A Building Heritage Knowledge Framework using Context Ontologies

Regenerations of industrial areas - the "Isola del Liri" case study

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The growth of urban areas and the increase of urban migrations caused an incorporation of industrialized areas in the development of cities. The difficulties related to city planning in these areas could be coped with more satisfactorily through the use of Geographic Information Systems (GIS) and Context ontologies plus reasoning rules to reuse old industrial buildings. The 'Context' entities and rules are studied using a Context Knowledge Model formalized with Protégé OWL (Ontology Web Language). The study was carried out on industrial buildings situated in southern Lazio - Italy - in particular a paper mill network. Applying GIS instruments to the study of these areas is not enough as designers can only obtain information, but not knowledge, which depends on the urban, historical, cultural, economic, environmental and juridical 'context'. The goal of this research is to create a combination of these technologies to manage knowledge for a more aware design to regenerate old industrial areas with new uses.

Keywords: *Heritage Building, Design Process, Context, GIS tools, Ontologies*

GIS, BIM AND CONTEXT KNOWLEDGE FOR HERITAGE REUSE DESIGN PROCESSES

The importance of the Context to regenerate disused industrial buildings, is based on the investigation about the reasons that have conditioned the land use, the development, the integration in the context and changes which influenced the removal.

The most common BIMs did not fill the gaps between the use of context in architectural design and the reuse of disused industrial buildings.

The existing GISs represent continuous and discrete territorial data and can be used to represent relevant processes such as pollution and land use activities and therefore make statistical forecasts of common interactions possible. Their great potentiality is not fully used to represent the processes of impact on architectural design. While the interoperability between GIS and BIM software tools has dramatically improved in recent years, this process still remains particularly limited. This shows the limitations of managing the information obtained in order to have an added value in architectural design context aware.

GIS instruments were used to analyze the sites and the relations between the factories and urban system based on different satellite images, past and recent cartographies in order to obtain an integrate overview and comparison.

The sizes of existing files, such as LandXML [1] or CityGML [2] provide great opportunities for interoperability between software tools. LandXML has deep roots in the development sector of the territory, and contains classes of valuable items for landscape architects. CityGML is much more recent, has been designed to be stored even more classes of items including buildings, bridges, tunnels, and mobile site. While LandXML is writable by many existing software tools, CityGML is not yet available as the file format in many existing tools, and this file format is widely adopted by industry specialists (Nessel, 2013).

The growing number of software tools available, the growing adoption of digital versus paper-based exchange of information, the internationalization of the design process and the growing demand for sustainable information on the whole life cycle of a building (Gero,1990) requires the use of tools able to support useful context entities for heritage architectural design.

The study focused on paper mill factories and showed that GIS technologies are not enough to have a complete understanding of the existing context for these factories and therefore it can be said that GIS technologies alone are not enough to support an informed design for these types of developments. GIS tools allow to overlap maps, to link traditional relational databases identify features in the urban landscape and to attach attribute data in order to analyze and to inform assessment of urban areas, but they did not allow to reason on these information; for this purpose the Context Knowledge Model (CxtKM) (Gargaro and Fioavanti 2013a), developed using ontologies, was used. The semantic structure of the model gives opportunities to have a wide range of analysis on industrial areas.

The core approach of this paper is the relationship between a CxtKM based on ontologies and GIS tools aimed at the regenerations of the industrial buildings and areas.

The Context Knowledge Model used for disused industrial sites can be applied to different scenarios. The power of this approach lies in the computational modeling of the context knowledge for architectural design, integrating it with the Semantic Web technologies that allows interoperability of the model with different tools, as GIS ones.

HERITAGE BUILDINGS AND THEIR DESIGN REUSE

The hypotheses concerning possible reuse scenarios for abandoned paper mills, without clashing with their building's character, led to alternative design layouts being considered, however it should be pointed out that the "constraining" aspects of old structures and industrial spaces needed to be taken into account, in order to be able to achieve these alternative usages.

Digital models for urban-building design should be able to represent these different characteristics and requirements old/new layout, old/new spaces to compare them, and this frequently is not an easy task.

Nowadays on one hand, traditional researches highlight links established between industrial buildings and their context (urban, industrial, social and physical); on the other hand, GIS tools are used to integrate the investigations and information, creating an information database for the paper mill network (Leggieri, 2013). Notwithstanding research efforts, these two research aspects remain practically separate. These research efforts were not sufficient to provide support tools for design knowledge which is the key point to any modification of existing paper mills.

Designers need an effective and complete understanding of the site to support informed design decisions; nevertheless GIS instruments can only give site information linked to position; they are not able to support knowledge that means adding semantics and reasoning to information. To this end the research defines a model of Context Knowledge specific for modern industrial buildings.

This approach is based on the recognition that it is smart and effective to combine CxtKM and GIS to regenerate industrial areas. This introduces the notion of a Building Heritage Knowledge Framework - BHKF - to facilitate public and/or private administration decision-maker (Plume et al., 2011).

The research has defined a model of information with the objective to support design process in a more conscious way taking care of intersection among individuals - construction - urban context. It provides a platform for the management of context-information-knowledge.

PAPER MILLS NETWORK IN CENTER ITALY - A CASE STUDY

The network of paper mills in Southern Lazio (the province of Frosinone) can be characterised as major industrial production site from the begin of the nineteenth century until the nineteen-fifties. The growth of a singular industrial infrastructure built along watercourses as the hydraulic system was very important for the region's development, involving all the surrounding areas beyond the urban area.

The paper mill districts were stratified over time so that they characterized the landscape, changing the original character of the agricultural environment and were grafted onto the natural landscape characterized by the presence of the close river network.

In these places there are visible traces of the hydraulic system derived from the courses of the Liri and Fibreno rivers, evidenced by the presence of factories, sluices, canals, water intakes, dams, visibly dialoguing with nature. This particular intertwining of urban and environmental system was the main value and peculiarity of the context. Nowadays, the urban area has grown so these paper mills are surrounded by city districts. In order to reuse abandoned industrial areas, it is important to consider their old contexts. Therefore the refurbishment design should essentially be based on the investigation of the reasons behind land use conditioning, development of industrial buildings, their integration into the old context, changes that have influenced their removal and new needs that arise.

The morphology of the territory shows some peculiarities (Figure1).

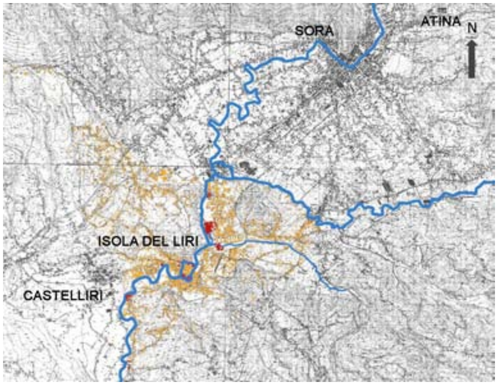

Figure 1
"Liri" watercourses and Isola del Liri and Sora cities

The unique orographic structure that characterizes the dowtown of historical cities is a constant aspect that characterizes the urban settlements.

Many of these structural features are relevant. The cities along the Liri River, which are placed in a peculiar context, have shaped the environment and natural resources. The features related to the water system influenced the origins of various urban locations. The origin and evolution of the settlement system of "Isola del Liri" were related to production activities that led to the current appearance of the site and its special position within the regional settlement. The current structure of the city center is built around the small island in the middle of the river. From this origin the city expanded with its factories adapting them to natural and man-made elements. The productive use of the water resources over time has characterized the urban landscape marking it with the hydraulic works for the derivation of water for industrial uses changing and impacting on the environmental features. The course of the Liri river creates particular jumps, scenic waterfalls that characterize the urban landscape. The use of hydraulic and hydropower production dates back to the oldest paper mills whose location was influenced by the neccessary presence of the water courses to take advantage of the mechanical motion of the river. Paper mills require the construction of branch ducts for the use and discharge of waters even when being located on the banks of the river. There are currently ten paper mills in the town of "Isola del Liri". Some of them are still working but some are in a neglected state and in decay.

DESIGN 'INVARIANTS' AND THE REPRESENTATION OF CONTEXT KNOWLEDGE

The aim of this research is the definition and development of tools to help designers better understand design opportunities and automate some design activities (Gero 1990, 2014).

The knowledge representation models to define structured information in specialized domains have always been present in CAAD tools, but rarely they were specifically applied to Context Knowledge for architectural design (Gero 1990; Gursel et al. 2009; Gargaro and Fioravanti 2013a; Gargaro and Fioravanti 2013b).

OIL, DAML and BKM use the concepts introduced in Resource Description Framework (RDF) extended knowledge related to the 'product' with implicit operators, multiple domains and constraints. The reasoning to control and infere on context knowledge is organized in a hierarchical set of different OWL. But only BKM introduced context entities that are not implicit, and take account simple properties.

The development of the context entities, proposed and implemented a specific model of context knowledge CxtKM (Context Knowledge Model; Gargaro and Fioravanti 2013b) that has been modified taking into account Europeran INSPIRE Directive and Italian GIS Agreement for the GIS databases in order to allow a better interoperability with standards and codes and used for heritage reuse.

The milestones of research are:

- Study the peculiarities of modern industrial buildings;
- Use GIS technologies to link technology features of paper mills, hydraulic system, and urban landscape;
- Populate context knowledge and information with urban, historical, cultural, economic, environmental and juridical data to raise designers' awareness;
- Improve the CxtKM (Gargaro and Fioravanti, 2013b) to formalize historical site evolution, land and soil use, characteristics and relationships among them.

BUILDING HERITAGE KNOWLEDGE FRAMEWORK USING CXTKM

The design could be described as a constrained activity context-dependent.

Architectural Design has, among many aims, to integrate designed buildings in their natural and social context. This process imposes constraints on the variables and their values dependent on context. The design activity is influenced by different aspects as the working environment in which designers work and the 'context' from which the development of the project depends. The designers' perception of context in architectural design changes in relation to changing perceptions of the designers. The design activity can be defined as a decision-making process in which the exploration of the context and learning activities are a goal-oriented work that influences the perception of the designers.

The changing environment characteristics lead to a reformulation of the building requirements for its use. This can be seen also when the evaluation of the comparison between the actual behavior of the structure and the expected behavior is insufficient and cannot be satisfied only by manipulating the structure (Gero, 1990). To overcome these difficulties we propose relational structures to relate context entities to the disused industrial building.

To make this possible each industrial building entity is related context ones using specific relationship, a Relation Structure - RS- which an inference engine can use to compute a goal for its regeneration (Carrara and Fioravanti, 2001).

There are two fundamental classes for the Building Heritage Information/Knowledge Process: that of the Building Invariance, which defines the building spaces that define the industrial building identity, and that of the context entities which gives the contextual peculiarities, defined using European INSPIRE Directive and Italian GIS Agreement for the GIS databases in order to allow a better interoperability of the CxtKM with GIS tools (Fig.2).

For instance, an architect can conceive a building reuse taking into account his/her own specific Relation Structure, dependent on the Building Invariants, that applies its inferential engine rules plus context rules to have a context-aware decision about industrial building refurbishment. Using ontologies to formalize the context knowledge is possible to have a formal structure of the context entities considered in a project (i.e. meanings, properties, rules, behavior, capability, etc.) and formal models (generally mathematical) that allow simulations, verifications and reasoning to be performed (Carrara et al., 2009), and filter mechanism (Fioravanti 2008; [3]) to reduce the space of possibilities.

The study of the disused building focused on paper mills. The starting considerations were based on the characteristics and relations between external and internal spaces to bring out the peculiarities of these industrial areas.

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The recognition was made using fillable tables in which were written the information about each space of the factory as dimensions, material, preservation status to obtain data and meanings.

This leads to determine the recurrent values of old building layouts, spaces, structures, functional uses, material and their relationships, but also criteria to regenerate disused areas and industrial factories in view of new needs - in a word the "invariants".

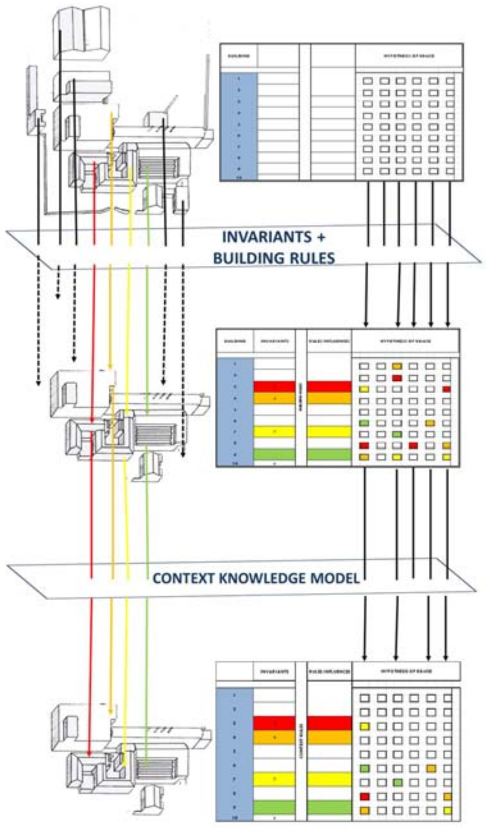


Figure 2
A Building Heritage Knowledge Framework schema

The "Invariants" of disused industrial areas are represented by diagrams and tables (Figure 3) in which the artifact is analyzed in terms of three groups of variables: function, properties and capabilities.

Figure 3
Function, structure and behavior 'Invariants'

After this phase of exploration and analysis, data and meanings were imported into GIS tools, giving to each entity a specific ID and then exported in Context Knowledge Model.

The Context Knowledge Model (CxtK) was implemented following these activities: formulation of the entities, analysis, synthesis, evaluation, selection and reformulation of entities hypothesis.

CxtKM was formalized though ontologies developed in Protégé 4.3 [4]. Then CxtKM is populated using GIS entities exported in excel and with the same ID of the context entities of CxtKM (Figure 4). Then different to-do (and not-to-do) lists and strategies for regenerating old paper mills were carried out and compared considering the constraint rules based on the analysis of typologies and contexts. The context information are enriched with the context rules and the building 'Invariance' deduced from the analysis and they are inferred though the inference engine JessRules [5], based on First order Logic, that allows to control all the declared and defined rules in the ontologies, to maintain the right class hierarchy that is very important when there are more than one parents, to have design advices and to reduce the possible design choices for a context-aware architectural design.

BHKF IMPLEMENTATION FOR HERITAGE ARCHITECTURES

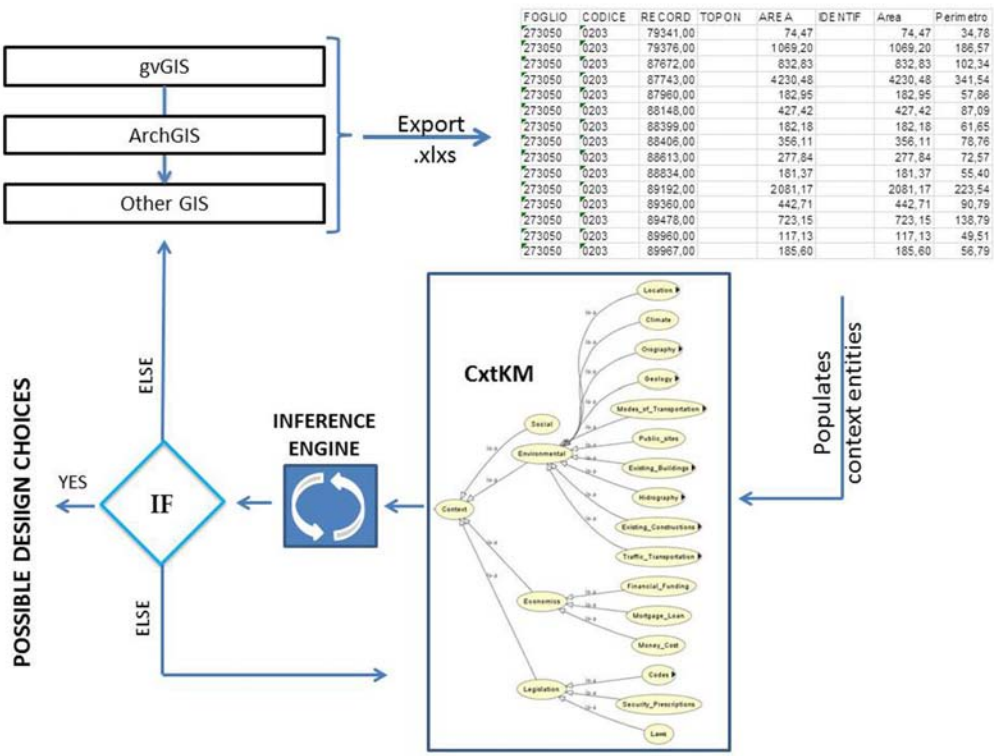
The CxtKM is built by ontologies (Beetz et al., 2006; Gursel et al., 2009; Rehman et al., 2008) links GIS tools through databases in order to support designers and allow them to model constraints, verify algorithms and check rules at different levels.

The starting point was the definition of *entities* and the creation of *rules* to link entities, properties, reports, functions, etc. The semantic structure of entities helps to provide knowledge that can be used to prune wrong design proposals and discover opportunities or suggestions for a wide range of analysis on old industrial areas.

Context was subdivided into sub-entities - Physical, Cultural, Normative and Economic.The entities are formalized using Protégé ontology language (OWL code compliant) and rules have been associated with each entity to define its behaviours.

The primary source of data was an empirical exploration of literature review and scientific ones carried out in parallel with the study of data collected and analysed for the purpose of discovering concepts and relations which are then organized into a knowledge structure.

A reasoning mechanism was used to reduce the industrial area regeneration design proposals, pruning inconsistent hypotheses, reducing the number of possibilities, avoiding the risk of combinatorial explorations (Bickhard an Terween,1995). Hence architects can concentrate their efforts on attaining goals of high quality design and innovative building (or part of it), as they do not have to consider all the possible strategies but a only reduced number that respects urban and building Codes and architect's goals and experiences. As the design process evolves, solutions and aim are modified and refined until the desired



FOGLIO	CODICE	RECORD	TOPON	AREA	IDENTIF	Area	Perimetro
273050	0203	79341,00		74,47		74,47	34,78
273050	0203	79376,00		1069,20		1069,20	186,57
273050	0203	87672,00		832,83		832,83	102,34
273050	0203	87743,00		4230,48		4230,48	341,54
273050	0203	87960,00		182,95		182,95	57,86
273050	0203	88148,00		427,42		427,42	87,09
273050	0203	88399,00		182,18		182,18	61,65
273050	0203	88406,00		356,11		356,11	78,76
273050	0203	88613,00		277,84		277,84	72,57
273050	0203	88834,00		181,37		181,37	55,40
273050	0203	89192,00		2081,17		2081,17	223,54
273050	0203	89360,00		442,71		442,71	90,79
273050	0203	89478,00		723,15		723,15	138,79
273050	0203	89960,00		117,13		117,13	49,51
273050	0203	89967,00		185,60		185,60	56,79

Figure 4
Conceptual Model Framework

behaviour or performance is obtained.

The formalization of Context Knowledge Ontology is related to environmental, cultural, economic and juridical entities, specifically aimed at rendering explicit the operational meaning through a structured set of classes / concepts / entities, relationships and reasoning rules among them.

The prototype of BHKF - Building Heritage Knowledge Framework - has been defined by the building functions (F), capabilities (C) and requirements (R). The constraints on the functions appear as required behaviour related to building capabilities. The capabilities of the building are the unexplored potentiality of it that can even change the type of the class. The functions are dependent not only on the requirements (R) but also on the behaviour of the building that define the building performances (P). These functions also need a Context Knowledge Model that allows to add variables, dependent on context (Cxt), included the location (L) in which the building stands.

This prototype could be used to reduce the range of possibilities for re-use during the design process.

A building design hypothesis can be symbolically represented as a function of:

$$B = f(F, C, R, Cxt)$$

```
where
C = g(R, P)
Cxt = h(B, L)
```

The Building function - f (B) - is non-linear, because it depends on context and on weights applied to building entities by designers. The weights are assigned to each entity in relation to the context importance and to the building requirements. They include, if required, the approximate evaluation of the expected costs so that the designers are allowed to choose not only the most promising or satisfying solutions, but also the cost-effective ones and the client can be acquainted with that.

PAPER MILLS RULE EXAMPLE: HYDROPOWER ENERGY PRODUCTION

The case studied for the evaluation of BHKF, as shown in the previous paragraphs, is located in Central Italy.

The existing industrial sites and buildings generated by very specific industrial requirements could be turned into settlements with the help of GIS and context ontologies. The context is characterized by particular jump shares and waterfalls that characterize these small towns and influenced by the paper mills development.

This context can be evaluable to be modelled by reasoning rules as for instance the high jump and quantity of water, but this consideration could not be enough to make the decision to use it in the 're-generated' building. In this example, the other problem that needs to be considered is the noise level due to the production of electricity, as some of the paper mills are very close to the city centre.

Case Studies

```
1.Waterfall(n)
2. if jump higher> 3 m
3. and if water quantity>1 mc/h
4. then <hydroelectic energy
 ↪ production> return true
5. else return false
```

The described rule was applied to two paper mills, one located in "Isola del Liri" and the other in "Atina" (a smaller town near Isola del Liri).

The example shows that the paper mill in Atina does not have the possibility of hydropower energy generation because a jump of one meter is not economically sufficient to produce electricity (figure 5). However the paper mill in Isola del Liri has the capacity to generate electricity due to fact that the jump is higher and the quantity is more than one cubic meter per hour (figure 6).

Applying the model onto other paper mills in "Isola del Liri" district and in some cases (Figure 7) the model infers that is not convenient to produce electricity, even if the jump and the quantity of water is sufficient, because the paper mill is too much close the city centre and so the acoustical protections necessary for the surrounding isolation are too much expensive or there is an incompatibility with the heritage landscape.

CONCLUSIONS

The common characteristics and relationships – the "*knowledge invariants*" - of modern industrial areas and buildings are not totally supported by GIS tools to help architects effectively utilize the knowledge from these tools. Therefore a Building Heritage Knowledge Framework - BHKF - has been created to link a Context Knowledge to GIS.

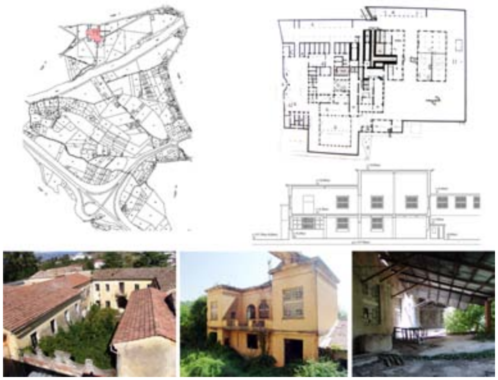
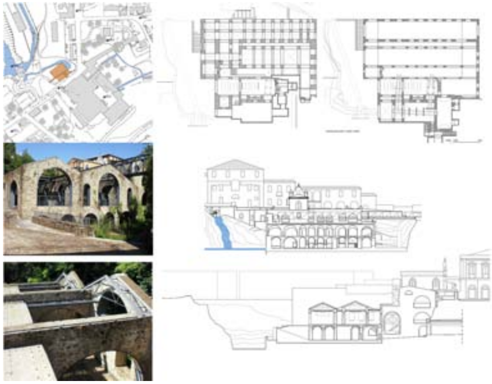


Figure 5

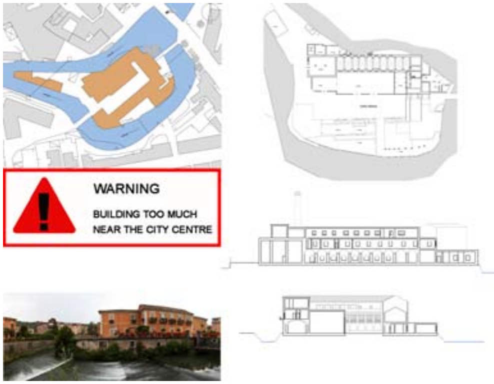
```
<hydroelectic energy production> =
 ↪ FALSE
```

Figure 6



```
<hydroelectic energy production> =
 ↪ TRUE
```

Figure 7
Inferred Rule
Example




```
<hydroelectic energy production> =
 ↪ TRUE
...
If <Industial Building Area> < 10
 ↪ mq from <Downtown>
then <hydroelectic energy
 ↪ production>
return FALSE
```

The development and implementation of the BHKF has been focused on old industrial area context knowledge, mainly concerning reasoning rules to give advice during re-design of these areas. This model is a promising tool to help designers to manage and share heritage context knowledge obtained from a GIS model and from formalized experience.
A Context Knowledge Model can evaluate a project a priori so as to evaluate constraints and offer suggestions for alternative design proposals, thereby explaining motivations or unsatisfied requirements.

In brief, BHKF could:

- Share and spread Context Knowledge to find better design solutions to reuse industrial buildings;
- Inter-operate various common tools to refurbish industrial areas;
- Facilitate dialogue between designers and public administrations;
- Help public administration to verify design proposals with reuse or refurbishment Codes.

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REFERENCES

Beetz, J, Leeuwen, JP and Van de Vries, B 2006 'Towards a Topological Reasoning Service for IFC-Based Building -information Models in a Semantic Web Context', *Proceedins of joint International Conference on Computing and Decision Making in Civil Building Engineering*, Montreal , pp. 3426-3435

Bickhard, MH and Terween, L 1995, *Foundational Issues in Artificial Intelligence and Cognitive Science*, Elsevier Science Publishers B.V., Amsterdam, NL

Carrara, G and Fioravanti, A 2001 'A Theoretical Model of Shared Distributed Knowledge Bases for Collaborative Architectural Design', *Strategic Knowledge and Concept Formalization III*, Heron Island, Sidney, pp. 129-143

Carrara, G, Fioravanti, A, Loffreda, G and Trento, A 2009 'An Ontology-based Knowledge Representation Model for Cross-Disciplinary Building Design: A General Template', *Proceedings of eCAADe 2009*, Istanbul (Turkey) , pp. pp. 367-374

Carrara, G, Loffreda, G and Fioravanti, A 2013 'A Proactive Platform for Knowledge Management in Cross-Disciplinary Building Design', *eChallenges e-2013 Conference Proceedings, IIMC International Information Management Corporation Ltd 2013*, Dublin, pp. 1-10

Fioravanti, A 2008 'An e-Learning Environment to Enhance Quality in Collaborative Design. How to Build Intelligent Assistants and 'Filters' Between Them', *Architecture and Modern Information Technology*, 4(5), online: see [3].

Fioravanti, A, Loffreda, G and Trento, A 2011 'Computing Ontologies to Support AEC Collaborative Design', *Proceedings of eCAADe 2011*, Ljubljana, pp. pp.177-186

Gargaro, S and Fioravanti, A 2013a 'Traditions based on context. How context ontologies can help archaeological sites', *Future Traditions: eCAADe International Workshop Proceedings 2013*, Porto, pp. 105-114

Gargaro, S and Fioravanti, A 2013b 'A Context-Knowledge Model for Architectural Design', *Proceedings of eCAADe 2013*, Delft, pp. 81-90

Gero, J 1990, 'Design Prototypes: A Knowledge Representation Schema for Design', *AI Magazine*, 11(4), pp. 26-36

Gruber, TR 1993 'Toward Principles for the Design of Ontologies Used for Knowledge Sharing', *Proceedings of the International Workshop on Formal Ontology 1993*, Padova

Gursel, I, Sariyildiz, S, Stouffs, R and Akin, O 2009 'Contextual Ontology Support as External Knowledge Representation for Building Information Modeling', *Proceedings of CAAD Futures*, pp. 487-500

Kelly, N and Gero, JS 2014 'Interpretation in design: modelling how the situation changes during design activity', *Research in Engineering Design*, 25(2), pp. 109-124

Leggieri, E 2013 *Analisi e prospettive per i complessi industriali dismessi. Il caso delle ex Cartiere di Isola del Liri in provincia di Frosinone (Analysis and perspectives for disused industrial buildings. The case study of the paper mills at "Isola del Liri" – Frosinone- Italy)*, Ph.D. Thesis, Sapienza University of Rome

Nessel, A 2013 'The Place for Information Models in Landscape Architecture, or a Place for Landscape Architects in Information Models', *Proceedings of Digital Landscape Architecture 2013*, Berlin, pp. 65-72

Fridman Noy, N and Hafner, CD 197, 'The State of the Art in Ontology Design A Survey and Comparative Review', *AI Magazine*, 18 (3), pp. 53-74

Peter, A, Newton, B and Wills, C 2009 'Visualising Architecture: A field study in rural England', *Proceedings of 11th Bogus Conference*, London, pp. 12-14

Plume, J and Mitchell, J. 2011 'An Urban Information Framework to Support Planning, Decision-Making & Urban Design', *Proceedings of CAAD Futures 2011 : Designing Together*, pp. 653-666

Rehman, F and Yan, XT 2008, 'A Case Study to Support Conceptual Design Decision Making Using Context Knowledge', in Yan, X.T., Jiang, C. and Eynard, B. (eds) 2008, *Advanced Design Manufacture to Gain a Competitive Edge*, Springer, pp. 13-22

Russel, S and Norving, P 2010, *Artificial Intelligence: A Modern Approach 3rd Edition*, Pearson Education Inc.

Stevens, R, Horrocks, I, Goble, C and Bechhofer, S 2001 'Building a Reason-able Bioinformatics Ontology Using OIL', *Proceedings of the IJCAI-2001 Workshop on Ontologies and Information Sharing*, Seattle, USA, pp. 81--90

Wurzer, G 2009 'Systems – Constraining Functions Through Processes (and Vice Versa)', *Proceedings of the 27th eCAADe Conference, Computation: the new realm of architectural design*, Istanbul, pp. 659-664

[1] http://www.landxml.org/

[2] http://www.citygml.org/

[3] http://www.marhi.ru/AMIT/2008/4kvart08/Fioravanti/Fioravanti_paper_AMIT_5.pdf

[4] http://protege.stanford.edu/products.php#desktop-protege - v4.3.

[5] www.jessrules.com/jess/index.shtml - v7