, 2008).

As a matter of fact, the correct formalization of the information exchanged is still an open problem: currently the excess of low level information exchanged, which is both the cause and the effect of the potential of new ICT, implies the simplification ('semantic impoverishment') of the information exchanged, thus leading to incomprehension among the actors and to a step backwards as regards effective communication among them.

The present research, referring to the collaborative working environment developed by the authors, focuses on an innovative general template for knowledge modeling (Figure 1). An explicit and structured knowledge includes the formal definition of building entities and their properties, together with well-defined formal rules. It allows logical-mathematical models to perform behaviour simulation and interpretation of the design solutions while facilitating reasoning in intelligent systems (Ugwua et al, 2005).

Actually the entities involved are generally represented by often dimensionless, symbolic graphic signs and jargon filled technical reports. No entity has any intrinsic meaning, but merely the one it has in the cultural, scientific and professional contexts it is situated in. Therefore the only way to give it a meaning is by an accompanying informative-explicative attachment.

Any of the abovementioned entities correspond to specific logical concepts which contain very little - often non-existent - meaning, even though they may possess an excellent figurativeness.

It is thus an exclusive task of the actors to 'translate' meanings, perceive differences among different versions, carry out comparisons among different

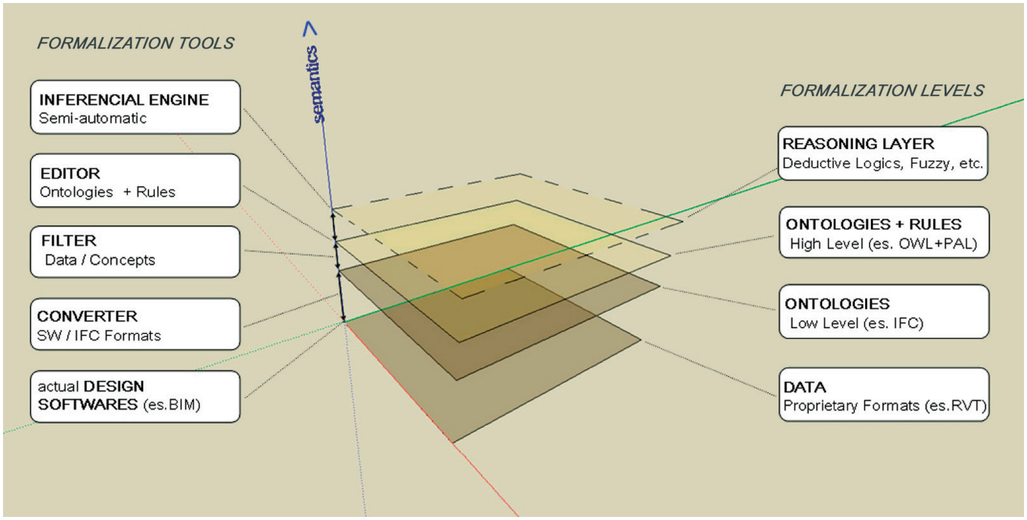
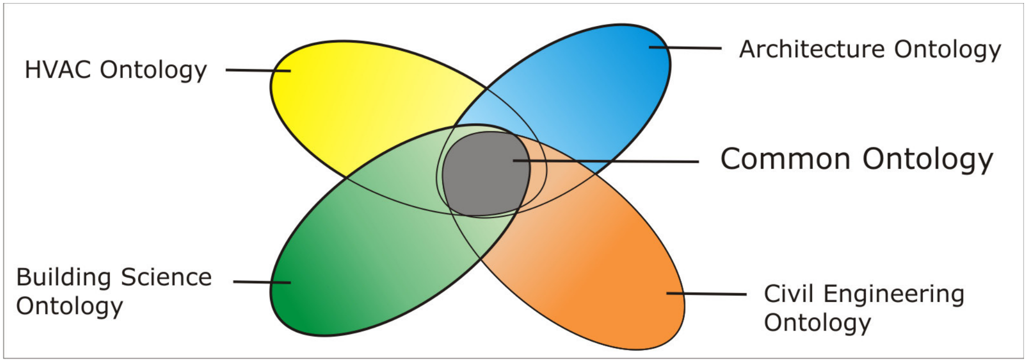


Figure 1
Logical structure of design knowledge representation and management

Figure 2
Common Ontology as the intersection set of Specialist Ontology



solutions, and point out conflicts and contradictions. All this hinders an easy and efficient collaboration among them (Carrara et al., 2004).

The representation of the product's model as a whole is thus a complex task as it has to be highly structured and in the meantime has to be poor enough ("lean" model) to be understandable by all.

The here presented general template allows the formalization of all knowledge related to each entity involved in the design process as an element of the Building Object Ontology (including both any kind of Spaces and Components). By means of an 'assembly process' and an 'enrichment process', as below specified, the general template is able to represent any integrated knowledge. The proposed innovative Knowledge Structure Model is set forth to achieve the objective of a new collaborative environment in which actors can share not only data, but also all related concepts and all knowledge attached to any entities involved in any specific design process (Loffreda, 2008; Carrara et al., 2009).

The general template of knowledge representation

The present work is focused on a new way of modelling building entities to create a collaborative and participative environment on which different specialist actors, client and final users can meet to share knowledge, targets and constraints to better gain the aimed result. In this context it is here presented a 'general template' of Knowledge Modeling to support collaboration in a building design process.

This extremely compact template allows a dynamic recursive approach to knowledge formalization, being able to be used for representing extremely simple entities as well as highly complex entities made of as many low-level entities as necessary.

Any entities part of the Common Building Ontology (including any kinds of Spaces and Components common to any actor of a design process) will be contextually present in the Specialist Ontology embracing the entities related to a specialist actor - as many as the disciplinary domains involved in the specific design process (Figure 2).

At any level of complexity any building entity will be represented by means of a Knowledge Structure, modeled by means of the here presented template, that allows to formalize all concepts, data and relationships related to it.

Any entity will be represented both in a 'Common Knowledge Structure' and in all the 'Specialist Knowledge Structures', connected through the so called Filter-mechanism allowing semantic enrichment by means of procedures, methods and algorithms. (Carrara et al., 2004).

Al all complexity/abstraction levels the Knowledge Model can be considered as a sort of the 'knowledge gene' of the considered building entity. This one, assembled with other entities through an

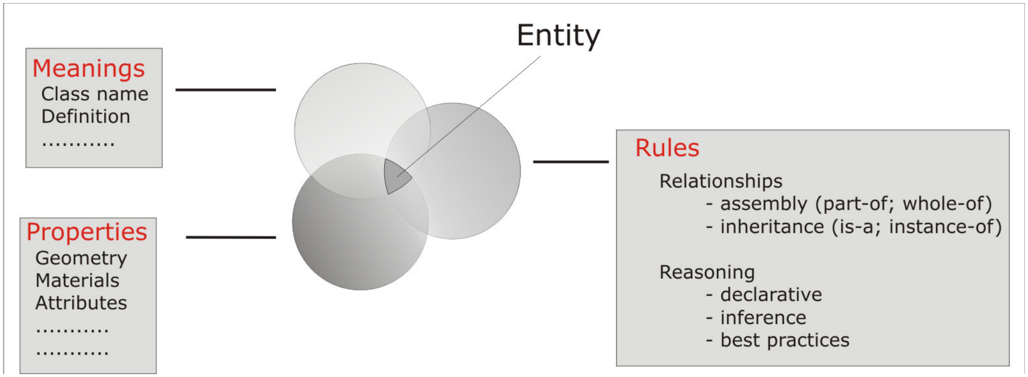


Figure 3
General features of entities

'assembly mechanism', will build up the design solution, whose set of 'genes' will constitute the 'knowledge genome' of the final product.

The proposed template for knowledge modeling is able to represent any building entities by different actors' perspective: architects as well as engineers up to client and users by using this model can represent entities in terms of 'their' meanings (specialist and maybe different for each of them), properties and rules, by this way being allowed to point out requirements and intents (Figure 3).

Any entity involved in the design process will thus consist of three formalized main features representing the synthesis of the necessary concepts needed to represent it (Table 1):

- Meanings
- Properties
- Rules

Meanings:

Are all and the only ones referred to the Building Ontology and will include all the declarative aspects associated to the entity's meaning:

- class name,
- definition/s agreed by all the actors involved in the considered Ontology: (General Building Ontology and/or Specialist Building Ontology).

This implies that all knowledge represented a Knowledge Structures is directly referred to the entities included in the considered Ontology, to which all the disciplinary concepts, methods and tools for designing and evaluating them are connected.

The Knowledge Model, even at the 'meaning' level, is flexible, dynamic and rule-dependant so, according to context, constraints, targets, and end-users' needs, meanings associated to entities can change, pointing out inconsistencies and violated constraints to the actors.

Both Common Meaning and Specialist Meanings are affected by the context in which the entity is located; on the basis of checking systems activation, the entity formalization will become more proper to the context.

For instance, a 'window' will be associated to a class name (Window) and to multiple definitions (not exhaustive) dependant on different context on which it could be used: it could be defined as an internal-external interface or as a transparent surface on a wall (architectural context); it could be defined as an "thermal transmission weak point" (energy context); or as an uniform load on a wall or on a beam (structural context); and/or as many more definitions as many the specific design process will need.

It will be utopian to formalize all the possible definition for each entity and, overall, it will exclude any chance to creative design approach.

Creativity can so be defined in this context as the ability to point out innovative, useful and efficient "meanings" attributed to each entity in specific design contexts.

Properties:

Include all the descriptive/behavioral aspects related to the considered entity:

- geometrical properties (shapes, sizes, dimensions),
- physical properties (materials and related attributes),
- behavioral properties (related to structure, energy, acoustics, lighting, etc) defined by means of specific values associated to attributes.

These ones can be computed through suitable methods, algorithms and or procedures including:

a. entity algorithm formalization: simple mathematical operations for computing values by means of other known parameters of the same entity,
b. calculation methods: more complex operations which are affected by parameters/values of other entities involved in the same design solution,
c. algorithms and external software: complex operations which need external software or complex algorithms to be well determined; external software will be activated by parameters and/or values and/or rules present in the same formal representation and by means of iterative simulations and procedures.

Rules:

Represent the "linking synapses" among each entity and the many different ones with which it is related to within the design assembly, spreading itself over the whole knowledge structure of the building design solution.

This kind of interleaved network is made of two basic types: relationship rules and reasoning rules.

Relationship rules among the entities can be:

- links between lower level entities and a higher complexity entity as results of multiple entities' assembly, or the other way around (Part-Of, Whole-Of);
- hierarchical relationships ruling entity generality stratifications in terms of Father/Son, Prototype/Instance ('Is-A', 'Instance-Of').

Reasoning rules can be made of:

- algorithms and formal codes for analyzing, checking and evaluating concepts associated to specific entities with inferential procedures of 'If-Then' type.
- context dependant rules referred to the in force law that will become constraints for the entities which they are related to;
- consistency rules: algorithms to check the consistency of values, parameters, attributes, instances, relationships and properties referring to the specific meanings associated to each entity in the specific context on which it is used;
- empirical rules, best practice codes and concepts that represent part of the reasoning process of any actor on his/her own specific disciplinary domain during the design process.

By means of a 'deductive layer' able to match rules among the considered entities belonging to the same ontology the system will allow the designers to use in a coherent manner different levels of abstraction and to exploit a real interoperability of concepts (Calvanese et al., 2008).

Coupling current problems with past experiences actors can be acknowledged ahead of time what will be the implications of their proposed action.

The here presented Knowledge Model, in order to enhance knowledge sharing and to improve collaboration among actors, allows two different design approaches that can be interactively and iteratively operated as the most suitable in the specific case:

- declarative design: the entities are first defined in terms of meanings, requirements and performances; then the entities will become instantiated by filling in all the values required and by establishing links, relationships and rules between them; a geometrical model of the design solution is represented on the basis of the geometrical properties associated to any entity;
- deductive design: geometric representation is the first step of this design approach; at any stage of the design process any actor associates meanings, properties, rules to each geometrically defined entity. In this case, some of the values

Table 1
Knowledge Representation Template

Class	**"name"**			
Meaning				
Definition	"descriptive definition of the class"			
name	is a	*"super-class _ 1"*		
		"super-class _ 2"		
		"super-class _ 3"		
		"super-class _ n"		
Properties				
name	has a	*"attribute name _1"*	type	*"attribute type _ 1"*
		"attribute name _2ù"	type	*"attribute type _ 2"*
		"attribute name _3"	type	*"attribute type _ 3"*
		"attribute name _n"	type	*"attribute type _ n"*
Rules				
name	has	*"relationship name _ 1"*	with	*"class/es name related to the present class"*
		"relationship name _ 2"	with	*"class/es name related to the present class"*
		"relationship name _ 3"	with	*"class/es name related to the present class"*
		"relationship name _ n"	with	*"class/es name related to the present class"*
name	in the relationship	*"relationship name _ 1"*	must soddisfy	*"condition/rule _ 1"*
		"relationship name _ 2"		*"condition _ 2"*
		"relationship name _ 3"		*"condition/rule _ 3"*
		"relationship name _ n"		*"condition/rule _ n"*

required by the Knowledge Structure could be deducted by the geometrical representation.

The added value of the present Knowledge Model refers to two main levels:

- at the specialist level the right formalization of each actor's specialist knowledge helps him/her on his/her private workspace checking coherency, congruence and consistency of the ongoing design solution;
- at the shared knowledge level (common knowledge) the possibility to check and verify each private design solution against all the ones made by other actors points out critical nodes, conflicts and possible solutions helping reduce costs and time overruns. By means of the formalized Knowledge Structure collaboration, intended as "problem sharing", is enhanced as common concepts and entities are shared and agreed by all the actors involved, helping avoid misunderstandings and lacks of data. By the so achieved acknowledgement of other's problems any actor can eventually propose design solutions not only within his/her own specific disciplinary domain, but also related to others' domains.

Conclusions

The presented model, result of many years spent on this field by the research group, is the core of a knowledge representation and management system that, by virtue of the interoperability established among the various semantic universes, aims at enhancing the level and the quality of the exchanged information while leaves unchanged the operating modes the designers are accustomed to.

By means of it any actors will be allowed to work using their own personal methods, algorithms, software and tools to represent and manage the complexity of their own instance as a solution of their own design problem, and to resolve contradictions working in their own specific (specialist) design workspace.

The ultimate aim of the presented Knowledge Model is to improve building design overall quality by actually enhancing collaboration among all actors involved in the design process: 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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