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TOWARDS AN APPROACH TO INTEGRATE TECHNOLOGICAL EVOLUTION INTO PRODUCT DESIGN

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ABSTRACT

The development, manufacturing and production of high value-added products, such as intelligent product, technological product and product-services, are part of the highest priority of today's competitive industries. This challenging objective highlights technology introduction issues in the development of current complex products in large-scale companies, especially in product design and manufacturing phases. In a recent past, researchers has been inspired by biology, mathematics, artificial intelligence and so on, so as to propose new models, algorithms and approaches for advanced product design and manufacturing. In such a context, new product development still requires an external vision. An analogical reasoning with medical transplantation is addressed in the present paper in order to describe the integration/evolution of technology in product design, from conceptual to detailed stages.

Keywords: integrated product development, new product development, design for X, design to X, computer aided design

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1 INTRODUCTION

Nowadays the design, manufacturing and production of high value-added products, such as intelligent products and product-services, highlights emerging needs to tackle current challenges in large-scale companies (Maxwell et al., 2006; Meyer et al., 2009; Vinodh and Rajanayagam, 2010). Customers and users' needs evolution (Voss, 2012) require new flexible and agile engineering/manufacturing capabilities in order to deliver more customized and personalized products by fulfilling a large amount of requirements and constraints related to all lifecycle phases (manufacturing, assembly, disassembly, etc.) and competitiveness factors (cost, quality, performance, reliability, etc.) in a concurrent even proactive manner (Huang et al., 1999; Sapuan et al., 2006; Demoly et al., 2012). This challenging objective stresses technology introduction issues in the development of current complex products in large-scale companies, especially in product design and manufacturing phases. In a recent past, researchers have been inspired by biology, philosophy, mathematics and so on, so as to propose new models, algorithms and approaches for improving product design and manufacturing efficiency and productiveness (Wang et al., 2009; Demoly et al., 2012).

As such, new product development still requires a novel vision in order to deploy proactive engineering and increase engineering capabilities for defining and assessing the impact of a technology-based decision on the product and its lifecycle complexity (Maropoulos and Ceglarek, 2010). Agility in engineering and design represents the fact of fulfilling functional requirements variety and changeability as quick as possible. This means that companies have to consider changes at various levels (i.e. organizational, social, technical, etc.) in an appropriate manner. It is therefore vital to introduce new models, approaches and tools, which enable any potential technology introduction/evolution and associate knowledge, so as to ensure a successful integration of technological features in complex product development. From a strategic point of view, the development of new technologies in industry encounters limitations, especially the lack of engineering knowledge and traceability of technology-based decisions. In general, knowledge is associated to past successfully realized projects, and in the context of technology introduction in product development, knowledge maturity is not suitable enough to develop robust and innovative products over its lifecycle. A solution may consist in using already developed technologies in another application domains and/or working with technology suppliers in a collaborative and integrated manner (Huifen et al., 2003; Dai and Schilli, 2006).

The main objective of this paper is to propose a novel framework based on an analogical reasoning approach with 'medical transplantation' (i.e. 'organ and tissues transplantation'), so as to address new technological integration/evolution into product design, from conceptual design to detailed definition stages. For instance, the flow of technology transfer, such as directed to the enquirer industry, can be understood as a man (i.e. current product design) receiving a transplant (i.e. technological part). Transplant in turn may be developed as part of new product in the same company or integrated as a whole. It is actually a common trend that technology transfer takes place between two organizations (e.g. an industry and a supplier, a company and a university, etc.). All such transfers require internal deployment therefore more or less depending on the nature of the technology and its transfer (Chan and Wu, 2002). In such a way, an analogical reasoning, which is based on idea association, combination and synthesis, will enable the development of a systematic approach featured by closed loop, knowledge integration and assessment techniques to name a few (Kiritsis, 2011).

Firstly, the industrial context with related expectations and needs is presented in Section 2, where a brief literature survey on proactive design for X is described. Built on this, in Section 3 a definition of technological introduction into product with the medical analogy in presented as a foundation. Section 4 introduces the proposed framework, called **ISEA** (**I**ntelligent and **S**eamless t**E**chnological tr**A**nsplantation into product design), and based on the transplantation concept, considering the technological introduction/evolution in the whole PLM process. Lastly, a small mechanical assembly as a case study is applied to a part of the proposed framework, therefore highlighting potential benefits, current challenges and future efforts to be done for a multi-level technological integration in complex product design.

2 INDUSTRIAL AND RESEARCH BACKGROUNDS

2.1 Industrial challenges and needs

High value-added complex products (e.g. car, gas turbine plant, aircraft, etc.) have to integrate a large amount of constraints and knowledge, and demand appropriate processes to fulfill customers/users' requirements. The industrial sector of complex products and related batch production is a narrow place wherein each company has to be present on each call for tender in order to ensure either its survival or its growth. This implies companies' reactivity and a high customization/personalization degree of products in order to effectively meet demand fluctuations and customer/user needs' variations while using common product architectures (Dahmus et al., 2001; Hölttä-Otto, 2005; Ulrich and Tung, 1991). By considering the current globalization, batch production requires manufacturers to use standard products or subassemblies to ensure better productiveness, which is quite similar to engineering stakes. Emerging technology development in industry is often seen as a new cross-discipline to be considered and rationalized (van Merkerk and Smits, 2008), as such it becomes imperative to set up a multidisciplinary organization with geographically-scattered teams and various engineering domains (e.g. mechanical, electrical, services, etc.). Based on this high-level goal, it is needed to investigate traditional engineering stages, usually starting from functional requirements to conceptual design and later detailed definitions stages (Pahl and Beitz, 2007; Komoto and Tomiyama, 2012; Chen et al., 2012). A technology-based decision in engineering will consequently impact engineering processes, product structure and geometric complexity and downstream processes (i.e. other lifecycle phases) (Whitney et al., 1999; Demoly et al., 2011b). As such, it is important to address the design, management and assessment of technology-based products by using specific models, approaches and indicators such as those currently existing in industry, product key characteristics (PKCs) (Zheng et al., 2008; Demoly et al., 2011a) and key performance indicators (KPIs) (Alemanni et al., 2008). Furthermore, it is assumed that most complex and large assemblies have a longer life span (e.g. in aeronautics industry, energy industry, etc.) than traditional mechanical products, and so technological evolutions as design alternatives need to be managed through all aspects of product lifecycle phases. Therefore past and current technological solutions have to be captured, contextualized and then adapted to emerging technologies (Tiwana and Ramesh, 2001; van der Valk et al., 2011).

2.2 Research issues related to proactive design for technological integration

Current challenges in product design are related to the improvement of traditional design approaches that have been successfully applied in concurrent engineering (Huang et al., 1999) towards a potential application in proactive engineering (Demoly et al., 2012). In that way, the integration of technology into product design falls under design for integration (DFI) issues. DFI can be considered as a set of relevant design for X (DFX) and design to X (DTX) components (Huang et al., 1999; Kuo et al., 2001). It can be understood in a way that technological integration requires numerous rules and constraints (DFX components) in order to meet properties' values (DTX components). To be accurate, a proactive DFI vision in the context of technological introduction consists in considering the following aspects: design for assembly (DFA), design for selective disassembly (DFD), design for maintenance (DFMT), design to performance (DTP) design to reliability (DTR) design for manufacturing (Elgueder et al.,2010) and even more in other specific applications (Kimura et al., 2007; Coulibaly et al., 2008).

Literature has provided numerous published research works in the above-listed fields; DFA seems to be the most investigated component in DFX. These approaches can be considered as semi-generative and based on heuristics and geometrics rules in order to tackle current difficulties in the management of the product structure complexity and related product modeling. Recent research efforts in proactive DFA (also called assembly oriented design) have proven that the early generation of admissible assembly sequences during conceptual design stages can be created in order to provide an appropriate contextual support for assembly design and modeling phases (Demoly et al., 2009; Demoly et al., 2011b), even for the geometric definition in a top-down way (Demoly et al., 2011c). Other DFX approaches are still described which use assessment techniques in order to evaluate the current product design according to specific lifecycle phase rules and constraints (Lambert and Gupta, 2004). Relevant future trends in decision-based DFX can also be found in (Holt and Barnes, 2010). From an information management point of view, the concept of closed-loop PLM (Product Lifecycle Management) seems to be a promising solution for integrating DFX and DTX features, especially for capturing the related lifecycle knowledge and for reusing it with the support of decision-making and reasoning layers (Kiritsis, 2011). Based on this brief review, a proactive vision on design for technological integration requires different layers such as: decision-making support at various abstraction levels, complexity assessment of the product and its lifecycle, design, product modeling from functional to geometric aspect, etc.

3 PROPOSED FRAMEWORK

This section presents an analogy of medical transplantation, on which the proposed ISEA framework is based. Such analogical reasoning will enable the description of a novel vision in engineering design, especially here the geometric introduction of the technological solution.

3.1 Towards an analogy of medical transplantation

The introduction of new technology requires an appropriate process so as to replace as easily as possible the deficient component (i.e. relation, part, subassembly, or system) of the current product and to minimally impact remaining components, stakeholders, KPIs, etc. The whole thing is to make an analogical reasoning with medical transplantation. In medicine, the first step consists in ensuring that the transplant will provide an added value to the receiver, while determining the compatibility between the donor and receiver.

Since technology integration issues in product design covers conceptual and detailed design stages, the proposed analogy is made at various abstraction levels (related the complexity level of the technology) and according to the origin of technology area. As such, Table 1 presents three distinct technological introductions based on medicine experience: graft, transplant and establishment. For each introduction scenario, some properties have been added in order to know if the proposed integration requires particular attention to the relationships with existing (Osterloff, 2003; Wang et al., 2003) product components and related stakeholders for both sides (i.e. receiver and donor). Another relevant property is the initial domain of the technology to be incorporated. For instance, graft and transplant are processed within the same domain, whereas establishment is carried out in another one in order to fulfill the novel requirements. Here relationship property can be illustrated with kinematic pairs, energy flows, information flow, etc. Finally a mechanical engineering example is introduced.

Table 1. Analogy of medical transplantation

Properties	Graft	Transplant	Establishment
With relationship	○	●	●
Same domain	●	●	○
Medical analogy	Cells	Kidney	Pacemaker
Engineering Examples	Standard part replacement	Car fuel switching	Introduction of an added service

3.2 Description of the ISEA framework

The need of technological introduction/evolution is actually related to requirements, which become more and more restricted through the numerous engineering domains and current state of the product's performances. So requirements need to be tracked through the product design process and transformed towards integrated solutions in order to incorporate new technology in a proactive and seamless manner. As consequence, the proposed framework, called **ISEA** (**I**ntelligent and **S**eamless t**E**chnological tr**A**nsplantation into product design), will provide an appropriate support to bridge existing gaps in engineering to cover any potential technological integration, which are not yet developed or considered in the company. This framework, such as illustrated in Figure 1, consists in designing, managing and assessing technology introduction in a complex product (i.e. high personalization and customization product with numerous parts and multi-physics interactions) design by considering its impacts on downstream processes. Figure 1 describes the relationships of some product aspects or viewpoints such as functional, structural, geometric and technological, as previously defined in a multiple viewpoints model called MUVOA (Demoly et al., 2010) with product lifecycle phases (i.e. manufacture, assembly, maintenance, disassembly, etc.). For each product aspect, different abstraction levels are described since technological introduction issues need to be considered in a top-down manner. As such, the technological integration covers the structural, geometric and technological aspects in order to fulfill the changed requirements of the functional aspect. In addition, integrating technology into product design will impact its lifecycle phases, since technology may come from a specific manufacturing process or just facilitate or get more complicated for the definition of lifecycle sequences (e.g. manufacturing and assembly plans).

This ISEA framework – mainly dedicated to product architects, system engineers and designers – begins with the identification of a functional deficiency or changed (more restricted) requirements, therefore impacting product performances. Based on this input, it is needed to evaluate the actual product state with the updated or theoretical product state from a structural point of view. To do this, a mechanical-oriented semiology of complex product will be addressed later, so as to represent such differences at all abstraction levels. For instance, an assessment (evaluation and weighting) of the existing product complexity through various abstraction levels would be interesting. In such a way, the introduction of assessment and related decision-support layers promotes in part the proactive aspect of the framework at the conceptual design stage.

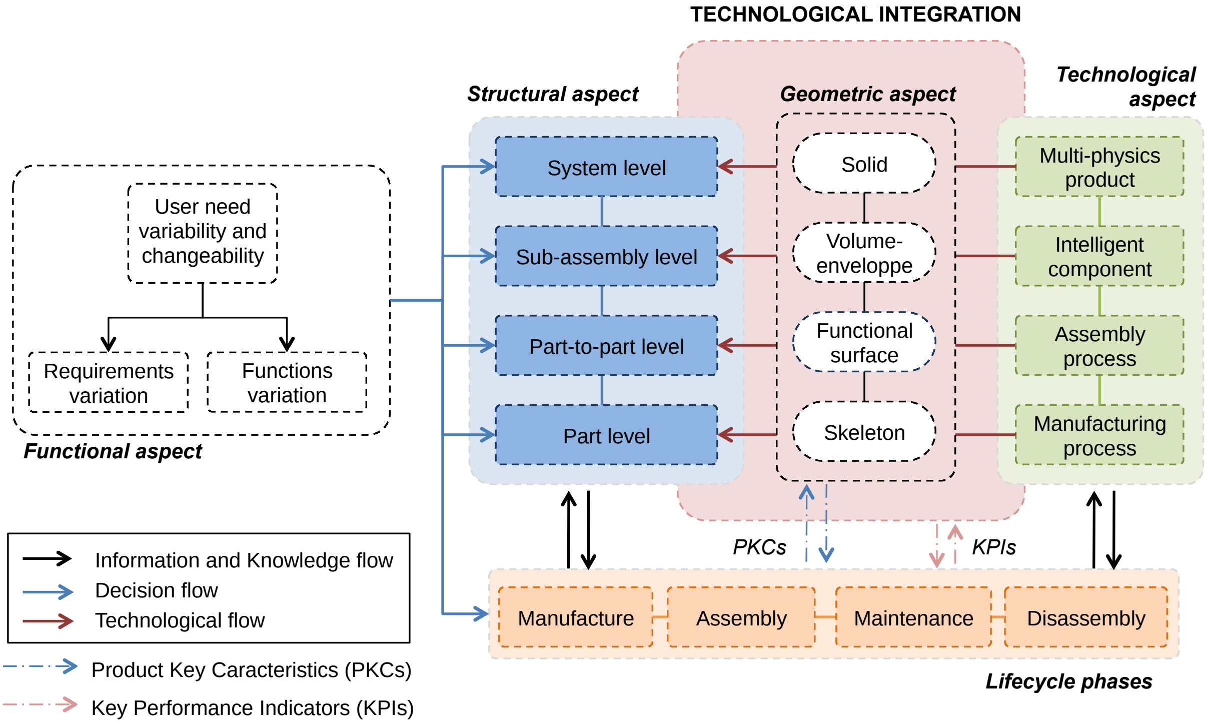


Figure 1: Proposed ISEA framework

To provide guidance, the visualization of this state and the incompleteness of existing systems may be part of pattern sorting requirements and related indicators (Königs, 2012). Also it is possible to make a codification (color, distance, size…) to represent the relevance of a selected criterion and its decomposition through the various levels of abstraction. Moreover, a set of interdependent matrices will be used to assess product/system complexity and traceability through functional, structural, geometric, technological and lifecycle aspects. Complexity introduction and gaps between old and new technologies need to be assessed, by identifying for example subassemblies, parts, relationships that have to be replaced, reconnected, even linked in case of compatibility issue. The final step consists in defining the technological solution in geometric modeling (geometric aspect) by considering the current product geometry.

4 IMPLEMENTATION AND APPLICATION IN A CASE STUDY

The proposed section introduces an implementation of the proposed ISEA framework within a small mechanical assembly as case study, by focusing on the technological evolution in the geometric aspect of the product. The objective here is to facilitate the ideas associations between medicine and engineering through the description of the technological evolution in geometric product modeling stage in a top-down manner. For this purpose, some assembly geometric skeletons are introduced to represent such assembly integration, i.e. straight lines, plans, or points (Demoly et al., 2011c). These skeleton entities will ensure the integration of technology in the existing product CAD model. The same thing can be identified in the medical domain, by considering the organ to be transplanted with the same connections or the length of blood and nervous bundles to ensure the success of the surgery to the receiver. Thus, based on the SKL-ACD (SKLeton-based Assembly Context Definition) approach, such as developed in (Demoly et al., 2011c), it is imperative to define the relationships (joints) of the technological solution with the surroundings parts of the existing product to be improved. At this stage, these joints can be led by artifact or the surrounding components, so the constraints propagation way will be related to the potential scalability of the overall system. As described in (Demoly et al., 2011c), these joints can be allocated to basic part-to-part relationships (e.g. kinematic and technological pairs), the torque pressure for fluid flow, etc. Built on this, an integration context, associated with the technology itself, is introduced and defined in order to instantiate (i.e. contextualize) the technological interfaces (Geum et al, 2011). Then with such interfaces, the path of information, material, etc. flows can be defined.

Here the analogy with medical transplantation consists in changing part-to-part relationship with different technologies in order to fulfill a prismatic pair. The proposed case study consists in three individual parts for which three relationships are defined (Figure 2), therefore building a small mechanical assembly. Base on this input, the starting point of the proposed geometric technological evolution (Figure 2) is to properly define the part-to-part relationships (i.e. kinematic pairs represented in **Step 1** of Figure2). Here, three kinematic pairs have been described, namely revolute, prismatic and cylindrical. In order to build step-by-step a skeletonbased model, which would be implemented in a CAD application, the early-defined kinematic relationships have to be transformed into geometrical elements (**Step 2** of Figure 2). Geometric elements here are also called skeleton entities. Once skeleton entities have emerged, a skeletons minimal graph is generated in order to build the assembly context for the technological evolution (**Step 3** of Figure 2). In this step, skeleton entities are related with commonly used constraints in CAD such as parallel, perpendicular, coincident, angular to name a few. In such way, **Step 3** of Figure 2 supports an assembly context with various product relationships, in which technological interfaces and later functional surfaces can be allocated to assembly skeletons. These interfaces and functional surfaces, defined in the CAD application (**Step 4** of Figure 2) with specific sketches, are related to technological choice of the designer and will enable the emergence of the final product geometry within the CAD application. The three different interfaces, such as illustrated in Figure 2, are considered as part of a unique plane as skeleton entity.

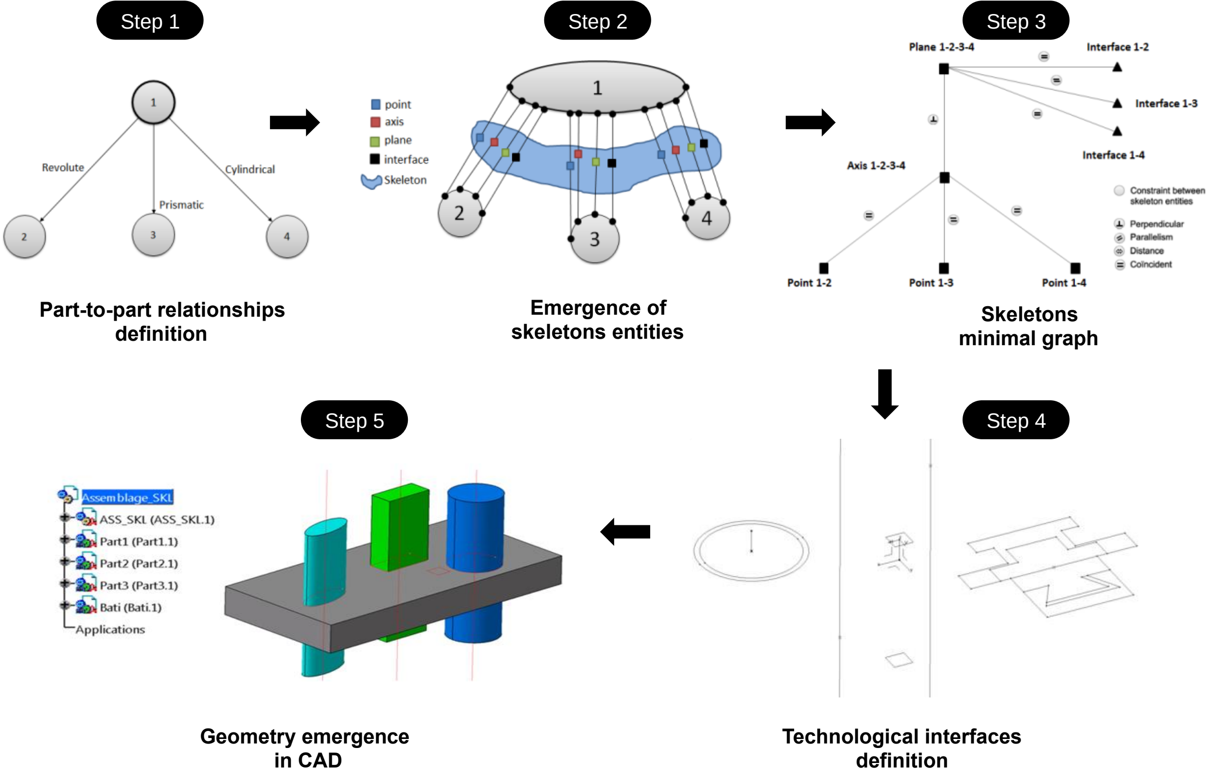
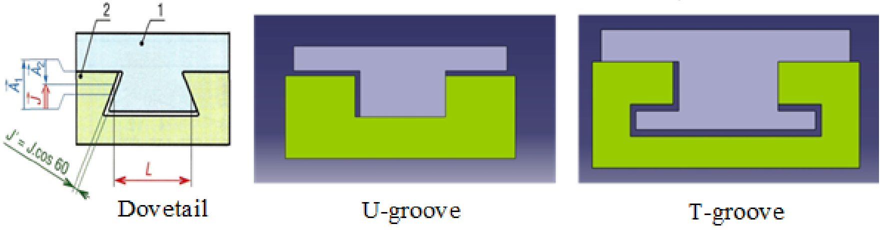


Figure 2: Technological evolution in geometric product modeling

Once the skeletons minimal graph is defined and so the global structure of the skeleton model, the product geometry (3D models) can be generated semi-automatically. **Step 5** of Figure 2 illustrates the final 3D assembly model within CATIA v5, which results from the definition of the constraints graph (**Step 1**) to the geometric aspect including technological features. For this case study, the three considered parts are controlled in a central manner, by introducing an additional part for gathering all skeleton entities, relationships and related technological interfaces (also called. “ASS_SKL” in Figure 2). So this skeleton part is composed of points, lines, planes and interfaces (and later functional surfaces). These skeleton entities are then published within CATIA v5 so that every single modification on one of them is propagated automatically to the whole model (e.g. skeletons can control the shape and the position of the three other parts).
The previous case results from the five-enumerated steps of Figure 2. In order to build a robust skeleton model that is able to manage the transition from kinematic to technological relationships, the construction has to be done a straightforward manner. Here, only two independent parts (except from the chassis) are considered, one for a prismatic pair and the other for both, revolute and cylindrical pairs. Before performing the next steps of the skeleton definition, it is important to know the abstraction level of the related relationships. By considering the prismatic pair, it is possible to select a technological solution/evolution based on the three-listed solution in Figure 3.



Dovetail U-groove T-groove

Figure 3: Technological solutions for a prismatic pair

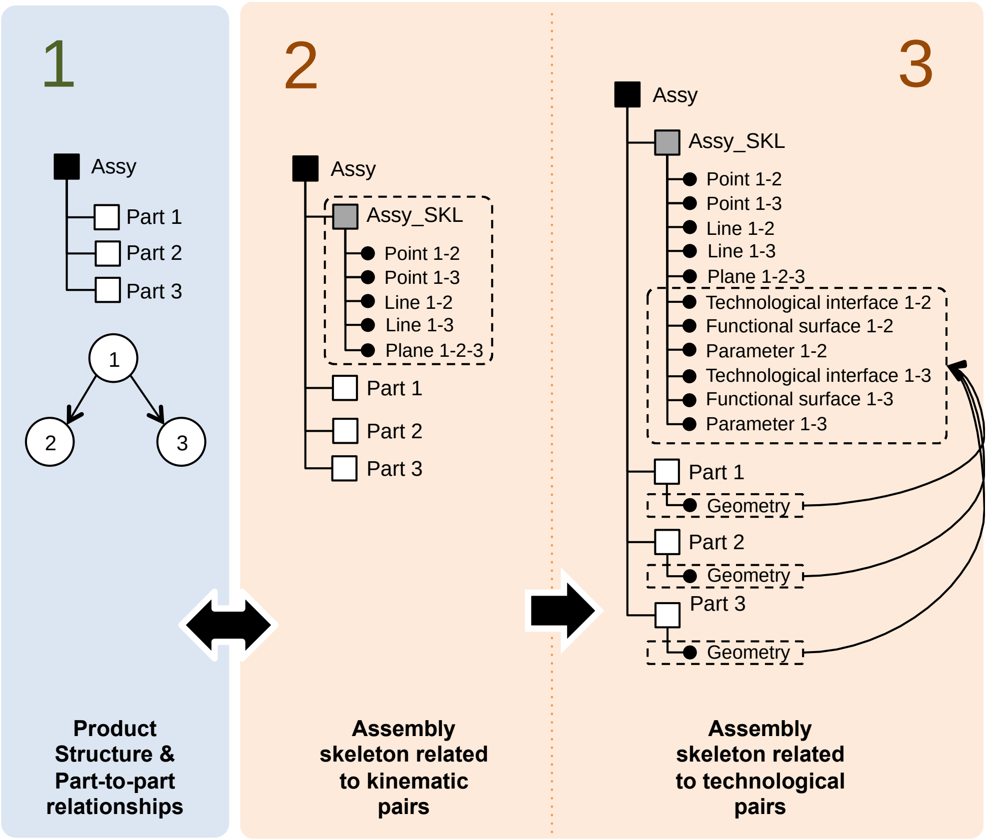


Figure 4: Technological evolution with the geometric aspect of the product

At this stage, the kinematic and technological skeleton can be defined to complete the construction of the global robust skeleton model. Thus, to define the prismatic pair and its associated technological representations (Figure 4), a skeleton part, containing a skeleton entities related to kinematic pairs and technological interfaces and later functional surfaces related to technological pairs, is introduced. The same principle is applied to other kinematic pairs of the case study. Built on this, the robust assembly skeleton model is finalized and designers can emerge the related functional surfaces based on technological interfaces and then parts geometries in order to build the novel product assembly within CATIA application.

In order to improve this robust skeleton and pursue its construction, the next stage would be to manage the volume generation of the different parts. An application or some rules that allow deciding either if the generated volume should be used to create an independent part or to perform a Boolean operation in order to subtract this volume from the support part. In more general terms, it would be interesting to complete this skeleton approach with an application, which would be a more ergonomic interface for the user than the specifications tree of the CAD environment (CATIA v5 in this application case). An appropriate way to construct such an application may be the Visual Basic-based application in the CAD environment.

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6 CONCLUSIONS AND FUTURE WORK

In this paper, a novel framework – called ISEA – and considered as part of a much larger project promoting the design, modeling and management of technological integration into product design – has been introduced. The proposed ISEA framework has been defined based on the analogical reasoning of medical transplantation. This research project consists in the technological introduction in complex products as early as possible in the product development process. This main objective requires the use of information and knowledge at numerous abstraction levels, therefore resulting in a huge challenge to be tackled. Previous work have covered geometric modeling issues in a top-down manner, the current issue of the paper was to reuse and improve this research work towards the technological evolution into product geometric modeling. To overcome the current difficulties and weaknesses of this approach and the related implementation, as previously discussed, future work will be addressed in several ways. One of these is to assess the complexity of the product and through its lifecycle phases.

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