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Highlights

Computers in Industry xxx (2013) xxx–xxx

Product relationships management enabler for concurrent engineering and product lifecycle management

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- Application of a product relationships management approach in PLM.
- Approach enabling the concurrent product design and assembly sequence planning.
- Implementation of integrated product-process data management techniques in a PLM hub application.

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ABSTRACT

The current competitive industrial context requires more flexible, intelligent and compact product lifecycles, especially in the product development process where several lifecycle issues have to be considered, so as to deliver lifecycle oriented products. This paper describes the application of a novel product relationships management approach, in the context of product lifecycle management (PLM), enabling concurrent product design and assembly sequence planning. Previous work has provided a foundation through a theoretical framework, enhanced by the paradigm of product relational design and management. This statement therefore highlights the concurrent and proactive aspect of assembly oriented design vision. Central to this approach is the establishment and implementation of a complex and multiple viewpoints of product development addressing various stakeholders design and assembly planning points of view. By establishing such comprehensive relationships and identifying related relationships among several lifecycle phases, it is then possible to undertake the product design and assembly phases concurrently. Specifically, the proposed work and its application enable the management of product relationship information at the interface of product-process data management techniques. Based on the theory, models and techniques such as described in previous work, the implementation of a new hub application called PEGASUS is then described. Also based on web service technology, PEGASUS can be considered as a mediator application and/or an enabler for PLM that externalises product relationships and enables the control of information flow with internal regulation procedures. The feasibility of the approach is justified and the associated benefits are reported with a mechanical assembly as a case study.

1. Introduction

The current academic and industrial product lifecycle management (PLM) vision—that consists in setting up a comprehensive set of models, methodologies, processes and information systems covering the entire product lifecycle [1–3]—has not yet fulfilled all life phases' requirements [5,4,6]. This is particularly right at the beginning-of-life (BOL) phase where product designers, process engineers, and assembly planners are still working separately without any recovery, overlap or feedback loop facilities/features in their tasks. Past research efforts have led to successful design for X (DFX) and knowledge-based techniques in product design in order to integrate all constraints of each life phases (i.e. manufacturing, assembly, disassembly and recycling) [7,8], but some gaps still exist in the management of the various technical entities and the control of information/decision/rationale flow through the product lifecycle [11]. This becomes a barrier for applying an efficient concurrent engineering philosophy in BOL and remains a huge challenge to be tackled [9,10].

Previous work argued that companies required efficient concurrent engineering (CE) [12] and PLM strategies [11] in order to maintain their business competitive edge. One particular industrial requirement is the need for concurrent considerations of lifecycle issues for different life aspects into the early product design process [13–15]. It is clear that current product geometry—based on traditional part and feature oriented modelling approaches—only

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Nomenclature

PLM	product lifecycle management
PDM	Product Data Management
MPM	Manufacturing Process Management
CAD	Computer-Aided Design
CAPP	computer-aided assembly process planning
BOL	beginning-of-life
DFX	design for X
CE	concurrent engineering
ASP	assembly sequence planning
AOD	assembly oriented design
PROMA	product relationships management approach
PASODE	proactive assembly oriented design
MUVOA	MUlti Views Oriented Assembly
ASDA	Assembly Sequence Definition Algorithm
ERP	Enterprise Resource Planning
SCM	Supply Chain Management
BOM	bill of material
eBOM	engineering bill of material
mBOM	manufacturing bill of material
BOR	bill of relation
UML	Unified Modeling Language
XML	eXtensive Markup Language

represent a limited view of product lifecycle information, and have limited benefits for CE and PLM strategies [16,17]. To overcome these difficulties, this paper proposed a Product design Engineering based on Generative Assembly SeqUenceS planning (PEGASUS) application and it is aimed to bring the potential benefits of CE into this integrated and concurrent product design and assembly sequence planning (ASP) stages.

Using previous research results related to assembly oriented design (AOD) and PLM issues [18], the paper presents the implementation of an approach, which aims to reveal the relationships among product parts and operations as well, and maximize the usage of these relationships whilst maintaining information consistency [19] and seamless flow between product design and ASP phases [11].

In Demoly et al. [20–22] a research background and framework entitled Proactive ASsembly-Oriented DEsign (PASODE) as well as a multiple views model called MUltiple Views Assembly Oriented (MUVOA) [23] and the Product RelatiOnships Management Approach (PROMA) to manage product relationships have been described in detail [11]. Here, the implementation of PROMA into a new PLM hub application called PEGASUS is detailed and it is carried out by using framework and models described in [22]. This approach implementation also uses web service technology to provide wider and easier access and distributed design and working, which is part of latest implementation efforts in PLM systems [25]. The whole approach is intended to extend the traditional PLM systems capabilities to be a new lifecycle oriented application with new theoretical model.

Section 2 presents a survey on current PLM systems implementations status in industry. This survey is followed in Section 3 by the description of the research background in terms of model, framework and approaches. Section 4 introduces the description of the PROMA application in PEGASUS, which is based on web service technology and used C# as programming language. The implementation aims to enable the reasoning and control of information flow between PDM (Product Data Management) and MPM (Manufacturing Process Management) systems, and CAD (Computer-Aided Design) applications. Last, considering the implementation as a prototype, an industrial case study has been undertaken and is detailed in Section 5, so as to demonstrate the applicability and the benefits of PROMA and PEGASUS.

2. Survey on application status of PLM systems in industry

Introduced at the beginning of the 2000s, the PLM strategy consists of the management of the whole product data-information-knowledge for its entire lifecycle [1,6]. This research topic has since also received much attention from industry where current practices are more focused on the management of product technical data and associated workflows through various engineering systems [24]. As such, many industrial engineering departments have tackled PLM issues, essentially in BOL and Middle-Of-Life (MOL) of the product, by implementing methodologies into various systems such as PDM, Computer Aided X (CAX), MPM, Enterprise Resource Planning (ERP), and Supply Chain Management (SCM) systems in a single and global digital environment, where all enterprise departments have a role to play [20].

In the above defined context of CE, several research issues have to be investigated and tackled on current industrial practices in PLM systems, especially on PDM and MPM systems [26,27]. Specifically, a PDM system is intended to ensure that the right information is available for the right person at the right time and in the right format by introducing various functionalities such as versioning, bill of material (BOM) management, workflow management, check-in/check-out procedures, and engineering change and configuration management to name a few [28,29]. Regarding engineering design data that consists of parts, sub-assemblies, BOMs, specifications, analysis results, configurations and so on, PDM systems can be considered as product model storage systems and still be centred on product information usually embedded and sometimes hidden in files and documents [11].

In addition to the above concerns, a lack of associativity in PLM systems has also been highlighted [30], where only "parent–child" (i.e. "is part of" class) relationship exists. For a large scale company, the management of relative positions of parts using positioning matrices is implemented in PDM systems in order to be more closely related to geometric models defined in CAD systems, and to facilitate change management and part positioning [32]. Furthermore, other authors [33,34] have proposed an advanced PDM system based on a property-driven development/design (PDD) approach by introducing the handling of predicted engineering characteristics (i.e. structure, shape and material) and properties (i.e. product's behaviour) of the product with their interdependencies in a separate manner. However, information related to product relationships and assembly process engineering is not effectively treated in their proposal. PLM systems have moved towards web-based and web service technologies, in order to facilitate information exchange and access in distributed and extended enterprises [7,25]. An additional effort towards ontology and semantic web can also be found [35–38]. Recently, Cantamessa et al. [39] in their PLM implementation survey have stressed a similar need about the future role of PLM in supporting and coordinating knowledge by allowing easier access to product data and embedded tacit knowledge.

According to the above applications and approaches, a lack of support of associability among product models using product relationships still exists and is a barrier for effective and integrated lifecycle oriented design [16,30,17].

At the interface of Computer Aided Assembly Process Planning (CAAPP) and ERP systems, MPM systems enable the management

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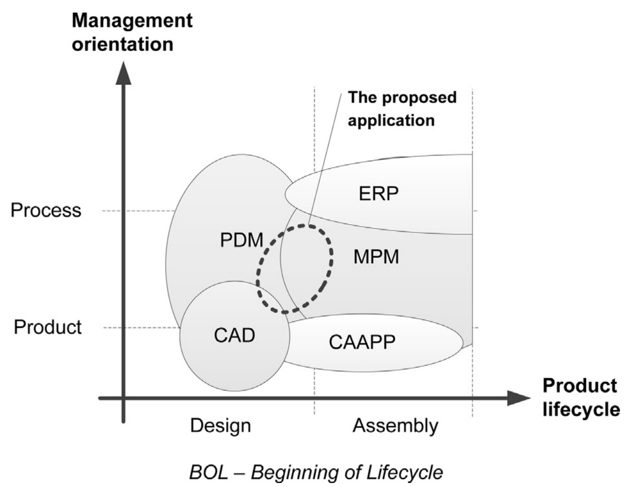

Fig. 1. PLM systems and CAX tools at the BOL phase [11].

of all the information (i.e. assembly operation, assembly sequence, manufacturing BOM and resource) related to assembly process engineering in order to cope mainly with assembly sequence planning [31] and assembly line balancing issues. The future trend for these kinds of system is to integrate current procedures used in PDM systems, so as to provide an integrated management approach (i.e. multi-BOM, product/process configuration management) in the broader context of PLM [40]. As such, Jun et al. [41] have introduced the closed-loop PLM concept, which describes new information flows in PLM (i.e. from use phase to design and manufacturing phases). Fig. 1 presents a research map of current PLM systems through the BOL (i.e. engineering design, assembly process engineering) and the related orientation management in order to situate the proposed application focus, enabling a better interaction between product and process data management systems.

3. Research background: model, framework and approaches

Over the past five years, the authors have addressed particular attention to the development of model, methods and tools, which cover the assembly-oriented design field, by considering concurrently product design and assembly sequence planning [18]. In the following subsections, a brief description of the research background is introduced.

3.1. MUVOA as a multiple views model

As part of an initial effort, the MUVOA model has been defined for describing product-process concepts, their related associations and structures so as to be used in an integrated and proactive manner. This model has been organised into several view models (functional, structural, behavioral, contextual, geometric and technological), which are consistent with viewpoint, concern, and purpose associated to each stakeholder (i.e. product architect, designer, assembly planner and process engineer) involved in product design and ASP phases (Fig. 2) [42,43]. A detailed description of this model can be found in [23] on which a proposed information flow in PROMA facilitating information propagation [11] is considered in the PEGASUS application, especially on concepts relationships (i.e. both in contextual view in product domain and assembly domains).

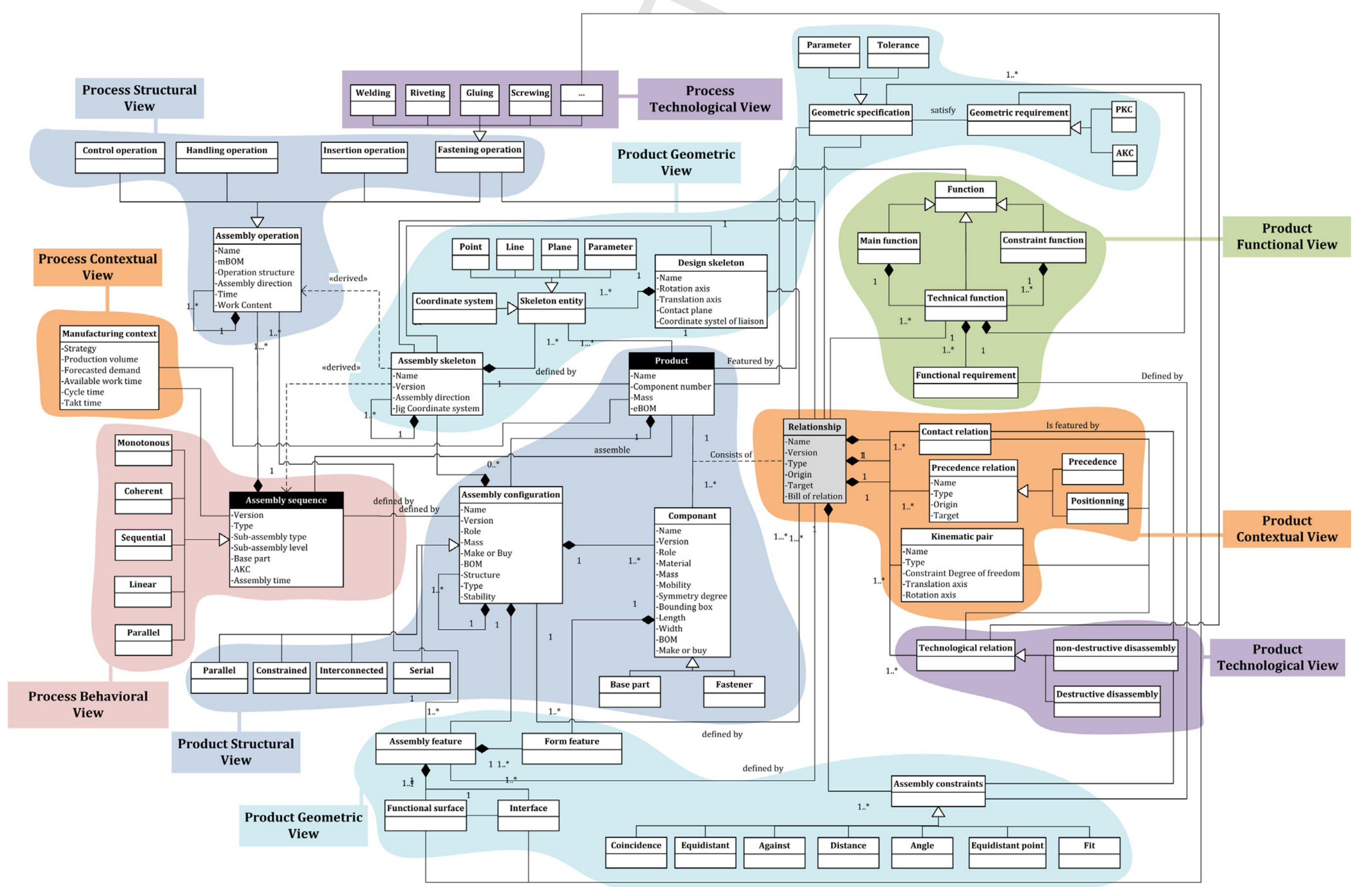

Fig. 2. UML class diagram describing the MUVOA model [23].

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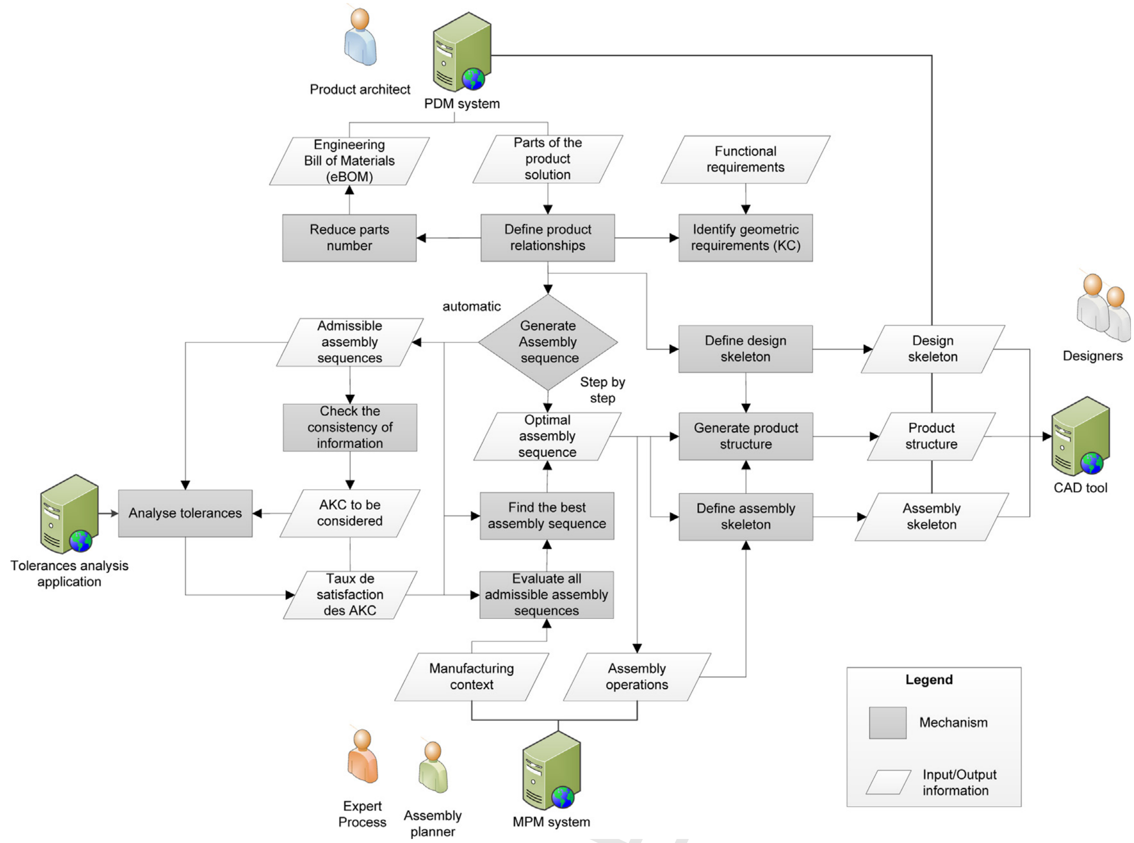

Fig. 3. PASODE framework [18].

3.2. PASODE as a comprehensive framework and related approaches

Based on this multiple views model which covers product design and ASP concerns, a general and comprehensive framework called PASODE has been proposed in order to promote a proactive AOD vision in the early product development process before defining product geometry (Fig. 3). This framework incorporates two mathematical algorithms related to two approaches:

- called *Assembly Sequence Definition Algorithm* (ASDA) based on DFA and ASP heuristics rules, associated to a tolerance analysis, which defines an optimal assembly sequence by considering as input the definition product relationships at various abstraction levels [20,22,21];
- called *SKLeleton-based Assembly Context Definition* (SKL-ACD) based on kinematic and technological pairs, which describes design intents from a top-down manner and therefore supports product modelling activity in CAD application through skeleton entities and structure [32].

As such, the act of defining an assembly sequence using part-to-part relationships information enables the definition of assembly skeleton (i.e. geometric entities) related to lifecycle engineering issues for geometric product modelling in CAD applications [15,32]. Fulfilling current stakes in AOD issue, the PASODE framework consists of various steps, in which four stakeholders, such as considered within MUVOA, are involved. At this stage the product architect can be considered as a highly skilled and experienced system designer who has an overall vision of the product or system definition and functionality. His major role is to define the product overall functionality and lifecycle requirements and generate a product architecture which fulfils functional and technical requirements related the product lifecycle stages. At lower abstraction levels, the designer is more concerned with the sub-assembly and parts definitions by taking into account the product architect's definitions for each of these parts or sub-assemblies. The assembly planner is concerned with planning task of putting parts together once they are completed and manufactured through the process engineer's inputs (i.e. technological information). So this framework presented in Fig. 3 can be deployed as follows:

Step 1. Based on functional requirements, geometric requirements —such as Performance Key Characteristics (PKC)—are deployed into the PDM system through the engineering BOM (eBOM).

Step 2. The part-to-part relationships definition phase is carried out by the product architect at various abstraction levels such as functional, behavioural, technological and geometric. Each layer of relationships information is computed to optimise part number and generate admissible assembly sequences.

Step 3. For each admissible assembly sequence, a consistency checking procedure related to constrained degrees of freedom is processed to highlight specific requirements namely Assembly Key Characteristics (AKC).

Step 4. All admissible assembly sequences and related AKC are introduced in a tolerance analysis tool in order to find which assembly sequence fulfils all geometric requirements of the product.

Step 5. So the selection of the well-balanced assembly sequence can be carried out by introducing AKC interval values.

Step 6. Once the assembly sequence is defined, several information embedded PLM systems views can be generated, including manufacturing BOM (mBOM) in MPM system, product

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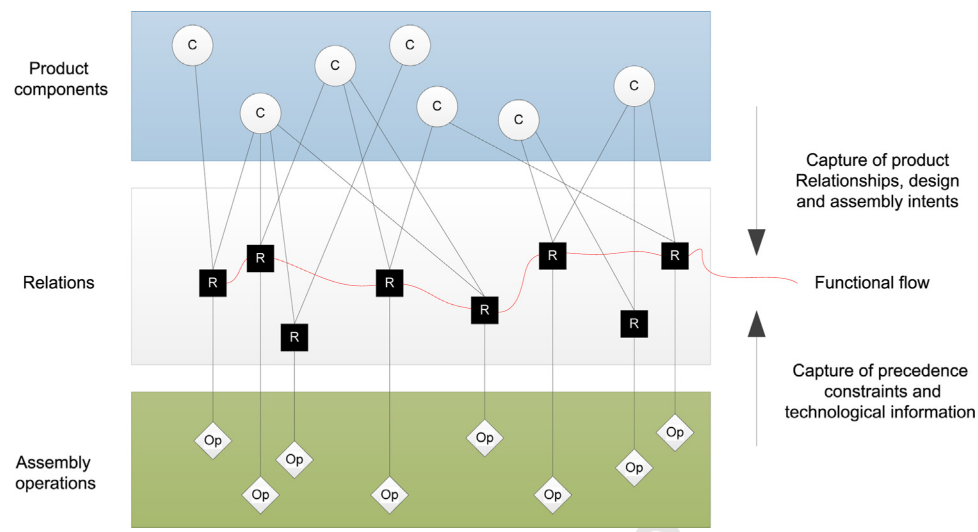

Fig. 4. Capture of product relationships from product components and assembly operations networks [11].

structure and skeletons-based assembly context in PDM/CAD systems.

Fig. 3 illustrates various mechanisms (grey boxes) and related input/output information (white boxes) to show the aforementioned steps. The relevance of part-to-part relationships as well as product relationships in these above-mentioned approaches requires emerging needs in their management so as to capture an original state of the product-process, propagate information from PDM system and CAD application and check information consistency with assembly technologies in MPM system.

3.3. PROMA as an internal regulation approach

Key to the concurrent development of product solution as well as assembly planning, a novel approach entitled PROMA has been developed as a critical technology in PEGASUS to improve the capabilities of current PLM systems (i.e. CAD, PDM and MPM systems) by introducing procedures of managing product relationships at various abstraction levels of information for a better information control and flow. It is the core mechanism to support the use and management of relationships extracted from product and assembly process domains in PLM systems (Fig. 4) [44]. It therefore provides a new support to control and organise information flow between product and assembly process domains in PLM systems. In such a way, a proactive and interactive concurrent product and assembly plan development using assembly process information, as a representative of lifecycle process, is enabled. More specifically, in such a design session, assembly process and information are used to externalise and highlight any potential negative issues and impacts caused by a product design decision.

For example, relying on the use of too many bolts and nuts for assembling two or more parts together results in much long assembly operations, hence higher assembly complexity and cost. Through revealing such design decisions and its associated consequences, it is possible and feasible to externalise these decisions and their negative impact on the design. At the same time, designers, assembly process planners and process engineers are encouraged to explore alternative assembly methods, technologies or means to fulfil the assembly process requirements.

In order to support this new and concurrent vision, the PROMA approach has been initially developed in [11] and can be illustrated in Fig. 5 where it deals with various traditional PLM modules, establishes important links among lifecycle models and bridges the gap between lifecycle models, especially at the BOL stage. These relationship types existing in product lifecycle include those between product structure and its function and design rationale; product structure and overall assembly sequences; part features and assembly operations; product structure and CAD models; eBOM (engineering bill of material) and mBOM (manufacturing Bill of Material); component material and suitable manufacturing processes including disposing processes and so on. Further details can be seen in Fig. 5, where the centralization of parts, assembly operations and assembly skeletons relationships is described. As such and according to the aforementioned PASODE steps, PROMA will manage the information propagation through design and manufacturing data structures (i.e. eBOM, CADBOM and mBOM) by using the Bill Of Relations (BOR) concept [11]. In order to facilitate understanding, this paper only describes and focuses on the relationships identified between product design and assembly sequence planning phases as an example of lifecycle activity to illustrate the PROMA philosophy. Similar approach can be extended and applied to other lifecycle phases such as maintenance, disassembly and so forth.

4. Implementation of PROMA in a PLM hub application

Based on this additional description of PROMA approach [11], its relevance and feasibility need to be demonstrated. As such, a PLM hub application (PEGASUS) as prototype application is introduced to manage information flows and provide internal regulation procedures between design and assembly planning stages.

4.1. Overview of PEGASUS introduction in current PLM systems

The PLM hub application has to fulfil current ICT requirements in design and manufacturing fields, especially at their interfaces. As addressed in Section 2, some common issues in PLM systems such as PDM and MPM systems are the lack of associativity, understanding and reasoning based on knowledge in order to promote reactivity and agility in engineering design. This explains in part the traditional barrier between design and manufacturing phases as well as between manufacturing and production phases. In Fig. 1, an existing gap has also been highlighted between PDM, MPM and CAD systems, and therefore Fig. 6 illustrates an

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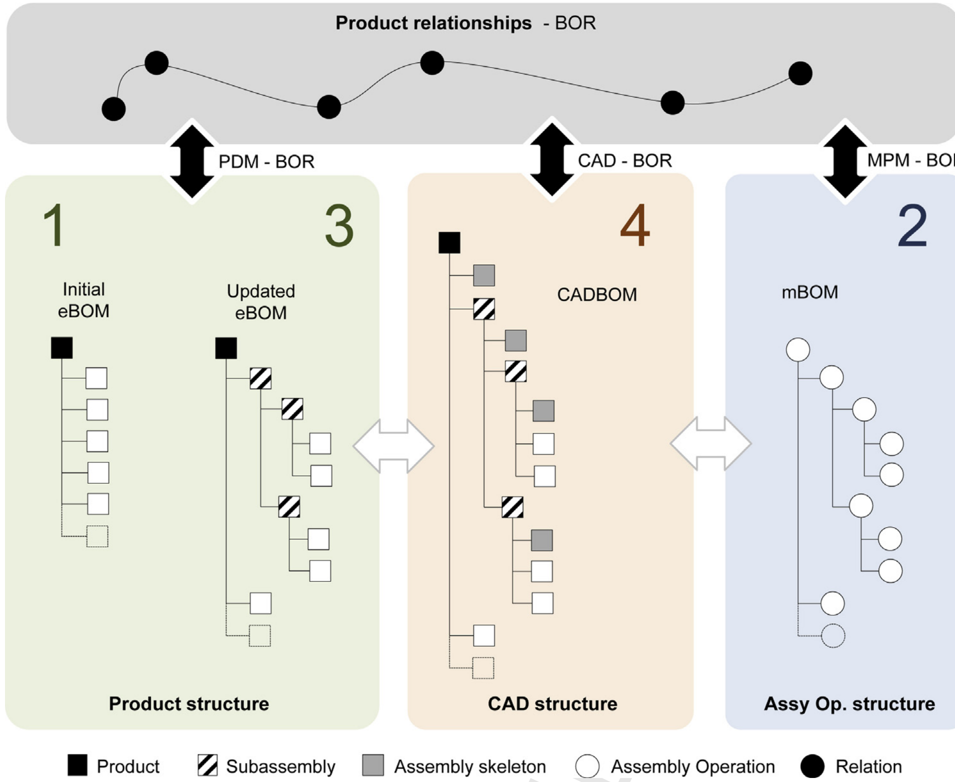

Fig. 5. Centralization of parts, assembly operations and assembly skeletons relationships.

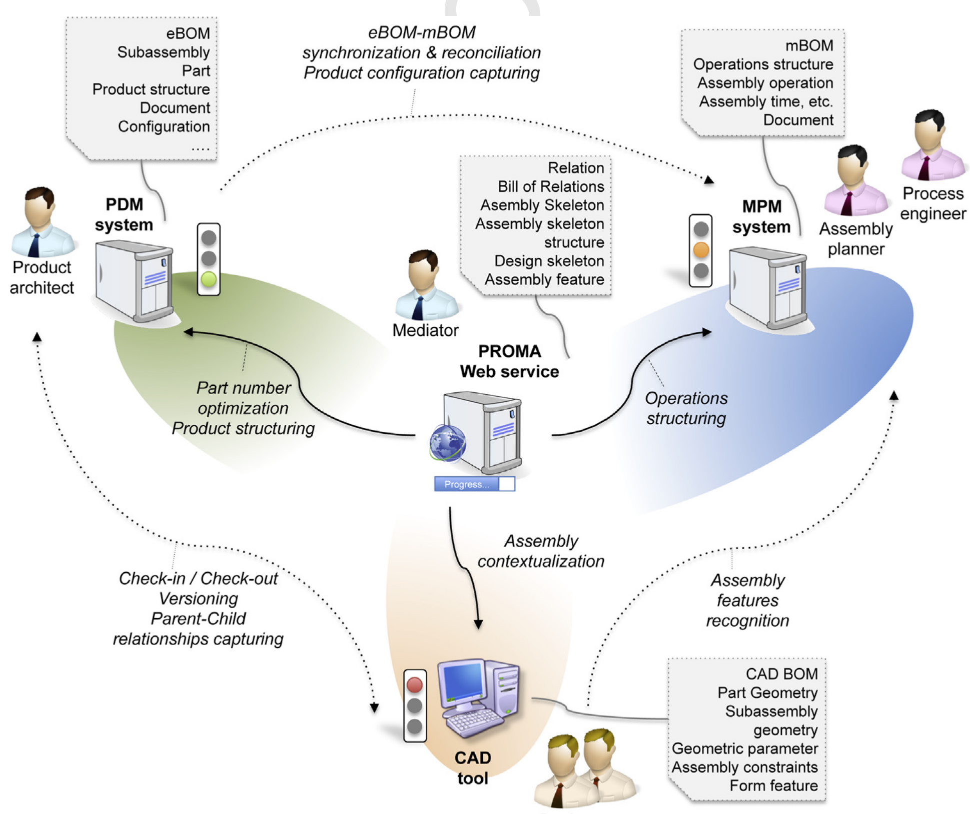

Fig. 6. Introduction of the PEGASUS application in connection with PDM, MPM, and CAD systems.

introduction of PEGASUS as a hub application which orchestrates information flows between above-mentioned systems.

Currently PDM systems enable the management of engineering technical data such as eBOMs, subassemblies, parts, product structures, documents, configurations, and provide comfortable support for designers and product architects. At the manufacturing side, MPM systems enable the management of manufacturing/assembly data such as mBOMs, operations, documents and so on, and provide assistance in assembly planning and assembly line balancing phases. At a lower abstraction level, CAD applications consist in modeling product geometry including its parts, subassemblies, forms, parameters, constraints to name a few. The current information exchanges between these systems are represented with dotted arrows, and can be understood as follows:

- a one-way eBOM–mBOM synchronization/reconciliation associated to product configuration capturing between PDM and MPM systems;
- bidirectional procedures of check-in/check-out and versioning between PDM and CAD systems;
- a one-way assembly features recognition between CAD and MPM systems.

To overcome current PLM limitations and increase its capabilities in information propagation and data consistency, a hub application is introduced as a central application which supports the orchestration and maintains associations between design and assembly technical data/information. As such, new technical entities, such as relations, bill of relations (BOR), assembly skeletons and so on, are introduced in order to provide an additional state of product-process information (i.e. a new picture of product-process engineering efforts), therefore enabling the understanding for both sides [11]. Thus this novel application integrates procedures associated to the PASODE framework in order to impact existing views in PDM, MPM and CAD systems [22,21]. Based on these explicit representations of relationships, PEGASUS reasons and highlights the relevant relationships to enable concurrent product and assembly process development. Moreover, the aforementioned exchange procedures are reviewed in order to be used and triggered in a central manner. These new exchange procedures will be described in detailed in the implementation section.

4.2. Functional specification of PEGASUS

PEGASUS, the so-called hub application, has to support four types of stakeholders of a product development process, namely, the product architect, assembly planner, designer and process engineer. Within PEGASUS, the tasks which are normally performed in a sequential fashion by the product architect and the assembly planner have been identified and represented as a generic set of integrated product development tasks. The potential inherent relationships between these two groups of tasks are also shown in Fig. 7 and they are vital for the concurrent design solution and assembly sequence generation. For example, when the product structure is defined, all key part-to-part relationships are then finalised. Using this information, it is possible to concurrently generate all admissible assembly sequences. Similarly, using the product or component material information in conjunction with product geometry information, it is possible to define the manufacturing context as well partial manufacturing process and assembly operations. This concurrent model can then be used to validate the design solution in terms of meeting product manufacturability, such as successfully tackled with assemblability issues [21].

The development of the proposed application first requires functional specifications in consistency with expected PASODE mechanisms and future PEGASUS functionalities before full implementation. Basically, the interlinked and concurrent tasks for stakeholders such as the product architect and the assembly planner have to be identified and represented first and in this research; they have been represented in a UML (Unified Modeling Language) use case diagram as shown in Fig. 7. It is important to emphasise that this representation introduces new integrated

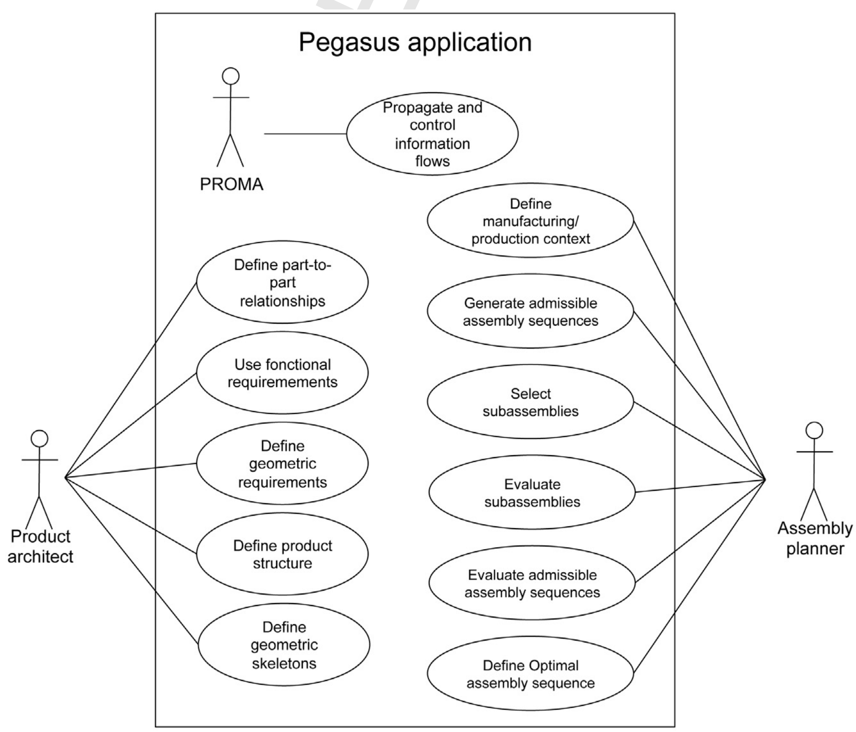

Fig. 7. UML use case diagram of PEGASUS application.

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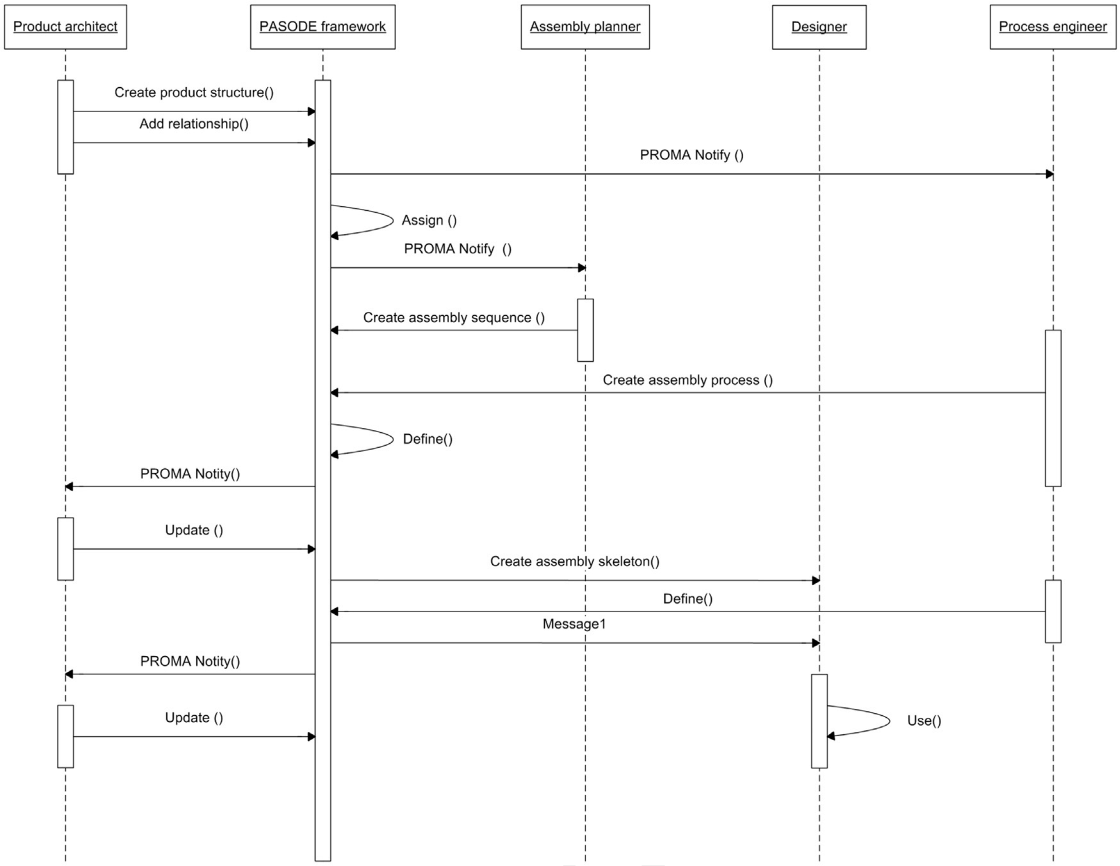

Fig. 8. UML sequence diagram related to PEGASUS interactions.

management functionalities to address the identified needs for PEGASUS application underlined in Section 3. At this stage, PROMA is considered as an additional stakeholder for facilitating information propagation through product and process views. This UML diagram also provides further engineering tasks derived from current PLM systems. In addition, the MUVOA model presented in Fig. 2, as proposed in [23], has been implemented as a data model on which PROMA approach is based, and PEGASUS consequently.

Once UML use case and class diagrams have been completed, a new UML diagram—considered as a macroscopic sequence diagram—is introduced in Fig. 8 to show expected scenarios in PEGASUS application. This UML sequence diagram is intended to provide an example of the chronology of concurrent tasks and automated operations embedded in PEGASUS and enabling the definition of the product and the assembly process models in a concurrent manner.

This UML sequence diagram (Fig. 8) illustrates information flows through tasks in the PEGASUS application in greater details and is an expansion of the PASODE theoretical framework [21]. It is now important to allocate views based on the MUVOA model illustrated in Fig. 2, which is considered as the data model of the PEGASUS application. Table 1 presents such a proposed allocation that highlights the implementation of the main view that is *product contextual view* into PEGASUS, in which part-to-part relationships are captured and managed. Once this view is defined, product design stakeholders can then focus on developing in-depth relationships, based on which integrate product design and assembly sequence planning can be achieved.

Table 1
Allocation of MUVOA views to PLM systems.

Domain	View	PEGASUS	PDM	MPM	CAD
Product	Functional	●	○	○	○
	Contextual	●	○	○	○
	Technological	●	○	○	○
	Structural	●	●	○	○
	Geometric	●	●	○	●
Assembly process	Structural	○	○	●	○
	Contextual	●	○	●	○
	Behavioural	○	○	●	○
	Technological	●	○	●	●

4.3. PEGASUS architecture and implementation

As a result, the PEGASUS application has been developed as a research demonstrator and Fig. 9 shows the proposed architecture of the system. Amongst the required functional modules, the PEGASUS architecture is composed of:

- a *product relationships definition module*, which captures the required input (i.e. relationships) at various abstraction levels for processing and reasoning in design and assembly planning phases;

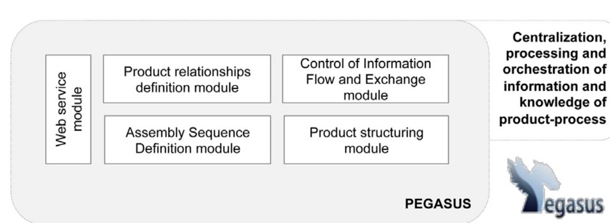

Fig. 9. Resulted PEGASUS architecture.

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- an *assembly sequence definition module*, which uses algorithms for assembly process planning (e.g. including generation/assessment of admissible assembly sequences) based on previously-defined part-to-part relationships;
- a *product structuring module*, which manages the product structure based on the resulting assembly sequence, product relationships and part number optimization;
- a *control of information flow and exchange module*, which maintains data consistency and ensure the propagation of information between PDM, MPM and CAD systems;
- a *web service module*, which enables interoperability over web with PDM, MPM and CAD systems.

The PEGASUS application has been developed in order to implement the PROMA approach. This PLM-based application actually uses the *Model View ViewModel* (MVVM) design pattern to support the development and is also mainly part of the technical specifications (Fig. 10). This emergent pattern includes three information layers such as the *Model*, *View* and *ViewModel*. The *Model*, as the first element, represents the content of actual state. The *View*, considered as the presentation layer, describes references to all elements, which are displayed by the graphical user interface (GUI). Last, the *ViewModel* represents the link between the *Model* and the *View*, so as to process the data through the context and therefore binding the model object properties to the *View* fields. This latter level also allows the control and propagation of changes made by the user to the *Model*. From that point of view, the *ViewModel* contains therefore the business logic aspect. Here the bindings enable the two-way data binding interactions between the *View* and the *ViewModel*. The related command allows the *View* to request a method related to the *ViewModel*.

Towards this end, Fig. 10 presents an overview on the MVVM architecture to AOD vision (i.e. including framework, approach, model and involved actors). An allocation is proposed for each layer of the MVVM architecture, as follows:

- MUVOA model will be considered as *Model* layer (a formal ontology integration called PRONOIA is also planned in order to reason on semantic and logic aspects [45]);
- PROMA approach will be implemented as *ViewModel*;
- PASODE framework will be instantiated as *View* layer;
- involved actors will mainly use the *View* layer (i.e. the PASODE framework).

Furthermore, since PEGASUS will be used simultaneously and in different geographic areas, its model needs to be considered in a distributed way. A web service has therefore been specifically developed in order to share concepts between different users in an immediate manner. This module is actually based on open standards and protocols. The XML-based syntax is used to encode the data and information independent of computing platforms. In addition, the Simple Object Access Protocol (SOAP) is considered as a communication protocol that enables the transmission of messages among computer entities [46]. However, this protocol does not define yet what messages can be exchanged to get a successfully interaction. The Web Service Description Language (WSDL) is also used in order to describe operations offered by the service, inputs and the outputs [47]. With such WSDL language, it is then possible to define the service location and communication protocol to be used.

On another level, the implementation of the PASODE framework sounds more complicated. It can be considered as a set of interaction rules, on which the user carries out an action via the *View*. Afterwards the *ViewModel* executes the related action and updates the *Model*. As such, the implementation of the framework is made at the *ViewModel* layer, therefore considering the interaction rules and the conditions to be executed. Since

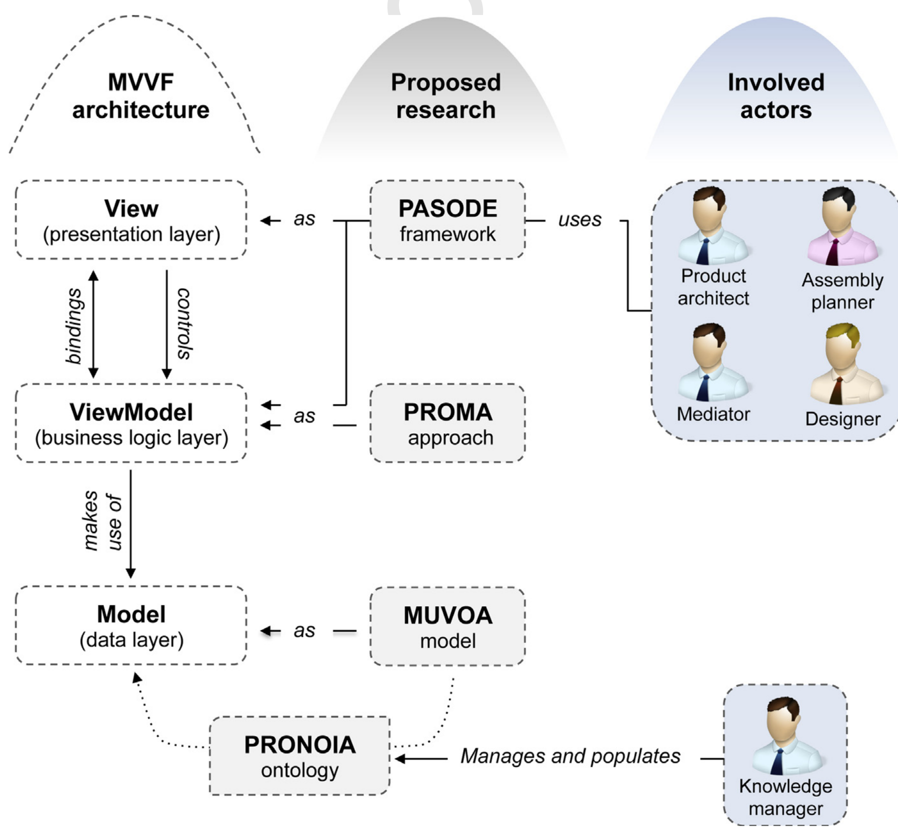

Fig. 10. PROMA, PASODE and MUVOA considered from the MVVM architecture.

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computer infrastructure is quite specific to each company, it is assumed that all business applications are accessed by using web services. With such a technology, the PEGASUS application will be able to evolve in a heterogeneous business applications environment.

5. Case study

The above described implementation has been applied to a well-known mechanical assembly as a case study in order to demonstrate the potential benefits and relevance of such an integrated and proactive engineering relationship management paradigm, especially at the interface of product design and assembly sequence planning phases. The chosen part is a PLAYMOBIL® toy. A number of tools and facilities developed for PEGASUS have been used to demonstrate the working principles and processes how this PROMA approach tackles the research issue.

5.1. PLAYMOBIL® and its design problem formulation

Built on the PASODE framework, and deploying the MUVOA model, this research derives a novel management approach called PROMA to tackling product relationships management. In order to achieve a successful product development, it is necessary to emphasise the importance and capture the relationships between parts and sub-assemblies of a product. This provides the basis to promote and control information sharing and flow in a proactive and intelligent manner.

From a lifecycle engineering point of view, this case study requires information consistency procedures between product design and assembly process specifications. Currently, all product parts are manufactured and assembled by the same company. The closer integration of assembly process and the product development process is crucial to meet success and avoid much rework. This whole thing is to apply PROMA approach within PEGASUS as early as possible in product design stage.

The proposed case study is illustrated in Table 2 and Fig. 11, where a parts list, and a previously developed isometric and exploded views of the final solution are presented. This description enables the understanding and contrast of traditional product development process versus the concurrent product design and assembly process planning. Currently, this product includes nine parts as listed in Table 2.

Moreover, three systems have been introduced in order to be connected with PEGASUS (i.e. PLM hub application enabling the definition and management of product relationships and the control of product-process information flows), namely as follows:

- ACSP (in French: Atelier Coopératif de Suivi de Projet) which is a legacy web-based PLM system and here used as a PDM (Product Data Management) system for the experimentation.
- NOTIXIA which is a commercial platform enabling the management of assembly process information and here considered as a MPM (Manufacturing Process Management) system.

Table 2
Parts list for the case study.

No.	Part name	No.	Part name
1	Body	2	Thorax
3	Legs	4	Head
5	Hair	6	Left arm
7	Left hand	8	Right arm
9	Right hand		

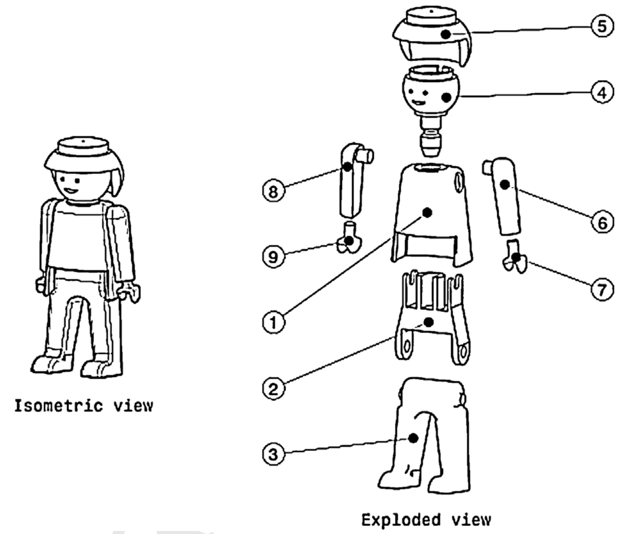

Fig. 11. Isometric and exploded views of a previously developed PLAYMOBIL® toy.

- CATIA v5 which is used to define and visualise assembly skeletons of the product and here used as a CAD (Computer Aided Design) application.

By introducing this prototype and the aforementioned commercial systems, it would be possible to evaluate the effectiveness of the approach, and at the same time, the practical difficulties one would face in implementing the PROMA approach.

5.2. System execution

Based on the above described technical implementation and case study, the proposed PEGASUS implemented within PLM systems is illustrated in Fig. 12, in which each step (steps–7) is presented consistently with the PASODE framework mechanisms. All information exchange procedures are supported by eXtensive Markup Language (XML) language format, i.e. X-oriented BOR (Bill Of Relations) [18]. So PEGASUS is considered as a hub application at the interfaces of PDM (ACSP), MPM (NOTIXIA) and CAD (CATIA v5) systems, which enables the centralisation, processing, and orchestration of information and knowledge of product-process, as described in the following steps:

Step 1. PEGASUS captures the initial eBOM which has been defined by the product architect in the PDM system (ACSP), by using the PDM-oriented BOR. At this stage, the product structure and part-to-part relationships are not yet defined.

Step 2. Based on the definition of part-to-part relationships within PEGASUS, the embedded ASDA algorithm enables the generation of admissible assembly sequences, and so the selection of the well-balanced one to be exported to MPM system (NOTIXIA). As such, the resulting assembly sequence is sent to MPM via the MPM-oriented BOR in order to build the assembly operations structure.

Step 3. Once the assembly operations structure is defined, the assembly planner and process engineer incorporate technological information for each assembly operation. This information is sent to PEGASUS via the MPM-oriented BOR and enables the definition of a technological layer of the product.

Step 4. Within PEGASUS, these relationships enable the product structuring based on the early-defined assembly sequence. This is done via the PDM-oriented BOR to PDM system (ACSP).

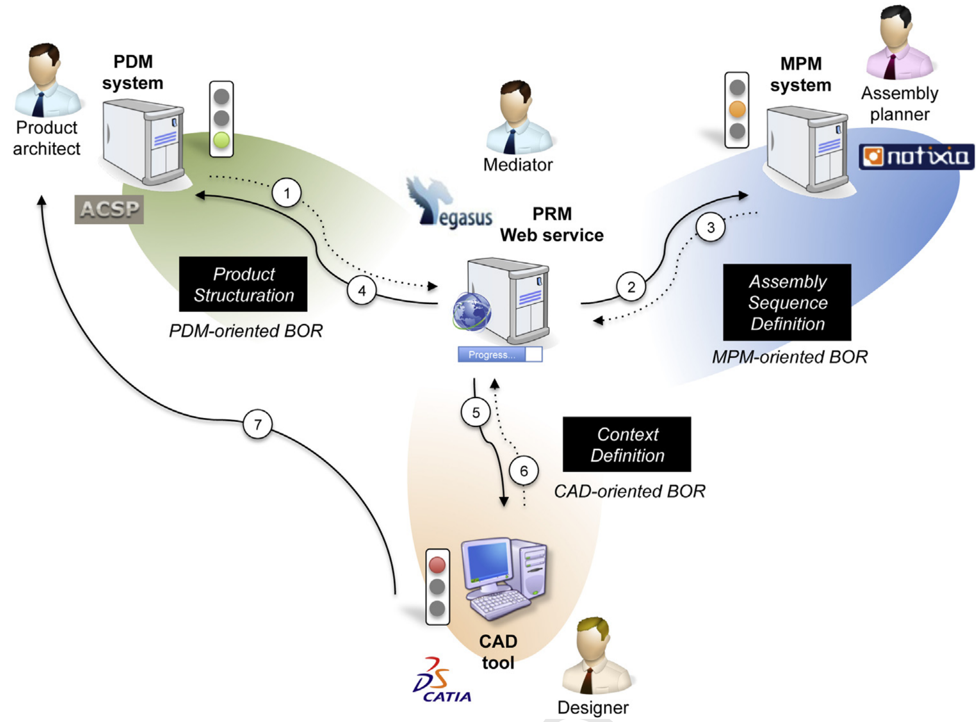

Fig. 12. Proposed implementation of PROMA within PEGASUS in connection with ACSP, NOTIXIA and CATIA v5.

Step 5. At the same time, PEGASUS generates skeleton-based geometry related to kinematic and technological pairs such as defined within PEGASUS. These skeleton entities enable the definition of an assembly context for designers. This can be done by considering the resulted product structure and assembly skeletons structure as captured in the CAD-oriented BOR.

Step 6. Based on this assembly skeleton structure, the product designer can allocate volume, shape, values related to each skeleton. At this stage, he is not allowed to directly change the assembly skeleton but a change request can be sent to PEGASUS via such CAD-oriented BOR.

Step 7. Once designer has defined all product geometric characteristics, the CAD models are stored by using check-in/check-out procedures in PDM system (ACSP).

As a consequence, this case implementation has been broken down into seven steps in order to reach objectives of the proposed PROMA approach. First, the process begins with the definition the initial eBOM (*product structural view*) in the ACSP system which is actually performed by the product architect (*Step 1*) as illustrated in Fig. 13. Based on this, the product architect has the possibility to define part-to-part relationships at various abstraction levels (*product contextual view*) in PEGASUS (Fig. 14) using the

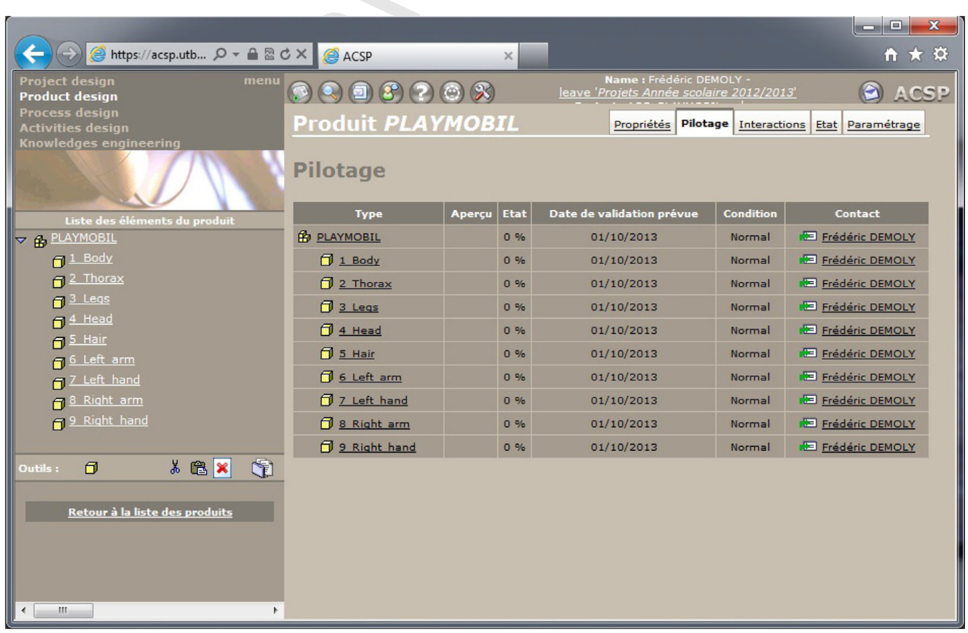

Fig. 13. Initial product structure (eBOM) in ACSP.

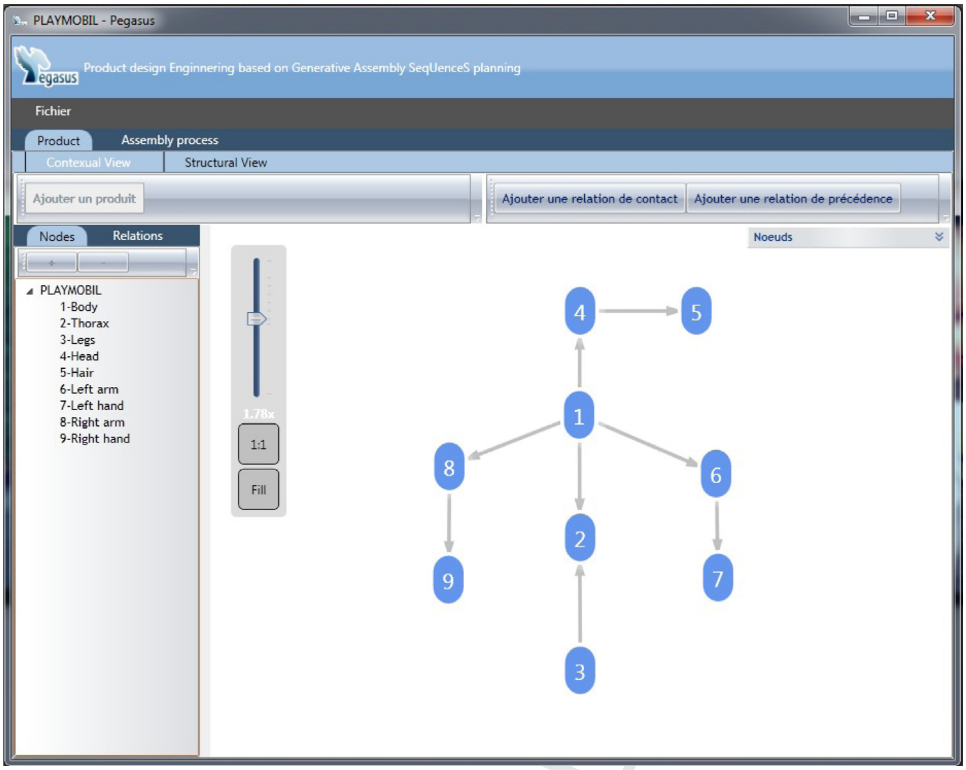

Fig. 14. Definition of product relationships in PEGASUS.

relationship types in [18]. The end results of this exercise is fully described in Table 3. Indeed, this actor has an overall view on the product, its function, its characteristics, etc., and so the authors have proposed to assign the product architect this new task.

Afterwards and based on a manufacturing context (*process contextual view*, Fig. 15), product relationships are automatically computed (*Step 2*) in order to generate all admissible assembly sequences and the well-balanced assembly sequence is identified through a tolerance analysis [18] (Fig. 16). This sequence (*process behavioural view*) can be represented in NOTIXIA with the MPM-oriented BOR generated by PEGASUS (*Step 2*) (Fig. 17). Once the assembly planner has obtained the assembly sequence, assembly operations (*process structural view*) can be defined and planned in NOTIXIA (Fig. 17) and the information automatically comes back to PEGASUS (*Step 3*). PEGASUS takes into account the assembly sequence and generates the PDM-oriented BOR in order to impact the initial product structure (*product structural view*) in ACSP system (*Step 4*) (Fig. 18). Then, starting from the assembly sequence and the updated product structure, PEGASUS computes again the product relationships to define and allocate geometric skeleton entities (*product geometric view*) in the product structure through the CAD-oriented BOR (*Step 5*) (Figs. 19 and 20), therefore providing a lifecycle oriented context for product modelling in CATIA v5.

From now on, the designer can start the product geometry definition phase (*product geometric view*), and—in the case where a relation is suspected—will able to send a change request with an updated CAD-oriented BOR to PEGASUS in order to modify the nature of the relationship (*Step 6*). Once the product modelling phase is completed, the product geometry embedded in CAD files is stored in ACSP system through the updated product structure (*product structural view*) (*Step 7*), and networks of product parts and assembly operations are synchronised through PEGASUS.

Table 3
Description of part-to-part relationships.

Relation name	Kinematic pair	Technological pair
R_{1-2}	Rigid	Press fit
R_{1-4}	Revolute	Snap fit
R_{1-6}	Revolute	Snap fit
R_{1-8}	Revolute	Snap fit
R_{2-3}	Revolute	Snap fit
R_{4-5}	Revolute	Snap fit
R_{6-7}	Revolute	Snap fit
R_{8-9}	Revolute	Snap fit

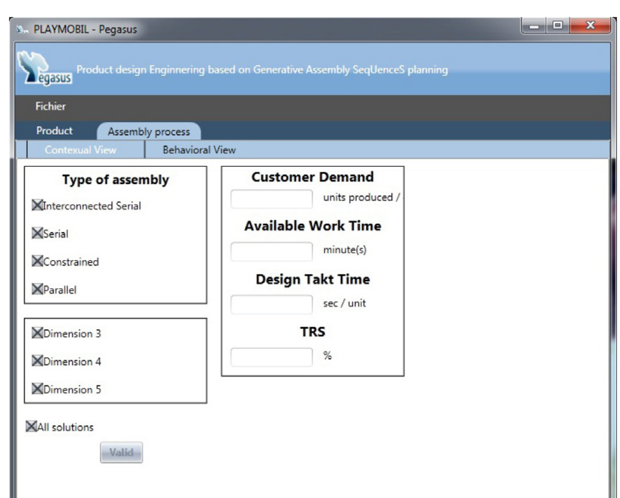

Fig. 15. Definition of manufacturing/production context in PEGASUS.

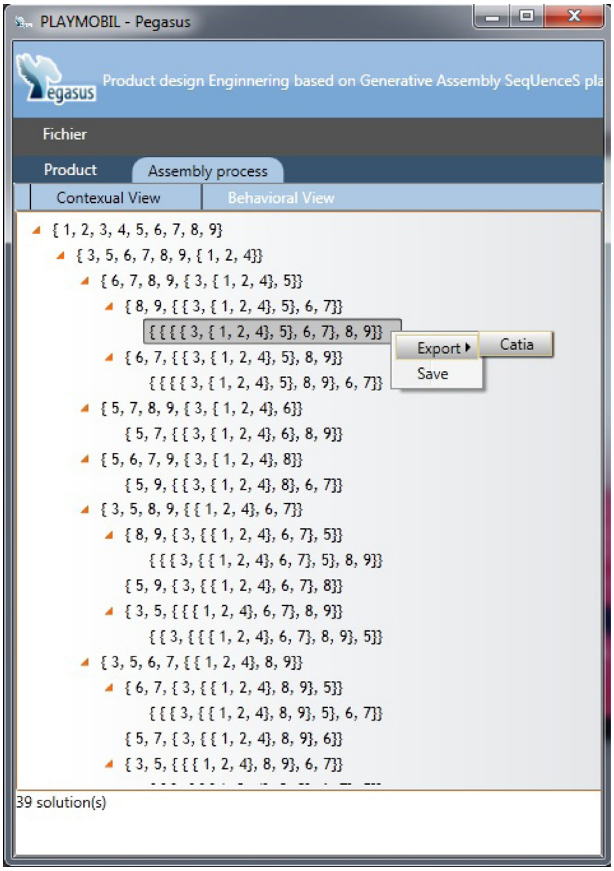

Fig. 16. Generation of admissible assembly sequences and export to CATIA within PEGASUS.

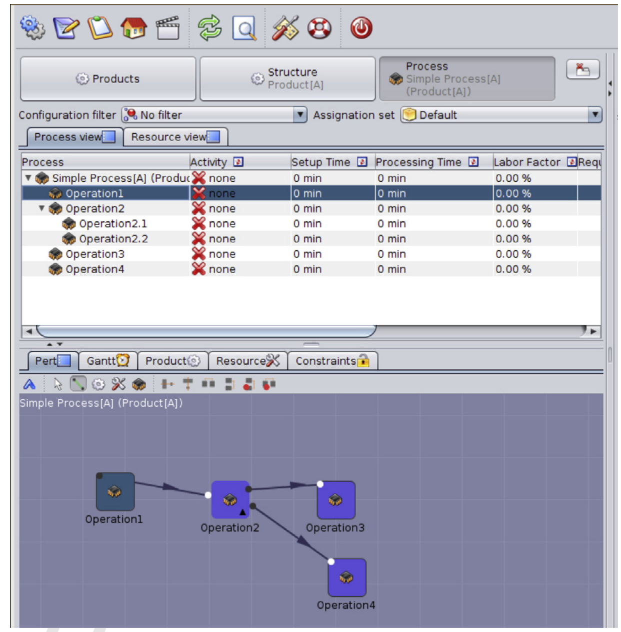

Fig. 17. Definition of assembly operations in NOTIXIA based on the generated assembly sequence in PEGASUS.

6. Discussion

The authors have argued all along the paper the novelty of such a product relationships management approach in its ability to support proactive assembly oriented design philosophy. This approach therefore bridges the gap between engineering management approaches [48] in product development and assembly process planning by integrating these two important aspects together. The proposed implementation in PEGASUS and experimentation through a well-known case study and PLM systems has highlighted strengths and weaknesses of PROMA. The case study shows the added value of PROMA in two aspects. Firstly, this approach enables better utilisation information and its flow between product engineering and process engineering by extracting the cross-view relationships of product development in a separate way [49]. This leads to the introduction of the concept of bill of relations (BOR) to facilitate information exchange between existing PLM systems at the beginning of the product lifecycle. Secondly, PROMA provides an effective support to apply the proactive framework PASODE in product multi-view relationship management as described in previous work [18]. Although the

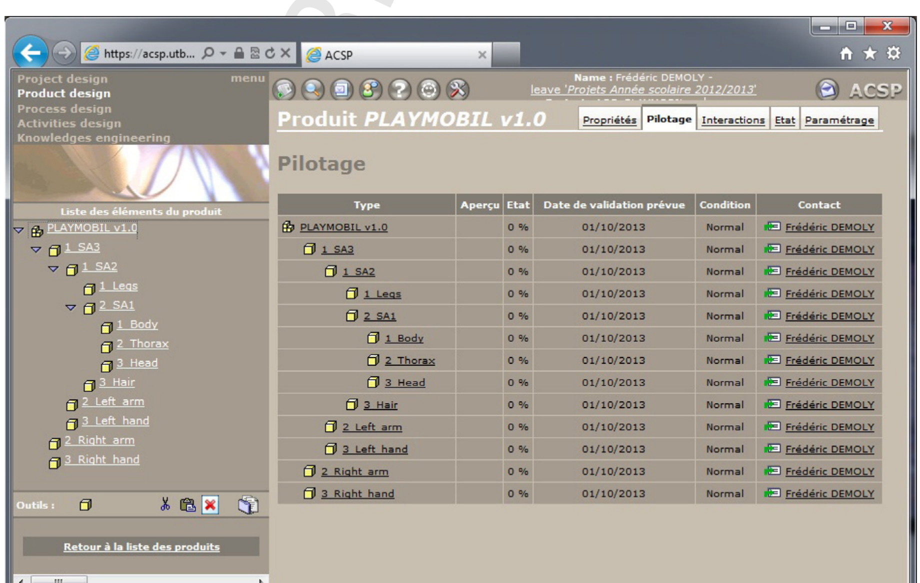

Fig. 18. Updated product structure (eBOM) in ACSP.

```
Sub CATMain()
  Set Product76Document = CATIA.Documents.Add("Product")
  Set Product76 = Product76Document.Product
  Product76.PartNumber = "PLAYMOBIL v1.0"

  Set Product76SpecificParameters = Product76.Parameters.RootParameterSet.ParameterSets.CreateSet("Paramètres spécifiques").DirectParameters
  Set Product76FunctionalParameters = Product76.Parameters.RootParameterSet.ParameterSets.CreateSet("Paramètres fonctionnels").DirectParameters
  Set Element670Document=CATIA.Documents.Add("Product")
  Set Element670=Element670Document.Product
  Element670.PartNumber="1_SA3"
  Product76.Products.AddComponent(Element670)
  Set Element673Document=CATIA.Documents.Add("Product")
  Set Element673=Element673Document.Product
  Element673.PartNumber="1_SA2"
  Element670.Products.AddComponent(Element673)
  Set Element676Document=CATIA.Documents.Add("Part")
  Set Element676=Element676Document.Part
  Element676Document.Product.PartNumber="1_Legs"
  Element673.Products.AddComponent(Element676Document.Product)
  Set Element676SpecificParameters = Element676.Parameters.RootParameterSet.ParameterSets.CreateSet("Paramètres spécifiques").DirectParameters
  Set Element676FunctionalParameters = Element676.Parameters.RootParameterSet.ParameterSets.CreateSet("Paramètres fonctionnels").DirectParameters
  Element676Document.Close()
  Set Element677Document=CATIA.Documents.Add("Product")
  Set Element677=Element677Document.Product
  Element677.PartNumber="2_SA1"
  Element673.Products.AddComponent(Element677)
  Set Element679Document=CATIA.Documents.Add("Part")
  Set Element679=Element679Document.Part
  Element679Document.Product.PartNumber="1_Body"
  Element677.Products.AddComponent(Element679Document.Product)
  Set Element679SpecificParameters = Element679.Parameters.RootParameterSet.ParameterSets.CreateSet("Paramètres spécifiques").DirectParameters
  Set Element679FunctionalParameters = Element679.Parameters.RootParameterSet.ParameterSets.CreateSet("Paramètres fonctionnels").DirectParameters
  Element679Document.Close()
  Set Element680Document=CATIA.Documents.Add("Part")
  Set Element680=Element680Document.Part
  Element680Document.Product.PartNumber="2_Thorax"
  Element677.Products.AddComponent(Element680Document.Product)
  Set Element680SpecificParameters = Element680.Parameters.RootParameterSet.ParameterSets.CreateSet("Paramètres spécifiques").DirectParameters
  Set Element680FunctionalParameters = Element680.Parameters.RootParameterSet.ParameterSets.CreateSet("Paramètres fonctionnels").DirectParameters
```

Fig. 19. Part description of a CATscript file generating the product structure in CAD.

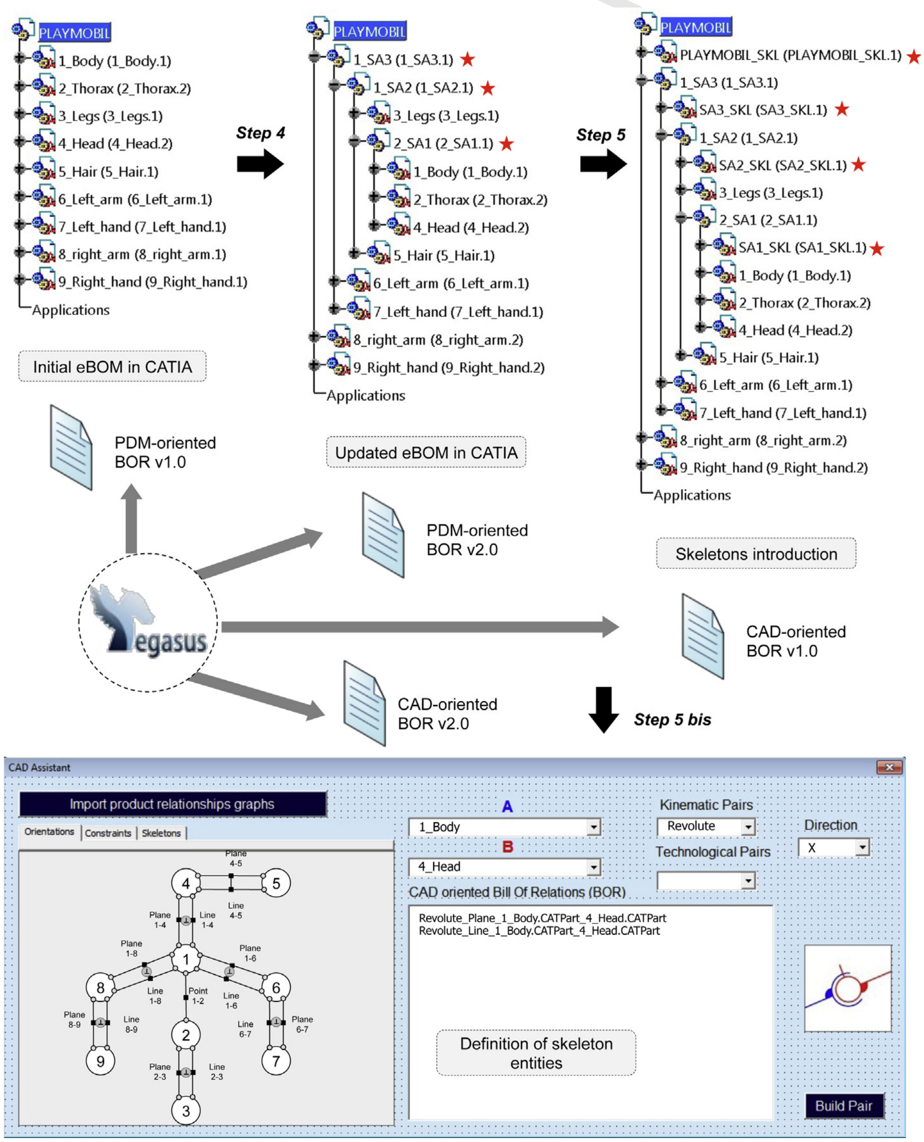

Fig. 20. From initial eBOM to updated eBOM including assembly skeletons within CATIA v5.

proposed approach and implementation have been applied small assembly, some additional industrial case studies have been tested and proved benefits.

Nevertheless, the introduction of such an effective engineering relationship management paradigm has highlighted the information exchange problems because the various heterogeneous systems involved at the beginning of the product lifecycle do not support seamless information sharing and exchange. This is mainly due to the limitation of the implementation of commercial systems used in this study [2]. If these were implemented as theoretical systems, there would have been no such an issue, which from the research point of view, will not present any problem.

7. Conclusions and future work

Current status and challenges in assembly oriented design and the related support of data-information-knowledge systems such as PLM systems highlight urgent needs for a better interaction, flexibility and information sharing between product and lifecycle oriented models [50]. Based on this need, a product relationship management approach called PROMA is proposed and implemented in a new application called PEGASUS in connection with PDM, MPM and CAD systems. The proposed approach enables the control of internal regulation procedures between product design and assembly sequence planning phases, so as to provide a proactive and interactive support for lifecycle oriented product development. Specifically, the PROMA approach is based on a PASODE framework which is featured by an assembly sequence definition algorithm (ASDA) [22] and a multiple view model (MUVOA) [23].

Hence, the proposed paper has addressed this urgent need and taken advantages of rich information available from lifecycle phase using assembly as an example, by proposing and investigating in a new product engineering management vision to support the dynamic and proactive aspect of assembly-oriented design. Managing product relationships and their evolution at various abstraction levels is a central issue to PLM strategy [17]. This paper has demonstrated a novel approach to product relationship extraction, sharing and proactive design support using these vital cross-view relationships, especially at lifecycle phase assembly. It is this area that the paper provides contribution beyond the current state of the art in broad concurrent engineering and PLM implementation in industry.

Further research is required to address the compatibility issues and extension of a similar approach into other life phases. The implementation of PROMA in PEGASUS addresses interoperability and compatibility issues related to others PLM systems such as PDM, MPM and CAD and this will be discussed in future work. In addition, more relational information among other life phases will be considered and captured, especially between the BOL and end of product lifecycle phases, such as maintenance, disassembly and recycling, where lifecycle oriented sequences have to be managed in a coherent way [51].

References

[1] J. Stark, et al., Product Lifecycle Management – Paradigm for 21st Century, Springer-Verlag, Berlin, 2004.
[2] G. Schuh, H. Rozenfeld, D. Assmus, E. Zancul, Process oriented framework to support PLM implementation, Computers in Industry 59 (2008) 210–218.
[3] S. Terzi, A. Bouras, D. Dutta, M. Garetti, D. Kiritsis, Product lifecycle management – from its history to its new role, International Journal of Product Lifecycle Management 4 (4) (2010) 360–389.
[4] M. Alemanni, G. Alessia, S. Tornincasa, E. Vezzetti, Key performance indicators for PLM benefits evaluation: the Alcatel Alenia Space case study, Computers in Industry 59 (2008) 833–841.
[5] D.T. Liu, X.W. Xu, A review of web-based product data management systems, Computers in Industry 44 (3) (2001) 251–262.
[6] W. Liu, Y. Zeng, M. Matlez, D. Brisson, Product lifecycle management: a review, in: ASME International Design Engineering Technical Conferences (IDETC) and Computers and Information in Engineering Conference, San Diego, August 30-September, 2009, pp. DETC2009-86983.
[7] G.Q. Huang, S.W. Lee, K.L. Mak, Web-based product and process data modeling in concurrent "design for X", Robotics and Computer-Integrated Manufacturing 15 (1999) 53–63.
[8] R. Holt, C. Barnes, Towards an integrated approach to "Design for X": an agenda for decision-based DFX research, Research in Engineering Design 21 (2009) 123–136.
[9] R.W. Helms, Product Data Management as Enabler for Concurrent Engineering, Eindhoven University of Technology, The Netherlands, 2002 (PhD Thesis).
[10] N. Bouikni, L. Rivest, A. Desrochers, A multiple views management system for concurrent engineering and PLM, Concurrent Engineering: Research and Applications 16 (1) (2008) 61–72.
[11] F. Demoly, X.-T. Yan, B. Eynard, S. Gomes, D. Kiritsis, Integrated product relationships management: a model to enable concurrent product design and assembly sequence planning, Journal of Engineering Design 23 (7) (2012) 544–561.
[12] S.M. Sapuan, M.R. Osman, Y. Nukman, State of the art of the concurrent engineering technique in the automotive industry, Journal of Engineering Design 17 (2) (2006) 143–157.
[13] J. Gao, A Market Survey of Industrial - Requirements for Product Data Management and Manufacturing Planning Systems, in: Proceedings of the 1999 IEEE International Symposium on Assembly and Task Planning, Porto, Portugal, July, 1999.
[14] X.T. Yan, J. Borg, N.P. Juster, Concurrent modelling of components and realization systems to support proactive design for manufacture/assembly, in: Journal of Engineering Manufacture, Proceedings of the Institution of Mechanical Engineers Part B, ISSN:0953-4054, 215, Professional Engineering Publishing, 2001 , pp. 1135–1141.
[15] F.U. Rehman, X.T. Yan, Supporting early design decision making using design context knowledge, Journal of Design Research 6 (1-2) (2007) 169–189.
[16] H. Bradley, P. Maropoulos, A relation-based product model for computer-supported early design assessment, Journal of Materials Processing Technology 76 (1998) 88–95.
[17] J. Brown, Managing Product Relationships: Enabling Iteration and Innovation in Design. Business Value Research Series, June, AberdeenGroup, 2006.
[18] F. Demoly, Conception intégrée et gestion d'informations techniques: application à l'ingénierie du produit et de sa séquence d'assemblage, Université de Technologie de Belfort-Montbéliard, France, 2010 (PhD Thesis).
[19] J.S. Goonetillake, T.W. Carnduff, W.A. Gray, An integrity constraint management framework in engineering design, Computers in Industry 48 (2002) 29–44.
[20] F. Demoly, B. Eynard, L. Rivest, S. Gomes, PLM-based approach for assembly process engineering, International Journal of Manufacturing Research 5 (4) (2010) 414–428.
[21] F. Demoly, N. Troussier, B. Eynard, H. Falgarone, B. Fricero, S. Gomes, Proactive assembly oriented design approach based on the deployment of functional requirements, Journal of Computing and Information Science in Engineering 11 (1) (2011), 6p.
[22] F. Demoly, X.-T. Yan, B. Eynard, L. Rivest, S. Gomes, An assembly-oriented design framework for product structure engineering and assembly sequence planning, Robotics and Computer-Integrated Manufacturing 27 (1) (2011) 33–46.
[23] F. Demoly, D. Monticolo, B. Eynard, L. Rivest, S. Gomes, Multiple viewpoint modelling framework enabling integrated product-process design, International Journal on Interactive Design and Manufacturing 4 (4) (2010) 269–280.
[24] K.K. Leong, K.M. Yu, W.B. Lee, Product data allocation for distributed product data management system, Computers in Industry 47 (2002), pp. 298–298.
[25] L. Georgiev, J. Ovtcharova, I. Georgiev, Modelling web services for PLM distributed system, International Journal of Product Lifecycle Management 2 (1) (2007) 30–49.
[26] N.W. Bowland, J.X. Gao, R. Sharma, A PDM- and CAD-integrated assembly modelling environment for manufacturing planning, Journal of Materials Processing Technology 138 (1-3) (2003) 82–88.
[27] X.G. Ming, J.Q. Yan, X.H. Wang, S.N. Li, W.F. Lu, Q.J. Peng, Y.S. Ma, Collaborative process planning and manufacturing in product lifecycle management, Computers in Industry 59 (2008) 154–166.
[28] A.-P. Hameri, J. Nihtilä, Product data management – exploratory study on state-of-the-art in one-of-a-kind industry, Computers in Industry 35 (1998) 195–206.
[29] B. Eynard, T. Gallet, P. Nowak, L. Roucoules, UML based specifications of PDM product structure and workflow, Computers in Industry 55 (3) (2004) 301–316.
[30] T.G. Tremblay, L. Rivest, O. Msaaf, R. Maranzana, The role of associations in CAD and PLM for handling change propagation during product development, in: Proceeding of the 2006 conference on Leading the Web in Concurrent Engineering: Next Generation Concurrent Engineering, 2006, 507–514.
[31] C.J. Barnes, G.E.M. Jared, K.G. Swift, Decision support for sequence generation in an assembly oriented design environment, Robotics and Computer-Integrated Manufacturing 20 (2004) 289–300.
[32] F. Demoly, L. Toussaint, B. Eynard, D. Kiritsis, S. Gomes, Geometric skeleton computation enabling concurrent product engineering and assembly sequence planning, Computer-Aided Design 43 (12) (2011) 1654–1673.
[33] C. Weber, H. Werner, T. Deubel, A different view on product data management/product life-cycle management and its future potentials, Journal of Engineering Design 14 (4) (2003) 447–464.
[34] H. Burr, M. Vielhaber, T. Deubel, C. Weber, S. Haasis, CAx/engineering data management integration: enabler for methodical benefits in the design process, Journal of Engineering Design 16 (4) (2005) 385–398.

[35] D. Fensel, H. Lausen, A. Polleres, J. de Bruijn, M. Stollberg, D. Roman, J. Domingue, Enabling Semantic Web Services – The Web Service Modeling Ontology, Springer-Verlag, Berlin, Heidelberg, 2007.
[36] P. Jiand, X. Shao, H. Qiu, L. Gao, P. Li, A web services and process-view combined approach for process management of collaborative product development, Computers in Industry 60 (2009) 416–427.
[37] A. Matsokis, D. Kiritsis, An ontology-based approach for product lifecycle management, Computers in Industry 61 (1) (2010) 787–797.
[38] B. Fabian, S. Kunz, M. Konnegen, S. Müller, O. Günther, Access control for semantic data federations in industrial product-lifecycle management, Computers in Industry 63 (2012) 930–940.
[39] M. Cantamessa, F. Montagna, P. Neirotti, An empirical analysis of the PLM implementation effects in the aerospace industry, Computers in Industry 63 (2012) 243–251.
[40] G. Feng, D. Cui, C. Wang, J. Yu, Integrated data management in complex product collaborative design, Computers in Industry 60 (2009) 48–63.
[41] H.-B. Jun, D. Kiritsis, P. Xirouchakis, Research issues on closed-loop PLM, Computers in Industry 58 (2007) 855–868.
[42] M. Hanneghan, M. Merabti, G. Colquhoun, A viewpoint analysis reference model for concurrent engineering, Computers in Industry 41 (2000) 35–49.
[43] H. Koning, H. van Vliet, A method for defining IEEE Sdt 1471 viewpoints, Journal of Systems and Software 79 (2006) 120–131.
[44] T. Madhusudan, An intelligent mediator-based framework for enterprise application integration, Journal of Computing and Information Science in Engineering 4 (2005) 294–304.
[45] F. Demoly, A. Matsokis, D. Kiritsis, A mereotopological product relationship description approach for assembly oriented design, Robotics and Computer-Integrated Manufacturing 28 (1) (2012) 681–693.
[46] SOAP. http://www.w3.org/TR/soap12-part1/.
[47] WSDL. http://www.w3.org/TR/wsdl.
[48] S. Liu, I.M. Boyle, Engineering design: perspectives, challenges, and recent advances, Journal of Engineering Design 20 (1) (2009) 7–19.
[49] J. Derrick, H. Wehrheim, Model transformations across views, Science of Computer Programming 75 (2010) 192–210.
[50] M.G. Marchetta, F. Mayer, R.Q. Forradellas, A reference framework following a proactive approach for product lifecycle management, Computers in Industry 62 (2011) 672–683.
[51] S.G. Lee, Y.-S. Ma, G.L. Thimm, J. Verstraeten, Product lifecycle management in aviation maintenance, repair and overhaul, Computers in Industry 59 (2008) 296–303.

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