

Human Activity Modelling Performed by Means of Use Process Ontologies

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Abstract. *Quality, according to Pirsig's 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 Users that interact with it. The problem we approach here, renouncing at the impossible task of modelling the actor's "libero arbitrio", focuses on defining a set of occurrences, which dynamically happen in the built environment. If organized in a proper way, use process knowledge allows planners/designers to represent usage scenario, predicting activity inconsistencies and evaluating the building performance in terms of user experience.*

With the aim of improving both, the quality of buildings and the user experience, this research explores a method for linking process and product ontologies, formalized to support logic synchronization between software for planning functional activities and software for authoring design of infrastructures.

Keywords. *Design knowledge modelling; process ontology; knowledge management.*

AEC INDUSTRY AND INFORMATION MODELS

The approach / methodology called Product Information Modelling (PIM), historically consolidated throughout the industrial world, is typical of serial systems. In the last decades, the PIM has proven its robustness and effectiveness even in the most complex areas, characterized by the uniqueness of the product, such as automotive, aero-spatial, etc..

Its final object, towards which this PIM production system, is realised by means of a unique process, characterized by low seriality. In the last decades, this production system revealed their experimentations to be successful with repeatable, optimizable and personal solution, the so-called mass customization.

The PIM operates by manufacturing prototype products and then contextualizing its instances

through the re-modulation of its structural general "core" adjusting it with little variations relevant to specific production requirements.

Through a slow process of technological transfer, still in early stages, PIM was introduced about ten years ago in the AEC industry, starting the so-called Building Information Modelling (BIM).

Well known peculiarities of AEC industry constitutes an important challenge for BIM approach, which in turn is a method / tool able to innovate this sector - central to the European economy - especially in a time of crisis like the current one.

In many European countries, governments pushed an industrial policy based on BIM, because the crisis in the sector has not only a financial nature, but, especially, an industrial nature. Moreover inef-

iciencies of property and infrastructure investments affect the public finances, even if current spending is much more relevant.

Through BIM which is accompanied by a more efficient information management, the sector may acquire a production quality typical of more mature industries.

The efforts of the community identified as International Alliance for Interoperability (IAI), established by scientific communities in partnership with key players in the commercial sector, in the last 10 years aimed at establishing BIM standards for the use of object technology in construction and facilities management.

These standards, known as Industry Foundation Classes (IFC) are now contained within the most comprehensive model of design, construction and Facility Management information yet created. All the main software developers in this industry segment worldwide are committed to producing IFC-compliant software.

Studying the IFCs structure, we can observe that they have been developed by means of a space-components product approach, successful in terms of data exchange and information interoperability between programs, not intended for human understanding. This lack of semantics is reflected in the modelled buildings, once it is required to simulate its behaviour in terms of usage, safety and comfort.

More specifically, to predict human behaviour in a building during its usage, by means of the actual standards, tools and technologies is an urgent open problem which challenges knowledge engineers and building designers since long time. As well it involves a lot of resources in terms of industrial research and developments in the fields of army and videogames.

FUNCTIONAL PROGRAM VS. BUILDING PRODUCT DESIGN

A shared goal, typical of all AEC industry products, is to functionally facilitate its direct and indirect users' activities, being aesthetically pleasing (Fioravanti et al., 2011a, p. 185).

In order to get this overall performance, buildings and cities behaviour has to meet various technical and non-technical requirements (physical as well as psychological) placed upon them by owners, users and society at large.

Research in this field will be seeking to reduce the gap between technology and society, to increase the quality of building production, by means of open and participatory approach.

In terms of technological solutions, the product knowledge has been fairly studied and a number of modelling techniques have been developed. Most of them are tailored to specific products or specific aspects of the design activities.

Current research on AEC product modelling can be classified in two main categories:

- geometric modelling, used mainly for supporting detailed design, and
- knowledge modelling, aimed at supporting conceptual aspects of designs.

Specifically, on the need to govern the symbiosis between building and its functions, so that computers can support every phase of construction (e.g. Solibri program), it is necessary to have information models based on an adequate knowledge representation, formally computable.

This kind of knowledge, oriented to solve complex technical problems, cannot avoid to qualify the product building through its relationship with the context and with the actors.

In terms of social contributions, on the other side, we need to clarify roles and identify responsibilities of actors involved along the building life cycle, starting from the client, through designers, providing for the participation of users from the early stages of design concepts.

The BIM methodology assumes that there is a client able to schedule formally a process of briefing, design, production and management, for example using "template" for the programming of functions and activities, and thus reducing the level of ambiguity in the requirements definition.

Client, especially if they must also manage the constructed facility, are the largest beneficiary of the

process-product models development, because of their risk-based reasoning approach drives the optimization of contract management.

Designers, challenged to become more aware of product and process models, are the key to the spread and development of the most advanced information systems. An open area of research works on the interface between designer and tool, to enable the first to clearly face pre-defined patterns and then customize them while using the software they are familiar with.

Users, generally, as well known, play the central role in Architecture. The problem we approach here, renouncing at the impossible task of modelling the actor's "libero arbitrio", free unpredictable will, focuses on defining a set of occurrences that dynamically happen in the built environment.

Planners' traditional approach consists in entering planned processes (expertise, technical regulations, best practices, etc.), in an architectural schema (Wurzer, 2009; Wurzer et al., 2010). However, those processes are correct only if the planner can correctly anticipate and inform the usage of the building by different building user groups.

If organized in a proper way, it is possible to represent usage scenario, predicting activity inconsistencies and evaluating the performance of the building in terms of user experience.

At the same time it is possible to design a building use programme if it can be re-modelled during the building design process.

With the aim of improving the quality of user experience, this paper explores a method based on process-product knowledge, formalized to support logic synchronization between the planning of activities and design of infrastructures

STATE OF THE ART IN META-PROCESS MODELLING RESEARCH

Many applications use process information, including production scheduling, process planning, workflow, business process reengineering, simulation, process realization, process modelling, and project management.

There are at least two problems with the way all applications typically represent process information:

- They use their own internal representations, therefore communication between them, a growing need for industry, is nearly impossible without some kind of translator.
- The meaning of the representation is captured informally, in documentation and example, so little automated assistance can be given to the process designer.

In terms of Process Knowledge Modelling, at the state of the art, it is important to refer to some ongoing researches at the international level.

NIST CPM

A design repository project at NIST attempts to model three fundamental facets of an artifact representation: the physical layout of the artifact (form), an indication of the overall effect that the artifact creates (function), and a causal account of the operation of the artifact (behaviour).

The NIST Core Product Model (CPM) has been developed to unify and integrate product or assembly information [1]. The CPM provides a base-level product model that is: not tied to any vendor software; open; non-proprietary; expandable; independent of any one product development process; capable of capturing the engineering context that is most commonly shared in product development activities. The entity-relationship data model influences the model heavily; accordingly, it consists of two sets of classes, called object and relationship, equivalent to the UML class and association class, respectively.

The buildingSMART

Standard for processes (formerly known as the Information Delivery Manual or IDM [2]) specifies when certain types of information are required during the construction of a project or the operation of a built asset. It also provides detailed specifications of the information that a particular user (architect, building service engineer, etc.) needs to have at a point in time and groups together information that is need-

ed in associated activities: cost assessment, volume of materials and job scheduling are natural partners. Thus the buildingSMART standard for proces offers a common understanding for all the parties: when to exchange information and exactly what is needed.

The linked Model View Definition (MVD) turns the prerequisites and outcomes of the processes for information exchange into a formal statement. Software developers can take the standard and specific Model View Definitions that derive from it and incorporate them into their applications [3]. The detailed information for this is described in the ISO standard: ISO 29481-1:2010 Building information modelling -- Information delivery manual -- Part 1: Methodology and format.

ISO 29481-1:2010 specifies a methodology and format for the development of an Information Delivery Manual (IDM). ISO 29481-1:2010 specifies a methodology that unites the flow of construction processes with the specification of the information required by this flow, a form in which the information should be specified, and an appropriate way to map and describe the information processes within a construction life cycle.

ASTM Standard Scales

The ASTM standard scales provide a broad-brush, macro level method, appropriate for strategic, overall decision-making [4]. The scales deal with both demand (occupant requirements) and supply (serviceability of buildings) (McGregor and Then, 1999). They can be used at any time, not just at the start point of a project. In particular, they can be used as part of portfolio management to provide a unit of information for the asset management plan, on the one hand, and for the roll-up of requirements of the business unit, on the other. The ASTM standard scales include two matched, multiple-choice questionnaires and levels. One questionnaire is used for setting workplace requirements for functionality and quality. It describes customer needs—demand—in everyday language, as the core of front-end planning. The other, matching questionnaire is used for assessing the capability of a building to meet those

levels of need, which is its serviceability. It rates facilities—supply—in performance language as a first step toward an outline performance specification.

A set of tools was designed to bridge between “functional programs” written in user language on the one side and “outline specifications and evaluations” written in technical performance language on the other. Although it is a standardized approach, it can easily be adapted and tailored to reflect the particular needs of a specific organization.

Limits

Building Modelling is not an objective process, but rather subjective, aimed at very specific purposes that depend, first and foremost, on contractual typology. On process models there are a lot of misleading quarrels, in the sense that many models have always appeared very reductionist and simplistic in relation to the complexity of the real and the articulation of the reasons of the different actors involved.

Typically, in architecture, when a product design falls, analysts want to insert a design process to fix the bad design. However, a one-size-fits-all design process does not exist. Experience teaches that it is quite hard to force a fixed process on a design team that every actor must follow. Every designer has their own unique way of solving design problems.

Design domain experts, usually, argue that bad product design is fixed by hiring good designers not by adopting a better design process.

There is a need to produce not more models, but environments where it is more easily possible to reformulate the existing process-product models.

Specifically, process models influence the Information Modelling much more than drafting based methods. Each actor instinctively wants to rearrange the software built-in model, because a single information model cannot meet all the Requirement.

To set up an information modelling process since briefing phase, implies reasoning primarily on the building functions and on the physical environmental solutions, such as energy modelling or usage planning.

USE PROCESS KNOWLEDGE MODELLING

To provide a reliable, comprehensive and up-to-date knowledge base on use process, 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; Fioravanti et al., 2011a; 2011b), and working to extend its application field to this specific purpose.

This general process representation model is linked to a specific Building Knowledge Model (BKM) structure, oriented to formalization and description of each entities composing design product (spaces, building components, furniture, equipments, etc.).

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 building design products, the new challenge is to extend it to the representation and evaluation of spatial and technological requirements defined according to user needs.

Specifically, the interdisciplinary processes which BKM aims to support include the following:

- Design of Use Functional Program to be performed in an existing infrastructure;
- Design of an infrastructure in accordance with a defined Use Functional Program;
- Design of an infrastructural renovation in accordance with a defined Use Functional Program and / or rescheduling of activities defined by Use Functional Program on the basis of the existing infrastructure.

Tetrahedron Of Knowledge

Scenario in which a building project is delineated by means of the outlines and guidelines is marked by four 'poles' of a Knowledge symbolic *Tetrahedron* that represent the different kinds of knowledge: product, context, actors and procedures (Fioravanti et al., 2011b).

The four 'poles' of knowledge shape what hap-

pens during the AEC design. Each 'pole' is constituted by knowledge-based system in its respective domain. In particular on the knowledge of the product (building - with its components and its multidisciplinary aspects), context (site - with reference to physical, legal, planning, ecological and climatological aspects), the actors involved (humans - professionals, contractors, customers and non-humans - agents, intelligent assistants) and procedures that regulate this process (such as commitment, design phases, economic and financial aspects, administrative and organizational rules). All these 'poles' evolve in time.

This Research Group (RG) has structured and formalized product knowledge, through a logic decomposition of the building organism. "Product ontologies" were implemented, starting from IFC standards and developing a method for explicitly modelling the rules that qualify the intrinsic meaning at different levels of aggregation.

The RG approached has structured and formalized context knowledge, both physical-environmental and juridictive, implementing with the same method the "Context ontology", allowing for ad hoc support during decision-making processes of architectural product design-programming.

In the last few years RG has been studying the "Actors ontology", approaching the problems related both to modelling specialist profiles involved in the design-programming process, and profiles involved in the process of use. Some rules governing the objective part of user behaviour have been identified.

This paper reports on early results of a study which explores a method for structuring "Process ontology". The backbone lemma of this tetrahedron "knowledge realm" is the recognition of the dynamic dimension that characterizes every process model.

"Tetrahedron of knowledge" finds its most complete application in real AEC problems because, unlike the existing knowledge structures, allows actors to dynamically model process-product structures, with explicit semantics.

The BKM system based on the tetrahedral knowledge structure, enables actors to intervene in the course of work on the definition of process enti-

ties and rules. The system supports the re-modulation of the constraints and objectives of the process that are bi-univocally related to functional and behavioural properties of the product.

“Situativeness” of development processes is a key issue in both the software engineering and the method engineering communities, as there is a strong felt need for process prescriptions to be adapted to the situation at hand.

Specifically, the formalization of Use Process Ontology, qualifies and is qualified through rigorously structured relationship with the product-context-user ontologies.

To model use process entities and rules means governing the integration between product form, function and behaviour and vice versa.

Use Process Design Knowledge

Use Process Knowledge is represented by means of Use Process Ontology, a structure based on Use Process Entities, qualified by a system of Use Process Rules. On one hand these process rules govern activities planning and on the other hand they control relationship with the rest of knowledge realms: who does what, where, when and how.

Use Process Knowledge can be described by means of process classes, at different levels of aggregation:

Use Process Actions: elementary class entities structuring the Use Process Ontology. They represent the process based on user's minimum ergonomic function.

Use Process Activities: a set of Use Process Actions structured in time and space, oriented by the functional programme. They qualify the relation between users and building (spaces, components, facilities, equipment, etc.)

Use Process Rationale: aggregation of Use Process Design Activities. The importance of representation for use rationale has been recognized but it is a more complex issue that extends beyond artifact function. It is function of social-economical-environmental sustainability. (The Design Structure Matrix (DSM) has been used for modelling design process

(activities) and some related research efforts have been conducted. For example, a web-based prototype system for modelling the product development process using a multi-tiered DSM is developed at MIT. However, few research endeavours have been found on design rationale (Peña-Mora et al., 1993)

Events: particular process entities, “milestones” that occur in the dynamics of the activities. Emergencies necessary to structure the causal and dependency relationship between Use Process entities.

Use Process Requirements, Performance, Behaviour

From a computational point of view, use process requirements can be defined as variables, because they establish a mapping between a set of process entities and a set of values which express some of their qualitative (and quantitative) aspects.

The specific values that satisfy a particular use process requirement in a particular situation (context and objective dependent) can be defined as use process performance.

The set of all use requirements and performances can be defined as the behaviour of the represented process entity/class in terms of use.

Design Goals Knowledge Structure

Design process goals can be stated as desirables performance measures of the sought solution. Alternatively they can be stated as set of constraints that the proposed solution must satisfy.

Each constraint indicates the specific level of performance a design solution should achieve in a particular category or an acceptable range of performance values.

It can be represented formally using this general annotation:

constraint (value | range)

where the vertical bar stands for ‘or’. A constraint can be stated in terms of a specific value it must satisfy or a range of values.

The function of the goals is thus to group a number of related constraints that should all be satisfied together (Carrara and Fioravanti, 2003). More

formally, goals can be represented by this general notation:
goal ({ goal } | { constraint })

This definition is recursive: a goal can be stated in terms of constraints, or in terms of goals. There is no inherent difference between goals and constraints. Rather, they form a hierarchical structure where terminal nodes represent constraints and intermediate nodes represent goals.

The conditions under which a constraint is considered satisfied must be established and eventually modified during the design process by the actors, according to the internal and external requirements.

LOGICAL IMPLEMENTATION PATH

The implementation pipeline, is oriented to predict and evaluate the performance of a building based on (planned or to be re-planned) usage scenarios and vice versa modelling scenarios of use in a (existing or to be renewed) building.

This work focuses on a multi-model view of process modelling which supports this dynamicity. The approach builds beside the BKM product representation (geometric and non-geometric), a BKM process representation.

Since BKM provides a semantic structure and a standard language (XML, OWL) what we are working on is the implementation of a bidirectional synchronization between software for Programming and software for Authoring space solutions.

The assumption of this process modelling approach is that process prescriptions should be selected according to the actual situation at hand, i.e. dynamically in the course of the process.

To implement this process, the proposed Building Knowledge Model, a formalized extension of actual Building Information Models, includes representation of both the characteristic of the ontology entity and the constraints. By means of Protégé, an ontology editor, we implemented some representative use process design requirements on top of some building ontology entities.

Knowledge Representation allows queries and constraint-verifications by means of proper reasoner

and rule formalizations. In order to interrogate Design Solutions, Ontology Rules have been implemented in SWRL and tested on prototype instances of developed Ontology Classes to check use process - product constraints:

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

In this specific case of study, the process representation is oriented to the use programming and designing, so as to match the Activity Program, defined by means of traditional project management software, together with the design solution of space configuration.

By means of BKM general knowledge structure, it is possible to connect a labelled graph of intentions, called strategy map, as well as its associated flowchart guidelines to layout solutions.

It has been implemented a critical path diagram of Hospital operating room renovation, and now we are working on the actual link to Process Activities Gantt chart. This map is a navigational structure which supports the dynamic selection of the intention to be achieved next and the appropriate strategy to achieve it.

A set of task guidelines, intended to help in the operationalisation of the selected intention, represents some basic ergonomic rules about flow of patients, staff, equipment and material.

Once accomplished the task of formally representing Use Process and Product Knowledge according to the BKM Knowledge Structure, the implementation steps are namely (Figure 1):

1. Connect Product Design Ontologies and Use Process Ontologies (e.g. expressed in OWL language by means of ontology editors, e.g. Protégé);
2. Connect Use Process Ontologies with actual BIM, or IFC (by means of API, or using Beetz et al. (2006; 2010) transcription of IFC in OWL language);

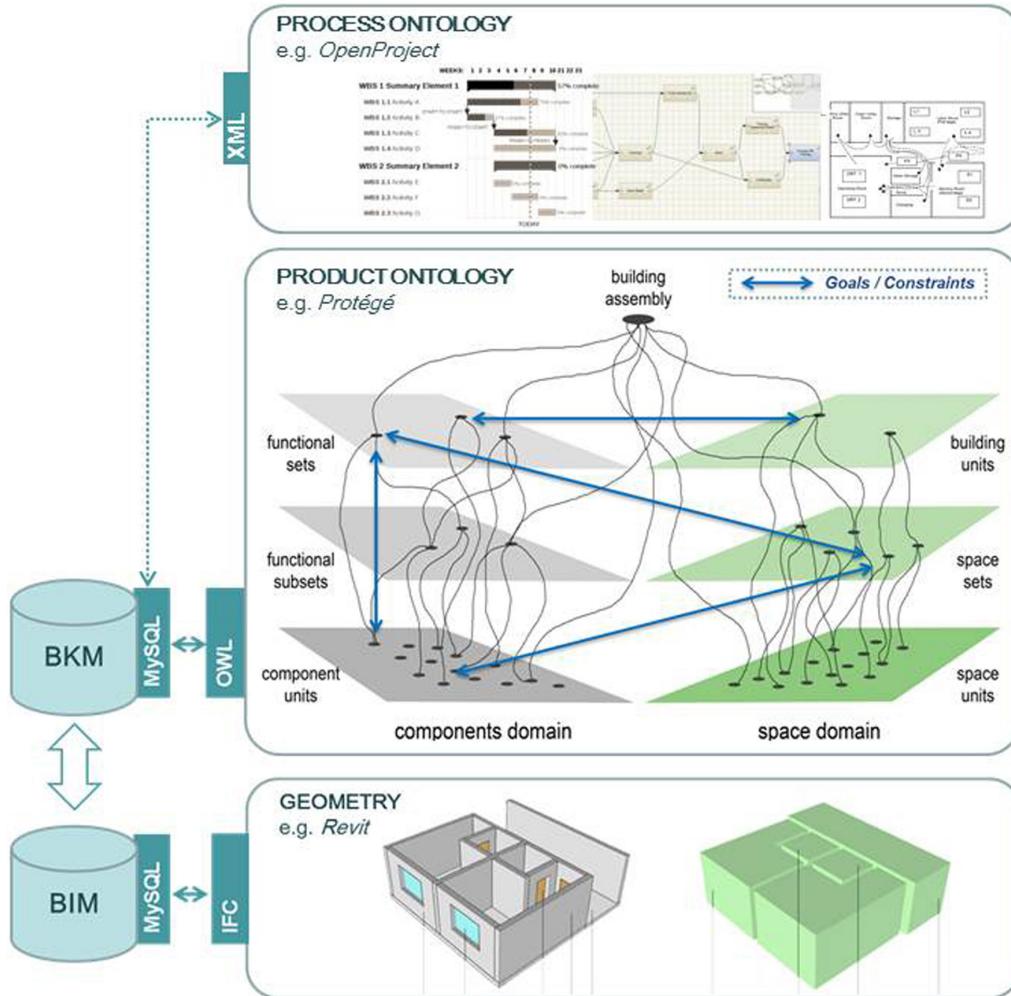


Figure 1
Building Entities and Goals
Knowledge Modelling.

3. Connect BIM + BKM with a Process Management environment (e.g. OpenProject, etc.).

In order to connect the modeled knowledge with graphics in CAD / BIM, technologies related to databases definition have been used. Specifically:

- BKM ontological structure has been exported to a query-able database,
- Autodesk Revit has been selected for CAD/BIM

software,

- by means of Revit DB Link (an Autodesk Revit add-in) it has been possible to export the BIM model to a database (also edit-able and query-able).

A proper database has been defined in order to ensure consistency check of the unique identifiers assigned by Revit to represented graphical entities

and instances of the implemented classes in the protégé Knowledge Structure.

Similarly, this approach has been used to realize the link between OpenProject software, used to manage the XML-OWL process instances, to the Use Process Knowledge Base, in Protégé.

Revit and OpenProject represented entities are associated to instances of the BKM Knowledge Structure; data associated to entity Properties can be “extracted” from the BIM model while other features can be manually specified in Protégé according to the implemented Knowledge Representation Structure.

Linking the database allows keeping consistency between IDs from the two different environments referring to the same represented concept.

CONCLUSIONS

There is an urgent need for tools able to link and translate business rules and programme-project processes to check where business processes are not following policies and rules.

A benefit of the proposed knowledge representation is to provide automated assistance for process development by defining the semantics of process entities in a computer-manipulable way. For example, many businesses have rules, policies, space-activity requirements, that their processes are supposed to follow.

However, the representation of these, typically do not enable tools to check whether they are consistent. BKM represents rules about processes in the same way as the processes themselves, and uses a formalism that supports automated reasoning.

Introducing and enhancing reasoning mechanisms it will go beyond the potential of existing commercial tools for supporting decision making activities.

The proposed knowledge-based system supports process traceability and, consequently, allows responsibilities recognition and re-usable experiences collection.

The possibility to coordinate design process between different actors (including clients, final users,

etc.) and to evaluate the building quality before its construction will increase the chances for the client to be satisfied and will provide more guarantees in terms of future efficiency and performance.

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