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On the integration of model-based feature information in Product Lifecycle Management systems

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ABSTRACT

As CAD models continue to become more critical information sources in the product's lifecycle, it is necessary to develop efficient mechanisms to store, retrieve, and manage larger volumes of increasingly complex data. Because of their unique characteristics, 3D annotations can be used to embed design and manufacturing information directly into a CAD model, which makes models effective vehicles to describe aspects of the geometry or provide additional information that can be connected to a particular geometric element. However, access to this information is often limited, difficult, and even unavailable to external applications. As model complexity and volume of information continue to increase, new and more powerful methods to interrogate these annotations are needed.

In this paper, we demonstrate how 3D annotations can be effectively structured and integrated into a Product Lifecycle Management (PLM) system to provide a cohesive view of product-related information in a design environment. We present a strategy to organize and manage annotation information which is stored internally in a CAD model, and make it fully available through the PLM. Our method involves a dual representation of 3D annotations with enhanced data structures that provides shared and easy access to the information. We describe the architecture of a system which includes a software component for the CAD environment and a module that integrates with the PLM server. We validate our approach through a software prototype that uses a parametric modeling application and two commercial PLM packages with distinct data models.

1. Introduction

Model-Based Enterprise is an emerging development paradigm where 3D models and Technical Data Packages are used as the main sources of documentation and communication throughout the lifecycle of a product. In a highly globalized world where technology evolves rapidly and digital information is vital, many organizations are moving away from the dependence on technical drawings to a model-based approach to design and manufacture their products. This move represents an opportunity to work more efficiently, increase performance, and ultimately remain competitive (Frechette, 2011).

In today's engineering and design environments, digital tools are used extensively to define all aspects of a product's lifecycle. For example, Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) tools are used to create, modify, analyze, optimize, and often fabricate a product. Other tools are used to create technical documents, manage information, resources, and services. By relying on digital technology, organizations can create information networks that can be used, shared, and leveraged by all stakeholders (Park, Fujimoto, & Hong, 2012; Regli, Hu, Atwood, & Sun, 2000). In this scenario, 3D models naturally become richer and more comprehensive data sources as they carry increasing amounts of design data and take the center stage of the product's lifecycle. For many design and manufacturing organizations that produce and consume large volumes of CAD data, automated and efficient solutions for managing these data are a must. These solutions often materialize in sophisticated file repositories and Product Lifecycle Management (PLM) tools, where data and processes are centralized, providing an efficient software infrastructure to coordinate product development activities.

The success of the MBE paradigm involves leveraging the benefits of annotated CAD models. When combined with PLM systems, these models facilitate the distributed development that is possible in the MBE setting (Caldwell & Mocko, 2008; Regli et al., 2000). For example, when a model is documented, both humans and computers can easily process and reuse the information, which eliminates errors, minimizes labor, and ultimately reduces the cost of supporting and maintaining

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the product throughout its life (Alducin-Quintero, Rojo, Plata, Hernández, & Contero, 2012; Drury, Pfaff, Klein, & Liu, 2013). However, the heterogeneous nature of the annotations as well as managing the links to the specific aspects of the model, make PLM integration a challenging task.

Modern CAD tools are beginning to embrace the MBE paradigm by implementing functionality to support model-based standards. This functionality is generally provided by Product and Manufacturing Information (PMI) modules. Because of the emerging nature of MBE and the fact that its use has not yet been widely adopted, PMI modules in many commercial packages are still incomplete and often provided as separate add-ons. PMI tools typically include symbols (such as dimensions and tolerances), and notes in textual format. Geometrical Product Specification symbols (GPS) [https://www.iso.org/publication/PUB100296.html] covers a subset of PMI with only manufacturing symbols, mainly linked to Geometric Dimensioning and Tolerancing (GD & T). The functionality is often limited to creating, editing, moving, and deleting annotations, although basic styling and formatting such as font size, color, and orientation can be adjusted. Advanced functionality such as annotation filtering, searching, and automatic processing, which are essential in collaborative environments, is currently missing. The limitations of current annotation tools are especially noticeable when working with heavily annotated models, and in collaborative environments.

In this paper, we lay the foundation for the development of a comprehensive information framework based on annotated CAD models for capturing, communicating, and sharing design knowledge. We present a software architecture that enhances the functionality of the standard 3D annotation mechanisms that are typically available in professional CAD packages by defining new data structures that can be connected and integrated with PLM systems. The proposed strategy combines the strengths of both internal and external representations to provide a richer and more comprehensive view of product-related information in an engineering development environment, which can significantly improve the information flows within collaborative CAD/CAM/CAE processes. Our approach demonstrates how standard annotation mechanisms can be used as the basis for a new infrastructure that supports information-rich CAD models where design information is embedded within the geometry. We validate our approach by implementing and testing a custom plug-in for a commercial CAD package with two distinct PLM systems with different architectures and data models running simultaneously. Technical and implementation details are described to ensure repeatability of our work.

2. Related work

2.1. Model-Based Enterprise (MBE)

Model-Based Enterprise (MBE) is an approach to product development that uses digital models to drive and coordinate all engineering activities throughout the entire product's lifecycle (Lubell, Chen, Horst, Frechette, & Huang, 2012). In this paradigm, 3D data are used as the main source of information and the entity from which other outputs and activities flow. CAD models become the vehicles that carry the product's documentation and enable collaboration among product teams (designers, analysts, technicians, manufacturers, procurement, etc.). Well implemented MBE environments have been shown to improve products, reduce time to market, and increase reusability (Boehm et al., 2010; Pellerin, Quintana, & Rivest, 2013). Recent initiatives to promote MBE include the ongoing efforts of the US Department of Defense and the US National Institute of Standards and Technology (NIST) Engineering Laboratory, both of which have been actively involved in the development of MBE for a number of years and have increased visibility of the MBE paradigm in both public and private sectors (Lubell et al., 2012; DoD, 2013).

The MBE paradigm is founded on the concept of Model-Based Definition (MBD). A product's MBD can be defined as a dataset comprising the model's 3D geometry and annotations (Quintana, Rivest, Pellerin, Venne, & Kheddouci, 2010). The annotations specify manufacturing and life cycle support data, known as Product Manufacturing Information (PMI), which may include Geometric Dimensions and Tolerances (GD & T), material and process specifications, and inspection requirements. To coordinate and communicate via a CAD model, it is necessary to not only define its geometry, but also to manage the associated notes and metadata that make the technical documentation of the product. The full technical description of a product is known as Technical Data Package (TDP) and consists of models, PMI, performance requirements, documentation, packaging information, and other details (DoD, 2013).

There are a number of benefits to migrate to an MBE environment. For example, many tasks can be automated, as digital data can be translated, processed, and shared easily as needed by users. The availability of design information across the system's lifecycle also leads to time savings, improved efficiency and data reuse, and ultimately cost savings for the organization (Silventoinen, Denger, Lampela, & Papinniemi, 2014). Many companies have already transitioned (or are in the process of transitioning), to paperless environments (Lubell et al., 2012). Because CAD models in the MBE environment are so inherently rich in information, it is necessary to implement mechanisms that can efficiently manage, track, and control product data. Similarly, to ensure the robustness of information and the effectiveness of communication, it is important to guarantee consistency in the creation and presentation of the digital CAD model. Maintaining the integrity of product information is the responsibility of all users and anyone who may add or change the model during its creation and revision. In this context, standards are critical as they dictate the necessary guidelines for efficient implementations and performance.

Two standards are relevant to the PMI approach based on annotated 3D models: ASME Y14.41 (Digital Product Definition Data Practices) (ASME, 2012) and ISO 16792-2015 (ISO, 2015). Both standards distinguish between the *design model* and the *annotated model* (or simply *model*). The design model is the "portion of the data set that contains model geometry and supplemental geometry." The model is "a combination of design model, annotations, and attributes that describe a product." In other words, design models become models when they are enriched by *attributes*, which are specifications that define certain properties (i.e. a type of metadata attached to the model). *Annotations* are instantiation of attributes (annotations display information of attributes).

Different types of annotations are defined: dimensions, tolerances, note, text, or symbols. The rules to display annotations are based on *annotation planes*, which are conceptual planes that either perpendicularly intersect or are coincident with one of the surfaces of the annotated feature. There are significant differences between symbols (in general, and also in the particular cases of dimensions and tolerances) and text (both notes and free text). Symbols are strictly defined—and thus are compact and strongly constrained—whereas text is free and more extensive than symbols, which makes it more difficult to process and automate. In addition, both ASME and ISO standards describe the expected behavior of the digital model when an attribute is queried: the corresponding annotation and its related information should be displayed. This action applies not only to the original CAD system, but also to any additional plug-ins.

Other standards such as the "SASIG 3D Annotated Model Standard" (SASIG, 2008) for the automotive industry, build on ASME and ISO guidelines to define how to work with free textual annotations. According to SASIG, the use of groups, layers, and links to views or sections of the geometry are recommended to make the model readable, as annotations in a complex model may quickly make visualization difficult (SASIG, 2008). In this paper, the previous standards are used to guide the development of the annotation structures that interact directly with the CAD environment and the user.