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Geometric skeleton computation enabling concurrent product engineering and assembly sequence planning

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ABSTRACT

This paper introduces a novel modelling approach to geometric skeleton computation enabling concurrent product engineering and assembly sequence planning. Current engineering vision has recently moved towards new modelling and management paradigms to maintain competitive edges all along the product lifecycle. Consistent with concurrent engineering and design for X stakes, this recent shift promotes cross-X and knowledge-intensive philosophies in the product development process, principally focused on lifecycle engineering.

The main objective of this research is to integrate assembly process engineering information and knowledge in the early phases of the product development process in a top-down and proactive manner, in order to provide a geometric skeleton-based assembly context for designers. The definition of the product and its related assembly sequence requires both the enhancement and the entire understanding of product relationships between the various product components, and its related assembly rationale. As a consequence, this new modelling approach highlights the need to integrate various stakeholders' viewpoints involved in the beginning of the product lifecycle. In such a context, earlier work has achieved the early generation of an optimal assembly sequence in the product development process, before the product geometry is completely defined. As a result, previous research has made possible to control and bind the product modelling phase through an assembly oriented product structure.

The aim of the proposed approach is to compute and define a geometric skeleton model based on product relational information and the early-defined assembly sequence. The proposed approach – called SKeLeton geometry-based Assembly Context Definition (SKL-ACD) – enables the control of the product modelling phase by introducing skeleton entities consistent with product relationships and assembly sequence planning information. A prototype application within a CAD tool has been developed for aiding geometric skeleton computation and generation. Lastly, an industrial case study is introduced to highlight the feasibility and the relevance of the proposed modelling approach.

1. Introduction

Nowadays, the product development process has become more knowledge-intensive and lifecycle-oriented to provide better products, fulfilling lifecycle engineering requirements and constraints in a more efficient way. This trend enables manufacturing companies to maintain their competitive edge and business drivers in terms of reactivity, flexibility and efficiency at the beginning of the product lifecycle (BOL), as already successfully realised in production with agile manufacturing processes and systems [1]. Following emerging practices in industry, the current need consists in providing strategic means to introduce lifecycle engineering information and knowledge, in the product development process through CAD (Computer Aided Design) models, at the beginning of the geometry modelling phase [2]. Despite the amount of research work on intelligent and collaborative CAD models [3,4], which embed deeply specific engineering knowledge through templates and parametric models [5,6], it is now important to consider CAD models in another fashion. Up until now, designers specified and defined the product geometry from a single point of view, i.e. functional aspect, and performed the related tasks in a sequential way compared to downstream processes.

Here, the breakthrough consists in providing lifecycle awareness and consideration for product architects and designers, by incorporating product lifecycle stages in an integrated and proactive

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manner, in the early product development process [7]; considering therefore the product geometry definition as the result of the integration and consideration of all product lifecycle aspects. The current engineering vision has recently moved towards new modelling and management paradigms to maintain competitive edges all along the product lifecycle, especially at the BOL phase. Consistent with concurrent engineering and design for *X* stakes [8], this recent shift promotes cross-*X* (domain, lifecycle, enterprise, etc.) and knowledge-intensive philosophies in the product development process, principally focused on lifecycle engineering [9].

In such a context, the authors focus on data-information-knowledge integration issues between product design and assembly process engineering. This paper introduces a novel modelling approach to geometric skeleton computation and definition, enabling both targeted lifecycle engineering domains. The main objective of the research is to integrate assembly process engineering information and knowledge in the early phases of the product development process in a top-down and proactive manner, so as to provide a geometric skeleton-based assembly context for product architects and designers. The definition of the product and its related assembly sequence requires both the enhancement and the entire understanding of product relationships between the various product parts, and its related assembly rationale [10]. As a consequence, this new modelling approach highlights the need to integrate various stakeholders' viewpoints involved in the beginning of the product lifecycle. Previous research work has achieved the early generation of an assembly sequence in the product development process, before the product geometry is completely committed, therefore controlling and binding the product modelling phase through an assembly-oriented product structure [11–14]. The aim of the proposed approach is to compute and define a geometric skeleton model based on product relational information and the early-defined assembly sequence. The proposed approach enables the management and the control of the product modelling phase by introducing geometric skeleton entities, consistent with product relationships and assembly sequence planning information. It also enables the product modelling phase in a top-down and proactive fashion.

The paper presents a brief overview on the significant amount of research work performed in concurrent product design and assembly sequence planning, and assembly modelling with special emphasis on skeleton based-geometry modelling approaches in Section 2. Section 3 introduces the proposed approach, called SKeLeton geometry-based Assembly Context Definition (SKL-ACD), in order to define a geometric skeleton-based assembly context in the preliminary product development process. In the last section, the implementation of the proposed approach, in a PLM-based application called Product design Engineering based on Generative Assembly SeqUenceS planning (PEGASUS) and a specific module called PEGASUS CAD Assistant within a CAD tool, is described with an industrial case study to demonstrate its application.

2. Literature survey

This section states a brief overview on the significant amount of published research work on concurrent product design and assembly sequence planning (ASP), and assembly modelling with special emphasis on graph-based and geometric skeleton-based modelling issues. It also provides a conclusion of the key findings of the current research status and challenges in these fields.

2.1. Concurrent product design and assembly sequence planning

The concept of integrating ASP with product design was introduced at the beginning of the previous decade in order to overcome the current limitations of Design for Assembly (DFA) and ASP approaches. Actually, most of the research work performed and reported in the field of DFA can be classified as of semi-generative approaches based on heuristics and geometric rules, in order to facilitate the assembly phase of the physical product [15–17]. Based on detailed product geometry, and a part-to-part oriented evaluation, DFA approaches lead most of the time to a redesign of products [18]. On the other hand, research work on ASP has resulted in generating, through algorithms, exact and heuristic methods – which are presented through graphs and diagrams – and evaluating assembly sequences with decision criteria from detailed product geometry and related assembly relational models [19,20].

In such a context, the issue of concurrent product design and assembly sequence planning [18,21,22] – also called "Assembly-Oriented Design" (AOD) [23,24] – has received much attention in research work during the last decade [25]. Product design and assembly sequence planning stages are normally undertaken separately and sequentially, which results in missing the true integration between both phases. AOD is a promising manner of tackling current engineering practices focused on detailed part geometry [26]. Here, the assembly-oriented practice of product development can be considered as a top-down approach by proactively considering the assembly related product design and its relationship issues in the early phases of the product development process [27]. This emergent trend highlights some challenges related to the recent shift in engineering design that promotes a relationship-based modelling and management paradigm [28]. Thus, engineering requirements consist of closer integration of product design models and lifecycle models. Earlier applications of lifecycle knowledge to generate design decision resulted in informed design decision making, better traceability on various levels of abstraction of the product, and rational and consistent information management support with the concept of "relational design".

2.2. Assembly modelling: from graph to geometric skeleton

Over the past three decades, assembly modelling has received most attention from researchers and manufacturing industries whenever various aspects of the product have been tackled. Assembly modelling can be considered here as the definition of an informational product model including all product components and the related relationship information at various abstraction levels, and dedicated to various purposes. More specifically, this section mainly focuses on graph-based and geometric-based modelling approaches, which are relevant and consistent with the aforementioned objective.

First of all, from a functional point of view, researchers have focused on assembly representation through various kinds of graphs, such as AND/OR [29], Petri net [22], directed graph [11,13,30], CSBAT (Connection-Semantics-Based Assembly Tree) [31], and so on. Initially, these graphs were introduced as relevant input for assembly sequence planning issues, where a lot of models and methodologies have been proposed and published [25]. Among the latest proposed models and ontology in the literature, relevant work has been done by focusing on assembly formalisms and semantics in a collaborative product development context [32–34]. In addition, NIST (National Institute of Standards and Technology) has suggested generic models, such as CPM (Core Product Model) [35], CPM2 [36] and OAM (Open Assembly Model) [37] that are particularly relevant to represent the product in an integrated manner, including assembly features and so on. More focused on multiple aspects of the product representation, the MUVOA (Multiple Viewpoint Assembly oriented) model has enabled its representation through its lifecycle by incorporating the