Journal of Cleaner Production xxx (2016) 1–18

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

An energy efficiency focused semantic information model for manufactured assemblies

Milton Borsato

Graduate School of Mechanical Engineering and Materials (PPGEM), Federal University of Technology - Parana (UTFPR), Av. 7 de Setembro, 3165, Curitiba, PR 80230-901 Brazil

ARTICLE INFO

Article history:
Received 23 October 2015
Received in revised form
19 September 2016
Accepted 23 September 2016
Available online xxx

Keywords:
Information model
Assembly
Manufactured assembly
Energy efficiency
Ontology
Semantic interoperability

ABSTRACT

Environmental Sustainability is one of the 'Grand Challenges' for manufacturing success in the 21st century. The present article mainly focuses on energy use during the manufacturing steps used for assembling products. In particular, industry still needs systematic and reliable ways to capture information for ultimately accounting for energy efficiency in manufacturing processes. For that purpose, an information model in the form of a formal ontology was created using information elements as building blocks, which emerge from manufacturing process models, supply chain operations, manufacturing process parameters, 3D form features and exergy-based thermodynamic analysis. These information elements were integrated by means of semantic relationships in an ontology. Once this information model was constructed, an application example of a welded hull panel assembly was used for verification of the model's representativeness and completeness. Results show that it is feasible to correlate all required data by means of semantic relationships for estimating energy efficiency indicators prior to physical prototyping, or ultimately comparing different alternatives for manufacturing processes regarding energy efficiency. However, manufacturing processes must be described in detail in order to allow energy efficiency analyses. In addition, geometric models need to be able to represent form features that can best relate to specific manufacturing process parameters. And finally, energy efficiency indicators, such as the degree-of-perfection can be derived from a comprehensive thermodynamic analysis, to be performed in each individual process step. Results indicate it is possible to provide an information structure for the calculation of the degree-of- perfection associated with an exergy-based thermodynamic analysis in assembly processes. Therefore, it has the potential to serve as a basis for a unifying framework for developing software applications that could allow the calculation of the degree of perfection in manufacturing operations. In addition, the resulting information model may facilitate data integration in the extended enterprise environment as well as the development of standards that can lead to seamless interoperability of manufacturing information systems. This paper presents the means by which energy efficiency can be accessed directly from an integrated semantic model, and opens the possibility to be extended for many different sorts of manufacturing processes.

1. Introduction

The traditional quality-cost-time paradigm, in which manufacturing companies operate, has gradually shifted towards considering sustainability aspects. The Integrated Manufacturing Technology Initiative has defined Environmental Sustainability as one of the 'Grand Challenges' for manufacturing success in the 21st century (Initiative, 2000). Environment-friendly products are more popular than ever, since consumers are more aware of future scenarios of scarce resources shared by an increasing world population (Peattie, 2010). In this scenario, companies have set strategies to both seize market opportunities and reduce production cost (Gutowski et al., 2005; Nidumolu et al., 2009). On the other hand, regulatory agencies establish directives for hazardous emissions, product disposal and energy consumption (Chaker et al., 2006).

Sustainability performance measures are now required in the manufacturing arena, where extensive consumption of water and energy takes place. Knowledge about the efficiency of

E-mail address: borsato@utfpr.edu.br.

http://dx.doi.org/10.1016/j.jclepro.2016.09.185
0959-6526/© 2016 Published by Elsevier Ltd.

manufacturing processes is required for the adoption of successful energy saving measures. In addition, a designer must be able to evaluate different concept alternatives, not only regarding product functionality and ease of use, but also bearing in mind its production methods and impacts on the environment (Thiede et al., 2012).

Companies are looking at their manufacturing processes to find ways to cause less impact on the environment (Duflou et al., 2012). Comprehensive examination of manufacturing processes as to their energy efficiency have led to the fact that state-of-the-art fabrication methods may be more precise or reliable, but on the other hand use enormous amounts of energy per weight of processed material (Gutowski et al., 2009). Moreover, a part of the energy used in the shop floor is spent in idle mode or auxiliary functions (Dittrich et al., 2012).

There is a need to investigate how efficient manufacturing processes are in fact and where possible opportunities for improvement may be. Amongst them, assembly operations are fundamental to provide complex products to the market. Although material processing operations cause large resource consumption, assembly operations include important energy consumption activities, such as the logistics of supplied parts and joining processes (e.g. welding). Complex products may have components shipped over from foreign countries requiring intricate joining processes that may greatly affect the overall energy consumption.

Available data in the extended enterprise scenario can provide the means for determining energy efficiencies and material consumption. But first, data has to be structured and converted into meaningful information, ultimately leading to well-formed decision making. Islands of information can cause huge losses in industry due to conversion errors, human intervention, ambiguity, interpretation flaws and unreliability (Ziegler and Dittrich, 2007). Although the issue of data integration has been examined for decades, it has been present in the daily lives of information technology professionals who strive to extract useful information from countless heterogeneous information systems that are still far from understanding each other's data and possible relationships between them.

Manufacturing is a wide knowledge area. Different concept domains overlap, and therefore the need for semantically rich information models rises (Young et al., 2007). Traditional information models built in EXPRESS (Goh et al., 1996), EXtensible Markup Language (XML) (Decker et al., 2000) or Unified Modeling Language (UML) (Rumbaugh et al., 1999) can be taken to the next level of representativeness should they include semantic content. One way of achieving that is by using ontologies.

An ontology consists of a vocabulary used in a given knowledge domain, enriched by some specification of the meaning or semantics of the terminology within the vocabulary using description logics. Computational ontologies are a means to formally model the structure of a system, i.e., the relevant entities and relations that emerge from its observation, and which are useful to one's purposes (Guarino et al., 2009). In recent years, ontologies have been created to add semantic meaning to data, so that different domains of knowledge can be branched across automatically (Antoniou and Van Harmelen, 2004). The possibilities of the semantic web are now available in the context of companies (or the so-called "extended company") with RDF (Resource Description Framework) databases, upon which semantic queries can be easily performed (Joshi et al., 2015).

Some researchers have built information models to represent assemblies. However, recent efforts to build information models have not considered the need for integrating assembly topological data with process plans, energy efficiency analysis, and material data. Therefore, these models cannot deal with resource usage or other sustainability issues. A review of recent advances in modeling manufactured assemblies, briefly summarized as follows, reveals that, even though significant progress has been made towards developing more expressive ways to represent assemblies, mainly for dealing with different needs (e.g. functional behavior, management, collaboration, process planning), there is a clear opportunity for relating assemblies and their specifics with the need for sustainability in the form of energy efficiency, which is the focus of the present work.

Li et al. (2010) present a XML schema over a model that is divided into four views according to different application fields: assembly process planning, management, virtual reality, and assembly resources. In this model, semantics is mentioned as a way to describe design intent.

Kim et al. (2006) present the Assembly Relation Model (ARM) to represent engineering, spatial, assembly, and joining relations of assemblies to promote collaborative assembly information-sharing environments. The model relates assembly topological entities, i.e. parts and assemblies, with form features. Various collaborative designers, while using collaborative design tools can then access this assembly information by using a semantic query.

Rachuri et al. (2006) present the Open Assembly Model (OAM), a UML/STEP[1]-based model that represents the function, form, and behavior of an assembly and defines both a system level conceptual model and associated hierarchical relationships. The model provides a way for tolerance representation and propagation, kinematics representation, and engineering analysis at the system level.

Lohse (2006) proposes the OntoMAS framework, an integrated design framework for the requirements driven specification of assembly processes and configuration of modular assembly systems. An extensive set of entities is created within an ontology, which establishes correlations between form features and process tasks. Sustainability-related entities have not been considered in this framework.

Li and Xie (2015) advocate a module partition approach for grouping existing CAD assembly models into modules based on component dependencies. Assembly information can be extracted by means of an algorithm and processed to generate a component design structure matrix (DSM), which represents hierarchical relations and dependency strengths between components. The corresponding manufacturing process information is not referred in such an approach.

Feng et al. (2015) conceive an energy assessment methodology for evaluating total use and efficiency, for mechanical and electrical product assembly processes. For that, a proposed sequence of activities includes goal setting, baseline definition, measurement, analysis, reporting, evaluation, and resetting the goal for product assembly processes. As such activities are pursued in an iterative process, incremental improvements towards sustainable manufacturing are achieved. This approach provides an overall guideline for manufacturers to make decisions that can be integrated with their business strategy. There is no intention, however, to bridge information that emanates from different knowledge domains (e.g. thermodynamic investigations, geometric features and manufacturing processes for assembly) for potentially facilitating data-analytics-supported decision making, for example.

The present work proposes a semantic information model that allows computer-aided calculations of energy efficiency indicators

[1] STEP: standard for the computer-interpretable representation and exchange of product manufacturing information.

Please cite this article in press as: Borsato, M., An energy efficiency focused semantic information model for manufactured assemblies, Journal of Cleaner Production (2016), http://dx.doi.org/10.1016/j.jclepro.2016.09.185