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A spatiotemporal information management framework for product design and assembly process planning reconciliation

Elise Gruhier [a], Frédéric Demoly [b,*], Samuel Gomes [b]

[a] Art et Métiers ParisTech, I2M, CNRS UMR 5295, 33405 Talence, France
[b] ICB UMR 6303, CNRS, Univ. Bourgogne Franche-Comté, UTBM, 90010 Belfort Cedex, France

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ABSTRACT

This paper introduces an innovative framework for product design and assembly process planning reconciliation. Nowadays, both product lifecycle phases are quasi concurrently performed in industry and this configuration has led to competitive gains in efficiency and flexibility by improving designers' awareness and product quality. Despite these efforts, some limitations/barriers are still encountered regarding the lack of dynamical representation, information consistency and information flow continuity. It is due to the inherent nature of the information created and managed in both phases and the lack of interoperability between the related information systems. Product design and assembly process planning phases actually generate heterogeneous information, since the first one describes all information related to "what to be delivered" and the latter rationalises all information with regards to "how to be assembled". In other words, the integration of assembly planning issue in product design requires reconciliation means with appropriate relationships of the architectural product definition in space with its assembly sequence in terms of time. Therefore, the main objective is to provide a spatiotemporal information management framework based on a strong semantic and logical foundation in product lifecycle management (PLM) systems, increasing therefore actors' awareness, flexibility and efficiency with a better abstraction of the physical reality and appropriate information management procedures. A case study is presented to illustrate the relevance of the proposed framework and its hub-based implementation within PLM systems.

1. Introduction

Over the last two decades, manufacturing industry has been progressively forced to compact its product lifecycles by ensuring a certain level of flexibility and efficiency as competitive edges, especially in the product development phase where design activities and decisions have a great impact on downstream processes. This has been done by considering the capture and integration of lifecycle constraints and knowledge in product design so as to deliver lifecycle friendly products. Nowadays, product design and assembly planning phases are almost concurrently processed in industry. This means that such effort has anyway provided competitive advantages in efficiency and flexibility by improving designers' awareness and product quality. Despite these efforts, some limitations are still encountered in product design regarding the lack of dynamical representation, information consistency and information flow continuity. This is due to the inherent nature of the information created and managed in both phases and the lack of interoperability between the related information systems.

Product design and assembly planning phases actually generate heterogeneous information. Indeed product design addresses the description of all information aligned to "what to be delivered", while assembly process planning focuses on the definition of all information related to "how to be assembled". In other words, the integration of assembly planning issue in product design requires reconciliation means with appropriate relationships of the architectural product definition in space with its assembly sequence in terms of time. The entire understanding of how parts are assembled within the embodiment design process is a critical issue and hence requires an appropriate context associated to assembly oriented design (AOD) issue. Actually the architectural definition of the product over the design process is defined by aggregating numerous design decisions/changes and multiple assembly constraints, which are generally triggered by either product architect or the designer, or better yet by the assembly planner in the AOD context.

* Corresponding author.
E-mail address: frederic.demoly@utbm.fr (F. Demoly).

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Nomenclature

PLM	Product Lifecycle Management
PDM	product data management
MPM	manufacturing process management
CAD	computer-aided design
ASP	assembly sequence planning
ASDA	assembly sequence definition algorithm
AOD	assembly oriented design
JANUS	Joined AwareNess and Understanding in assembly-oriented deSign with mereotopology
PROMA	product relationships management approach
PRONOIA2	PROduct relatioNships description based on mereotopological theory 2
MUVOA	MUlti-Views Oriented Assembly
MERCURY	a ManagEment framework appRoaCh of prodUct and process Relationships in assemblY and design phases
ASDA	assembly sequence definition algorithm
BOM	bill of material
eBOM	engineering bill of material
mBOM	manufacturing bill of material
BOR	bill of relation
DMU	digital mock-up
GIS	geographical information system
OWL	ontology web language
SWRL	semantic web rule language
XML	eXtensive Markup Language

From an information system point of view, product design and assembly process become more and more knowledge-intensive and therefore demand adapted and intelligent environment able to ensure dynamical representation, information consistency and information flow continuity in PLM systems. Currently, multiple PLM systems covers the beginning of the product lifecycle, such as product data management (PDM), manufacturing process management (MPM) and computer aided design (CAD) systems to name a few. Such systems have been introduced to ensure the management of the entire digital mock-up (DMU) of the product including its data structure and geometric definition, and its related manufacturing and assembly processes. As a result, some interoperability issues remain to be tackled since such systems consider spatial and temporal information without appropriate semantic and logical relationships [33]. Moreover, the fact of considering such heterogeneous points of view about the product development generally leads to inconsistencies, multiple design iterations and a lack of information continuity [50,52]. This operational challenge is emphasised by considering the proactive nature of assembly oriented design philosophy, which leads to propose a specific orchestration of the product-process information flows including appropriate viewpoints.

Some similar issues exist in the domains of geographic information system (GIS) and building information modelling (BIM), where ontology model is commonly considered as a solution to solve heterogeneity issues [28]. As such, one promising way to overcome this limitation is to introduce semantic and logical layers to product architecture definition via a multi-layer ontology [13]. Built on this, PRONOIA2 (PROduct relatioNships description based On mereotopologIcAl theory 2) ontology has been developed and will be considered as a foundational basis for the proposed framework. The ontology will provide a useful bridge in order to connect current PDM, MPM and CAD data models and ensure information flow continuity and orchestration.

As a consequence, this paper focuses on product design and assembly planning reconciliation in the context of AOD, which intends to consider assembly process planning issue in the embodiment design stage in a proactive manner. Here the main objective is to provide a spatiotemporal information management framework based on a strong semantic and logical foundation in PLM systems, increasing therefore actors' awareness, flexibility and efficiency with a better abstraction of the physical reality and appropriate information management procedures. In this context, the entire and seamless integration of assembly planning in product design has to be ensured with consistent relationships in the embodiment design phase to ensure a reliable product definition [30].

Firstly, the paper presents a brief literature survey on heterogeneity management issues in product design and assembly planning. Then, in Section 3, research background introduces the JANUS (Joined AwareNess and Understanding in assembly-oriented deSign with mereotopology) theory based on mereotopology, the PRONOIA2 ontology, and the product relationships management approach (PROMA), considered here as the foundation of the proposed framework. Section 4 presents the core of the contribution with a spatiotemporal information management framework so as to manage product evolution from a design and assembly points of view. In Section 5, a case study based on drones' design is described in order to illustrate the relevance of the proposed framework and its hub-based implementation within PLM systems. Finally, the advantages and limits of the framework are discussed in Section 6, and conclusions and future work are given.

2. Heterogeneity management issues in engineering

Some research issues remain to be tackled in PLM systems and more especially in PDM and MPM systems [29], where critical information is still lacking in order to have a full understanding of the design and process activities. As an example, PDM systems currently manage purely spatial product information embedded in documents with various functionalities such as versioning, bill of material (BOM) management, workflow management, check-in/check-out procedures, change and configuration management and so on [22]. It intends to ensure that the right information is available for the right person at the right time and in the right format. Despite the information brought by PDM systems, few even none information about the relationships between parts and changes undergone by the product during its development is captured and managed. For instance, some comments on product documents' iterations enable the understanding of what has been changed between the different versions of a file, but a lack of semantic description of changes in such systems is highlighted. Besides, MPM systems are restricted to manage temporal information. The description of relationships between assembly operations are actually limited to precedence and equal relationships [32].

The current issue of PDM and MPM systems in industry is their unidirectional way of reconciliation, which leads to inconsistent product definition over space and time, especially if a concurrent engineering strategy is adopted. Indeed, such procedure exists in MPM systems and enables a kind of continuity of product-process information via the engineering BOM (eBOM) and manufacturing BOM (mBOM) reconciliation link, but limited to a structural level. At this stage, it is vital to work at an architectural level, enabling the link of product and process models in the spatiotemporal dimension in order to better represent real phenomena, otherwise the lack of information about product evolution will be propagated on CAD models with a static description of the product. David and