Title:
An Ontology-based Framework for Sustainable Factories

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Introduction:

Sustainable development is a relevant problem in European countries and all over the world; it requires considering environmental sustainability according to social and economic constraints. The world's energy consumption has doubled over the last 40 years and it is estimated that one-third of the consumption comes from industry [9], thus it becomes of outmost importance to increase the efficiency in energy waste in industries for the sustainability of the factories and consequently of the whole environment. The optimization of the industrial production in terms of energy consumption and pollution reduction has to consider both manufacturing processes and building behavior by encouraging the use of alternative energy (see Horizon 2020 objectives) and improving indoor environmental comfort of the workers. This need asks for the design and management of the factories as a whole. Different tools are available in the market to support the whole factory lifecycle, from the design to the construction up to the operating phase; unfortunately, these tools often adopt different programming languages and platforms, failing in interoperability as they use different terminologies to describe the same domain, or even same terms with different meanings. This lack of interoperability results in not fully satisfying customer requirements, being inefficient and missing opportunities to gain competitive advantages. Moreover, often the high costs make tools unavailable for small and medium enterprises. In addition, different protocols are used in the various countries to assess sustainability of industrial buildings, using each one different data. Tools for assessing the environmental sustainability of buildings are already available but they are mostly developed to meet the requests of a specific country and they use different knowledge and data (i.e. BREEAM for United Kingdom [1], LEED for the U.S.A. [6], CASBEE for Japan [3], DNGB for Germany [4], Protocollo ITACA for Italy [5]).

The analysis of energy and environmental sustainability of an industrial building requires the use of heterogeneous data and knowledge [7], involving various and very different aspects varying according to the factory lifecycle phase under consideration. The design phase requires information on the site where the building will be placed, building characteristics, materials that will be used, space destination usage, energy, and maintenance plan. The construction phase requires data on the products used, building installation characteristics and logistic of the site. Finally, the operating phase requires mainly information on the resource utilization.

Main idea:

The Italian funded project Sustainable Factory Semantic Framework (SuFSeF) aims at building a framework, based on an integrated collaborative virtual environment, facilitating the sharing of the complete factory information and knowledge between various tools, supporting the sustainable design and management of all the factory entities. The platform extends the Virtual Factory Framework conceived within the European project VFF [8] to include data and processes necessary for the energy and environmental assessment. The platform considers various software layers allowing the access of modelling and evaluation tools to proprietary data through the use of a reference semantic data model. In particular this framework provides: (1) shared and extensible factory data model (VFDM) formalizing information to describe the characteristics of site, building, product, resources, processes performed within the factory; (2) enablers for the connection of tools to the framework (commercial applications and tools developed during the project) supporting factory design and management throughout its lifecycle, (3) synchronization between the virtual and real factory for monitoring purposes.

SuFSeF extends the VFF by providing a common language to share knowledge and information with a particular focus on the environmental aspects related to all the factory domain constituents (site, building, product, process, resources, indoor comfort) and by developing and integrating tools for sustainable factories design, characterisation and evaluation. Such a common language needs also to fit other requirements such as the possibility of being reused and extended when needed. Moreover, it should not be linked to a particular assessment protocol, but it should describe general concepts that can be reused and fit the different data used for different evaluation protocols. All these concepts refer to, physical and technological properties of the factory objects that need to be harmonized within the data model. For example data characterizing building aspects for the sustainability assessment include geometric data (e.g. net and gross floor area, gross volume), use data (e.g. water consumption, CO_2 heating emissions), climate data (e.g. building volume heated), Energy data(e.g. total heating primary energy) and management data (e.g. maintenance strategy).

The paper focuses on the development of the common language that is a key pillar of the proposed SuFSeF platform. To fulfill the mentioned requirements, a Semantic Data Model (SDM) providing a semantic representation of the data and knowledge required for sustainability assessment is proposed. The data model is developed as a set of interconnected *ontologies*, adopting the *Semantic Web* technologies. The Semantic Web technologies offer, indeed, the possibility to represent a formal semantics, to efficiently model and manage distributed data, to ease the interoperability of different applications, and to exploit generic tools that can infer from and reason about an ontology, thus providing a generic support that is not customized on the specific domain. The SuFSeF semantic data model is based on the ontology set of the Virtual Factory Data Model (VFDM), which exploited as much as possible already existing technical standards for manufacturing to facilitate the interoperability between software tools. Despite the generality of the approach, the VFDM does not provide the detailed building and resources information necessary to carry out the evaluation of the energy and environmental sustainability of factory buildings. Moreover, VFDM does not include the concept of state of resources which must be formalized as the energy consumption varies dramatically depending on the state in which the resource is (e.g., idle, busy and failed). The SufSef data model is the result of a complex process, based on the analysis of the criteria, rules and procedures adopted for the sustainability assessment. The analysis is not trivial since a lot of heterogeneous knowledge and data are essential to carry out a full assessment, involving various and very different aspects such as energy, water and material use, urban configuration, comfort of indoor spaces and management. This variety determines the use of different document sources, which also depend on the specific phase of the building lifecycle. The identified data have been checked with respect to some specific certification protocols to verify their applicability and then to the available VFF data model and Industry Foundation Classes (IFC) [2, 10] standard to identify the necessary extensions. This approach required both translating and including in the data model the already existing classes from IFC standard that were not taken into account in the current VFF and the definition of new concepts and relations to describe all the data needed for the sustainability assessment, whenever they are not included within the reference standard.

Conclusions:
This paper illustrates the SuFSeF platform, its objectives, the innovative approach and the idea of the sustainable factory as a whole set of aspects whose integrated analysis is a key factor. In particular the paper focuses on the developed semantic data model and illustrates its validity in adequately expressing all the knowledge necessary to the different tools that are used for planning and monitoring the different phases of a factory lifecycle taking into account environmental and energy sustainability.

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