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Edited by Henri Achten, Jiří Pavliček, Jaroslav Hulín, Dana Matějovská

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Digital Physicality

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Building-Use Knowledge Representation for Architectural Design

An ontology-based implementation

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Abstract. *During building design processes, designers have to predict and evaluate future building performances oriented to its intended use and users. Current BIM and IFC technologies support designers allowing data exchange and information interoperability but, since their lack in semantics, they don't provide any knowledge implementation about how the designed building will be actually used and how people will interact with it. The research described in this paper aims to overcome this shortcoming by developing a new modelling approach, oriented to representation and management of knowledge related to future building use and users. The proposed representation model is based on an already accepted ontology-based structure and will make this large amount of knowledge accessible and usable by designers during architectural design processes, in order to enhance the final quality of the design product.*
Keywords. *Design Knowledge Representation and Management; Ontology-based Systems; Building Use Process; Building Performances prediction and evaluation.*

INTRODUCTION

Quality, according to Pirsig's (1981) universal statements, does not belong to the object itself, nor to the subject itself, but to both and to their interactions. In architecture it is terribly true as we have a Building Object and Man/Women that interacts with it (Fioravanti et al., 2011 p. 185).

In a Building Object even if it were very well "formed" in its spaces and technology elements and it were correctly addressed by Relation Structure towards goals, its success would depend on its concrete use. Just for instance the Marcello's Theatre in Rome was (and it still is) actually used as a residential building or the Musée national d'art moderne - Centre Georges Pompidou in Paris is used by visitors and district inhabitants - just for exhibition -, as the public square under the building was never opened because of terrorist attach fear.

How people "live" a building, their holistic sensation passing through and around its spaces and the perceived quality, relies on two aspects:

- Functional ones – anthropometric movements and perceptions –, f.i. can be represented by Relation Structure and Inference Engines;
- Soul ones - personal believes and social and cultural habits, f.i. can be represented by agent-based models simulating single human behaviours.

The present paper mainly refers to the first aspect of human user behaviour in living buildings and the corresponding knowledge modelling it for a better architectural design process.

In order to improve the quality of a design product, a central task for a multidisciplinary team is to test the proposed design solution, predicting its future performances before, during and after its passage from digital model to real world and vice versa: Digital Physicality | Physical Digitality.

Designers know very well the importance of how the building is modelled in order to manage the design process and to enhance their control on the final product quality.

The advent of BIM technologies and their pervasive diffusion in the professional design studios are introducing an interesting modification of designer habits, extending their capacity to deal with problems and manage conflicts during the building process (feasibility, design, construction, maintenance, use, demolition or re-use phases).

At base of this "designers' thinking change" is the fact that the decision making process – multidisciplinary, complex and for some aspects highly recursive – relies on the way product/process related knowledge is modelled in the usual CAD design tools.

Studying the most common standards in this field (IFC), we can observe that these classes have been developed by means of a **space-components product approach**, successful in terms of data exchange and information interoperability between programs, but not intended for human understanding.

This lack of semantics mainly affects the modelled buildings efficacy when it is required to represent and predict its behaviour in terms of usage, safety and comfort.

At the same time, it's important to consider that, beside the product knowledge representation and its aforementioned deficiencies, what is missing is the representation of **design process knowledge** and how to capitalise such a knowledge.

More specifically, the prediction of future building use by means of the actual standards, tools and technologies is still an open problem, that challenges knowledge engineers and building designers since long time.

Is a matter of fact that human behaviour representation, and its related knowledge management, is a problem that has been faced with more efforts in other research fields such as military operational management or videogames industry.

The aim of this research is the development of a new approach for modelling process knowledge, specifically about building use and user's behaviour in order to make it accessible and able to support performances simulation.

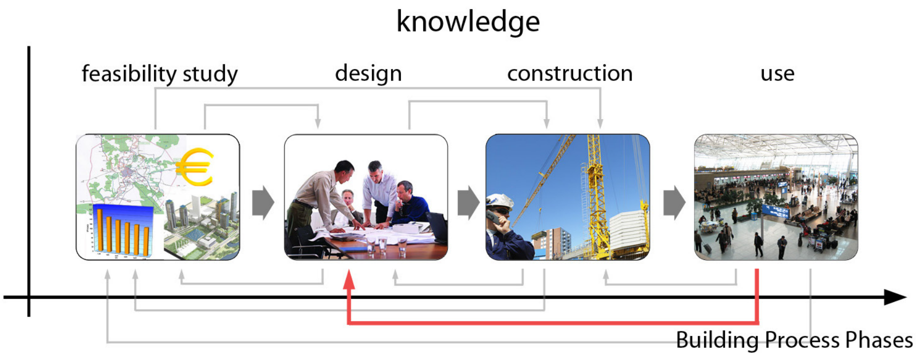

Figure 1
Capitalizing Knowledge - Forward and Feed-back knowledge in the building process. In red the present paper subject: building use and architectural design.

Final goal has two main beneficiaries:

- Building designer, whose awareness can be enhanced, since s/he can learn from formalised user's behaviour;
- Building user, that can obtain a better comprehension of her/his interaction with building spaces, and learn how to correctly use them.

This paper reports on advancements achieved in such a direction in terms of theoretical contents and some early implementations developed in the general framework of an on-going, funded International Research.

REPRESENTING USERS-RELATED KNOWLEDGE BY MEANS OF ONTOLOGY

Planners traditional approach conceives in the overlapping of planned processes, usually based on general and consolidated knowledge, to an architectural schema (Wurzer, 2009, 2010).Technical norms and regulations, best practices and, most of all, personal level of expertise, have partially supported designers in evaluating the impact of their design choices on life and 'experience' of building users. Despite that, the increasing complexity of building design in both product and process, the rapid change of how people act in a built environment and their activities because of the introduction of new tools and technologies, and the birth of new design paradigms – the sustainability just to mention maybe the main one – have shown all the limitations of these ways to implement knowledge about users. In addition, the non-deterministic and not a-priori definable nature of human behaviour, its context dependence and its general complexity make the prediction task very daunting for designers, leaving them just the possibility to count on their own, often limited and biased, understanding of use phenomenon.

To provide a reliable, comprehensive and up-to-date knowledge base on human-building interaction, we thought of relying on a general structure for knowledge representation already presented and discussed among the scientific community by this research group (Carrara et al., 2009) and work to extend its application field to our purpose.

This comprehensive model of architectural design process (Fioravanti et al., 2011) is illustrated by means of a symbolic "knowledge tetrahedron" during the design process (Fig. 2). It makes explicit the "Time" feature: the four knowledge Realms, namely Product, Actor, Context and Process 'shape' the Design Solution during $t \div t1$ time period, representing the states of the system and its dynamic variations of state during the design process.

As of its high abstraction level and its comprehensive universal approach, the same model can be easily extended from the design process to all the following phases of building life cycle: feasibility study, design, construction, use. In fact, representing the knowledge related to building during its use, the realms proposed are still fully valid, while the part of knowledge considered for each of them is different from the design process phase. In this case the Actors Realm comprises knowledge about the future users, their profiles, their attributes; the Procedures

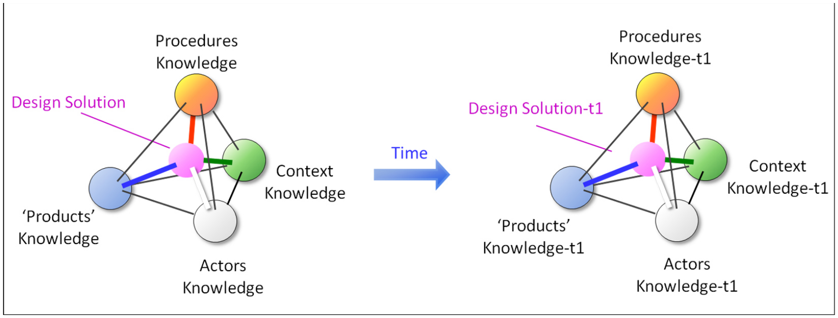

Figure 2
A comprehensive model of architectural design process: knowledge tetrahedron.

Realm is where is formalized the knowledge about the actual process of use of the building, in terms of structured systems of activities, their requirements, their last and so on; in the Context Realm are represented data on how the process of use will be affected by context status (meant in a broad sense involving social, cultural and economic aspects) – for instance if the same product is conceived to be built in different parts of the world, inevitably it will be used in a different way and perceived in different customs–; the Product Realm will contain knowledge about building response to use, as whole and in all its entities (spaces, components, etc. and their use modalities and specifications).

This general representation model is linked to a specific knowledge structure oriented to formalization and description of single entities composing the design product (spaces, building components, furniture, equipment, etc.) freezing the control on the other knowledge realms, context, actor and process. Each entity is represented in its main features and in its relations with other entities by means of the 'knowledge template (Carrara et al., 2009) based on the already discussed "Meaning-Properties-Rules" structure.

Starting from this representation model, already applied to represent a building design solution, but not studied to support the testing of its performances while-in-use, the new challenge is to extend it to representation of human behaviour in building in order to manage such information in a CAD environment. An implementation of such knowledge domains will give designers the possibility to count, during the analysis, synthesis and evaluation phases of design process, on:

1. a reliable, specific and up-to-date knowledge about how the building will be used;
2. a strong system of data as hypotheses for dynamic simulation of behavioural phenomenon happening in the building-in-use process.

THE PROPOSED APPROACH

Use process in the ontology-based model

Several researches have shown the capability of ontology-based representation systems in supporting collaboration among different specialists during the design process (references). The template for knowledge modelling previously proposed by our research group is able to represent the design solution

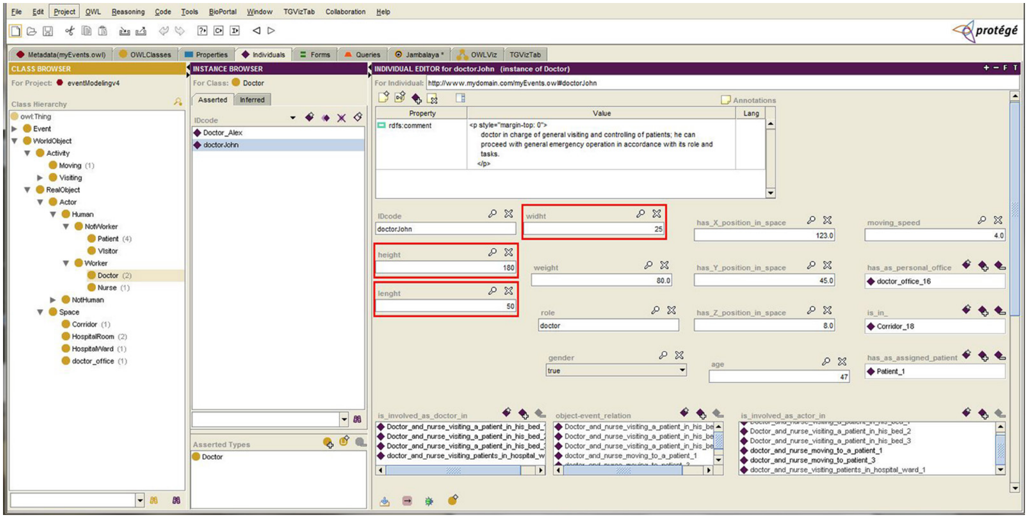

Figure 3
Representation of a user's profile by means of ontologies, in protégé environment.

as a whole by means of formalization of knowledge related to all its entities (spaces and components). At present, this approach provides just a static representation of the building, without providing necessary information about how the future building will interact with its process of use, in terms of actors involved and activities performed.

On other hand, the accepted "Meaning-Properties-Rules" structure, with its ability to model both real objects and abstract concepts, is applicable to the representation not only of product-related entities, but also of all those entities involved in the definition of the building use process (users with their profiles, activities, other resources involved, etc.).
Furthermore, process-related entities and product-related entities cannot easily be structured and linked each other because of their heterogeneity; the ontology-based approach (and in particular the Meaning-Properties-Rules structure) can address this problem offering a common, homogeneous way of representation of such entities (Fig.3).

The result of such approach is a 'knowledge structure" composed by a set of entities representing both the design product in its space-component elements, and the process of use, in terms of users involved and activities performed in a standard use scenario. While BIM and IFC have a strong capability in representing geometrical values of product entities, they are "semantically poor", and don't allow the implementation of knowledge related to building use processes. The ontology-based system proposed can overcome this lack in representation providing a semantic network in which all the entities involved in the definition of the design product and of the building functioning can be integrated and connected.

Ontologies model and simulation

The above proposed model can support designers during the phase of definition of a partial or final design solution; nevertheless, this is not sufficient to guarantee that the design solution will really interact as expected with users during its functioning. As matter of fact, human behaviour in building is a hardly predictable phenomenon because of its dynamic features, and the strong influence of users' *libero arbitrio*, context (in a broad sense) status, stochastic components, etc. Narrative and simulative approaches have been developed in the last years to dynamically represent specific aspects of the process of building use (Yan,2004; Koutamanis,1996; Cenani, 2008), but their results normally consisted in a simulation of very specific aspects of users' behaviour (such as fire egress, pedestrian movement), based on a limited set of initial hypotheses.

At central core of this research is the idea to use the ontology-based model to provide all the hypotheses needed for the effective testing and simulation of the process of use. It provides a formalized, well-defined system of knowledge representing:

1. the built environment in all its parts (spaces, building components, furniture, equipment, etc.;
2. the system of users, their profiles, their attributes;
3. the system of activities to be performed, both taken as single entities, and as structure sequences and network of them to represent the developing of the process of use.

The whole model representing these elements is the result of the design process: the product obtained in the synthesis phase and ready to be evaluated in its effective use features.

Integration between a semantic model representing both environment and its intended use and users, and a dynamic calculator able to simulate how this will overlap, match and affect each other, will be able to provide a more reliable and comprehensive prediction of building future use during a certain span of time. The results of this simulation will be a virtual, general phenomenon that designers could measure, threat and evaluate in accordance with their specific objectives. As results, designers will be able to intervene on the design solution in order to solve critical points, inconsistency, unexpected functioning without really stepping into the construction process.

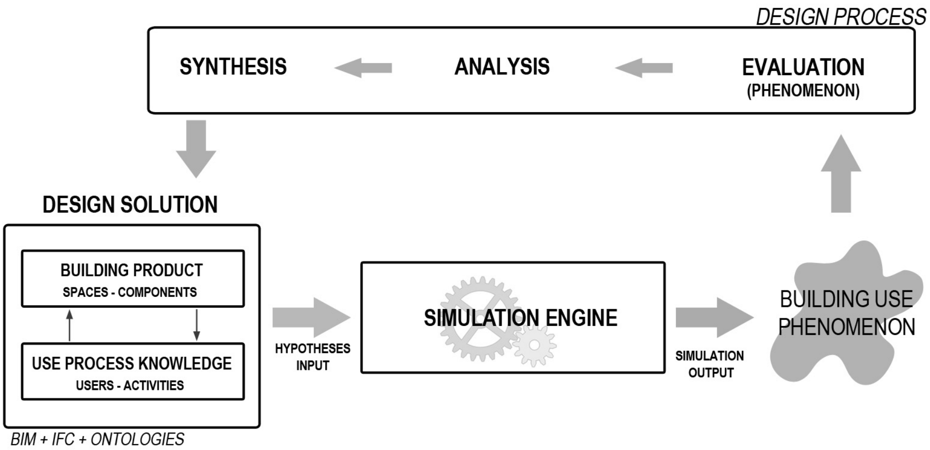

Figure 4
The design process supported by building use simulation.

IMPLEMENTATION PROCESS AND EXPECTED RESULTS

For implementing this theoretical model, we are using the ontology technologies in order to model the product and use process entities, physical or abstract, and their space-time relationships structured by means of meanings, properties (defining their state) and rules (relations, reasoning rules, consistency, best practices).

Analysis, checking, evaluation and control of concepts associated to specific entities is performed by means of inferential engines, with deductive 'If-Then' type procedures.

A system of engines – matching rules among the ontologies – will work on a deductive layer overlapped at the actual BIM level, allowing the designers to use in a coherent manner different levels of abstraction, or to exploit a conceptual interoperability.

The implementation steps are namely:

1. represent Design Knowledge of Use Process Ontologies (e.g. expressed in OWL language by means of ontology editors, e.g. Protégé);
2. connect Ontologies with actual BIM, or IFC (by means of API, or using Beetz (2009) transcription of IFC in OWL language);
3. connect BIM + Ontologies with a Narrative management environment (e.g. Virtools, etc.);
4. explore and find out in the semantic web community or build inference engine to perform the user's behaviour in the building.

The dynamic and semantically-specific representation performing human behaviour simulation will detect coherent/favourable situations by means of a constraint rule mechanism, allowing be highlighting and managing in real time.

At the same time it allows actors to make alternatives, more consciously reflecting on the consequences of their intents. By this way the impact of a networked ontology-based system makes actors more aware of overall design problems and allows them to operate more participative and to share choices and experiences.

CONCLUSIONS

Ontology technologies do not belong to the present generation of commercial building design tool. At the same time it's a fact how easily today we can model a structured domain ontology.

This paper proposes how – in a very general case study – ontology reasoning can be an efficient automatic resource for assisting actors (human or software agents) in decision making process along recursive building design sessions, performing event based simulation of human behaviour in a defined building environment.

At present the proposed general framework has been only partially implemented: it can count on a limited but sufficiently representative number of building entities formalized by means of current ontology editing systems in order to be used for design reasoning, using the large family of ready-built inference engines and information extraction, checking and verification facilities developed in the last few years by a growing international community.

Research work is planned to develop various software agents, in particular prototypes to simulate integrated collaborative hospital design.

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DIGITAL PHYSICALITY

vol. 1

Digital Physicality is the first volume of the conference proceedings of the 30th eCAADe conference, held from 12–14 September 2012 in Prague at the Faculty of Architecture of Czech Technical University in Prague. Physicality means that digital models increasingly incorporate information and knowledge of the world. This extends beyond material and component databases of building materials, but involves time, construction knowledge, material properties, space logic, people behaviour, and so on. Digital models therefore, are as much about our understanding of the world as they are about design support. Physical is no longer the opposite part of digital models. Models and reality are partly digital and partly physical. The implication of this condition is not clear however, and it is necessary to investigate its potential. New strategies are necessary that acknowledge the synergetic qualities of the physical and the digital. This is not limited to our designs but it also influences the process, methods, and what or how we teach.

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