INFORMATION STRUCTURE FOR MANUFACTURING SUSTAINABILITY ASSESSMENT: STEP FOR LCA

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ABSTRACT

Environmental performances need product, processes and life cycle modeling and evaluations. There is direct need of assessment tools to monitor and estimate environmental impact generated by different types of manufacturing processes. Indeed, eco design and products optimizations can be done with the manufacturing process choices. But the manufacturing systems are very complex and they are driven by physicals laws that are heavy to model. This research proposes a manufacturing informatics framework for the assessment of manufacturing sustainability based on an EXPRESS information model developed to represent sustainability information. It is the first step of association of sustainability information with product design specification. In the next phase of research, investigation will be conducted to integrate sustainability information model and existing standardized product design model ISO 10303 AP 242.

INTRODUCTION

The manufacturing industry is often cited as the cause of many environmental and social problems, yet it is acknowledged as the main mechanism for change through economic growth (Baldwin 05). Industry is confronted with the challenge of designing sustainable products and manufacturing processes. Many sustainable development strategies have been proposed by government agencies and academia since the late 1990s. Research in sustainable manufacturing field can be categorized into the following four main themes (Mayyas 2012, Ashby 2009, Barker 2007, Govetto 2008, Perry 2012, Vijayaraghavan 2010): a) Life-Cycle Assessment (LCA), b) design-for-X principles and design for sustainability, c) end-of-life studies, and d) energy efficiency monitoring and studies. But it remains a lack of manufacturing system and sustainability information integration hampers the widespread adaptation of the best sustainability practices in the manufacturing industry.

INFORMATION MODELS OF PRODUCT DESIGN AND MANUFACTURING PROCESSES

In recent years, information technology has become increasingly important in the manufacturing enterprise. Effective information sharing and exchange among computer systems throughout a product's life cycle has been a critical issue (ITM 1995, Lee 1999). An information model is a representation of concepts, relationships, constrains, rules, and operations to specify data semantics for a chosen domain of discourse. Amongst these information models, the STEP and STEP-NC information models are the most advanced and standardized ones, developed by ISO committee to provide the basis for product design, machining standardization, and integration of part inspections with machining. The information is modeled in EXPRESS language. STEP Application Protocol (AP) 203 editions 1 & 2 (ISO10303 1994, 2007 & 2009) (Configuration Controlled 3D Designs of Mechanical Parts and Assemblies) provides the data structures for the exchange of configuration-controlled 3D designs of mechanical parts and assemblies. AP 203 comes from ISO 10303 product data standard, and is not a data standard for configuration management of a product throughout its entire life cycle. The AP is centered on the design phase of mechanical parts and the high-level information entities.

PROPOSED MANUFACTURING INFORMATICS FRAMEWORK FOR THE INTEGRATION OF LCA AT DESIGN STAGE

In order to integrate LCA information into the product design stage, necessary information must be properly represented and associated to the product PLM information. In the proposed research, a case study was first conducted to examine what LCA information should be modeled. Composite parts give interesting examples on a simple piece such as a pedal crank developed with recycled carbon fibers for thermoset organic matrix composite as shown in Figure 3. During the design, product models have to integrate materials information such as matrix composition, reinforcement type (glass, carbon, aramid, and natural), their architecture (unidirectional, woven) and the structure composition (orientations of the different layers in the depth of the product). Other information like inserts or coating completes the bill of material. Currently in STEP AP 203, only very limited material information is modeled as shown in the following entities in table 1. To associate composite material information to a product design, the following entities were developed in this research. The new entities are written in bold-italic.

Figure 1: pedal crank made with recycled Carbon Fibers (developed at I2M) (Perry 2012)]

ENTITY Material_identification; material_name : STRING; items : SET[1:?] OF material_item_select; END_ENTITY; TYPE material_item_select = SELECT (Anisotropic_material, Braided_assembly, Coating_layer, Isotropic_material, Laminate_table, Part_view_definition, Substance_view_definition, Woven_assembly); END_TYPE; ENTITY Composite_material_identification SUBTYPE OF (Material_identification); DERIVE composite_material_name : STRING := SELF\Material_identification.material_name; END_ENTITY; TYPE material_item_select = SELECT	***ENTITY composite_matrix ABSTRACT SUPERTYTPE OF (ONEOF (mud, cement, polymers, metals, ceramics)); name: STRING; END_ENTITY; ENTITY composite_resin ABSTRACT SUPERTYPE OF (ONEOF (polyester_resin, vinylester_resin, epoxy_resin, shape_memory_polymer_resin)); name: STRING; material_property: STRING; END_ENTITY; ENTITY composite_reinforcement ABSTRACT SUPERTYOP OF (ONEOF (glass_fibre, carbon_fibres, aramid_fibres, boron_fibres)); name: STRING; architecture: fibre_architecture; END_ENTITY; ENTITY fibre_architecture; ABSTRACT SUPERTYPE OF (ONEOF (short_fibre_reinforced,***

(Anisotropic_material,	continuous_fibre_reinforced));
Braided_assembly,	name: STRING;
Coating_layer,	direction: fibre_directions;
Isotropic_material,	END_ENTITY;
Laminate_table,	
Part_view_definition,	ENTITY fibre_directions;
Substance_view_definition,	SUPERTYPE OF (ONEOF (continuous_aligned,
Woven_assembly	discontinuous_aligned, discontinuous_random,
Composite_material);	unidirectional, woven));
END_TYPE;	END_ENTITY;

Table 1: STEP AP203 entities enriched with composites material information

Manufacturing data must also been included in order to ensure the product / material / process combined design in the case of composite parts. Promoting recycled carbon fibers eco-design (Perry 2010) imposes to access to material data (from end of life scenario and properties) at the early stage of the design. It means developing specific data storage for material properties (depending to the recycling process) and properties models prediction (based on the different type of fibers) as illustrated on Figure 2.

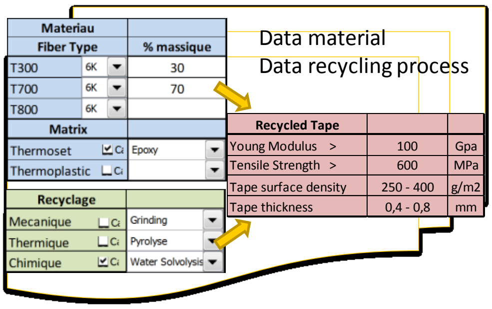

Figure2: Recycling End of Life scenario and product/material properties evaluation tool.

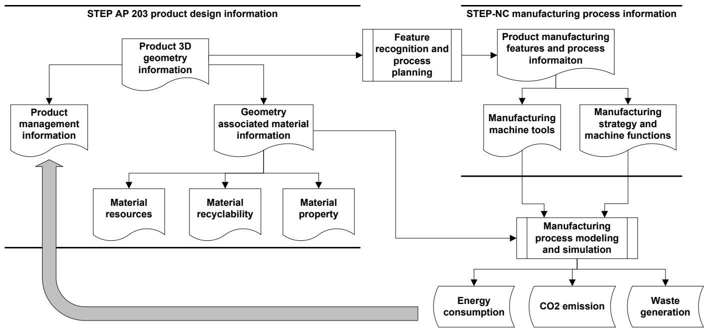

Figure3:Proposed information framework for integrating LCA in product design stage

Currently in STEP AP 203, the limited material information, shown above in unbolt entities, is not associated to design geometry. The material information is defined only for annotation display. In order to fully integrate material information with design process, the association between product geometry and its material must be semantic. Today no integrated environment allows taking all these facets into consideration. And the next step is to compare, for an expected set of functions, the n-plet (Mayyas 2012) in order to optimize both technically, but also environmentally with specific focus such as material resources minimization (mix of less material and improved end of life possibilities), energy optimization and/or pollution reduction. These multi objective optimization needs to handle all these data, models, life stages, functional unit definition in a coherent environment and at the early stage of product development. STEP and STEP-NC is the most suitable information structure framework that needs to be enriched by the environmental aspects of the product/process data as shown in Figure 3. Eventually, with the proposed information framework, LCA related information is integrated to the design and process planning aspects of product development. The LCA knowledge and data accumulated throughout a product life cycle can be fed back to the product design stage to improve new product development and to reduce environmental impact.

FUTURE WORK AND CONCUSIONS

The research reported in this paper is the very beginning stage of developing an information framework to support the integration of LCA at the product design stage. A simple case study was conducted to examine what composite material information should be defined in association with product design information. The next steps of the proposed research are for the data structure level: i) identify the Product Life Phases needs in terms of environmental data versus the existing data into STEP, ii) identify a dynamic ontology of environmental data for product development, iii) structure the data and evaluation models to propose, usable simulation results for decision making, and iv) propose a STEP extension for End of Life support. For the data acquisition level: i) low level implementation (at the process level for the manufacturing phase) in order to enrich STEP with environmental concepts and start creating data base for process evaluation and optimization, ii) develop design approach and integrated tools specification based on STEP.

Sustainable product design and manufacturing is the future of today's manufacturing industry. The lack of manufacturing system and sustainability information integration hampers the widespread adaptation of the best sustainability practices in the manufacturing industry. In order to provide product designer with comprehensive material and environmental related information at the design stage, a complete information structure must be developed to associate sustainability information with product design information and product manufacturing process. This research proposes to develop such an information framework based upon STEP and STEP-NC information models. An initial case study was conducted to identify composite material information that should be defined for product design.

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