Supporting Product Development Activities By Reverse Engineering Technique

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Abstract

Several product design processes were proposed in the literature. Their implementations in curriculums, however, do not equip students with the range of skills needed for designing innovative products. To address this issue, the proper integration of reverse engineering in product development processes can have a significant advantage for pouring insightful knowledge into their associated hands-on activities. This work illustrates the integration of reverse engineering techniques into a widely used process in engineering education. In order to test its relevance, the results of it use by a class of engineering student is illustrated. This approach is thought to provide students with a more effective design process for the acquisition of both explicit and tacit knowledge of design.

Keywords
Product development process, Reverse engineering and Engineering Design.

1. Introduction

Nowadays, engineering educators are compelled more than ever to improve the methods of engineering design teaching to cope with of the job market need. In fact, companies are striving for competent engineers capable of designing continuous flows of innovative products. But, because of the use of complex processes such as “Product Design and Development” and “Engineering Design: A Systematic Approach” in engineering education in our context, students encounter difficulties in applying these processes due to the lack of some knowledge and skills (Kojmane and Aboutajeddine 2016). To address this, there is a great need to propose a new process based on *knowledge and skill feeding* hands-on activities like reverse engineering. There are several product developments processes that can be used in teaching, for example: (David G. Ullman 2011; Pahl et al. 2007; Ulrich, K. and Eppinger, S 2015; Wood et al. 2001). The processes most cited in the literature are described below:

Ulrich and Eppinger consider product design and development as an interdisciplinary activity that requires the contribution of almost all the functions of a company (Ulrich, K. and Eppinger, S 2015). Their process is composed of several interdependent phases. It begins with a planning phase directly related to R&D and technological development activities. The result of this phase is the project mission, which becomes the basis for initiating the development phase of the concept that will guide the design team through the other phases. It should be noted that this process is generic and requires that it be adapted to the specific context of each company. This process illustrated in Figure 1 is often used for design education. Ullman proposed a six phases process for product development (David G. Ullman 2011). Each of these phases involves the implementation of generic tasks, and the success of a phase is approved by a design review, which marks its completion.

Figure 1. Product design and development process of Ulrich and Eppinger

According to (Tomiyama et al. 2009), the design method proposed by (Pahl et al. 2007) is the most used and best known in industry and education. This method places design as a core activity of the entire product life cycle. But despite its complexity and also the need for a long experience, this method has been successfully taught in many engineering designs courses. As illustrated in Figure 2, this method is composed of four essential phases: Planning and Clarifying, Conceptual Design, Embodiment Design and Detail Design.

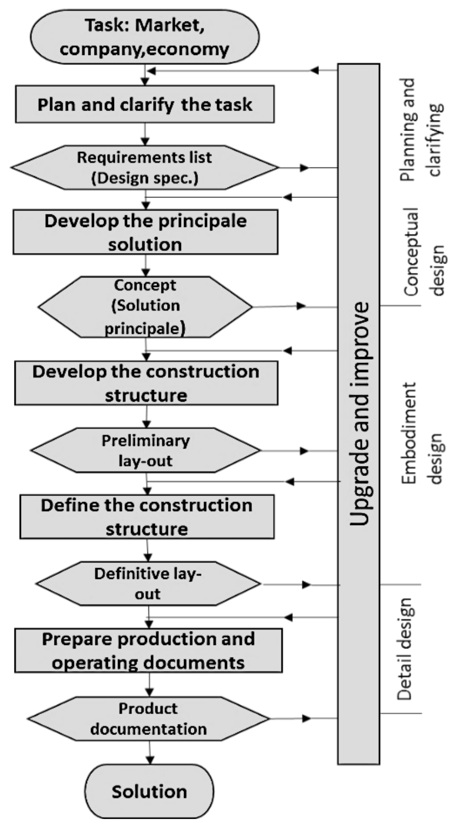

Figure 2. Product development process of Pahl and Beitz

Cooper proposed a linear model that contains three steps (Cooper , R. G 2011): business case, scope analysis and construction. In addition, he proposed three doors for decision making between the phases. In 2014, Cooper improved his process by making it more flexible, adaptable and iterative(Cooper 2014). On the other hand, some authors pioneered the integration of reverse engineering (RE) within the engineering design process to better understand concepts (Orta, Guerra-Zubiaga, and A. Ramírez-Mendoza 2006). Otto and wood have decomposed their reverse engineering and redesign methodology in three detailed phases: (i) reverse engineering, (ii) modeling and analysis, and (iii) redesign (Wood et al. 2001). Under this method, the product under investigation will be tested to determine how it works exactly. This will lead to disassembly and a concrete understanding of how a design works.

In our context, and in order to integrate a more concrete and practical experience in the process of Ulrich and Eppinger used in the engineering design course. We have based on the reverse engineering methodology to understand the physical principles and the design parameters of the product. this new process makes it possible to teach students the design using practical technique. This article is structured as follows: In section 2, we detail the proposed design methodology. Section 3 is devoted to the application of the process with a real case from students' projects. Section 4 illustrates the results from the process. We present in section 5 the limitations and future work. Section 6 is dedicated to a conclusion.

2. Methodology

In order to empower Ulrich and Eppinger process by reverse engineering activities and make it more actionable (simple to use) (Kojmane and Aboutajeddine 2016), we have rearranged it by adding a reverse engineering phase and merging some other phases in one phase only Figure 3.

This integration is the results of our experience with students in project design (Kojmane and Aboutajeddine 2016), but also by examining literature studies (Ulrich, K. and Eppinger, S 2015) and (Wood et al. 2001).The five phases of the proposed process are explained in the following.

- Planning: This phase consists of generating and identifying opportunities by using idea generation methodologies
- Reverse Engineering: This is the phase where students practice design. The first step is to choose a product similar to the concept chosen when looking for opportunities or a product that achieves the same desired features. Then, the students dissemble the chosen product to have an exploded view of the product which will be the basis for drawing "Force Flow Diagram" and "Functional Model". The results of this step help students to identify customer needs, identify product features, identify engineering specifications, and characterize the shape of different mechanical parts....
  NB:
  Force flow Diagram: represents the relationship between each component. The circles illustrate the components and the arrows represent the connection between the components.
  Function model: represents the functionalities of the dissected product as well as the type of relationships between each functionality (energy, information and material).
- Concept Development: Based on the second phase, students identify the needs of customers (using: interview, focus group, RE...). These needs are transformed into engineering specifications. Then, the third step consists in generating concepts that satisfy customer needs and validate functionalities. The fourth step is to select the best concepts by the "PUGH" method. If the students choose parts of the dissected product in the concept generation phase as components of the new concepts, the students must digitize these parts by 3D scanning machines in order to use them in the final step. This step consists in recovering the cloud of points of the digitized part in order to make the reconstruction of the part while passing by the various operations on software such as: CATIA, SOLIDWORKS, GEOMAGIC and others. Finally, students test the feasibility, desirability and viability of the product.
- Detail Design: After testing the designed product, students must complete the specifications for geometry and material... and also eliminate physical and engineering contradictions on the product.
- Test and refinement: This phase consist in building a prototype (Alpha) to test its functionality and later a beta prototype for a final testing of customer desirability

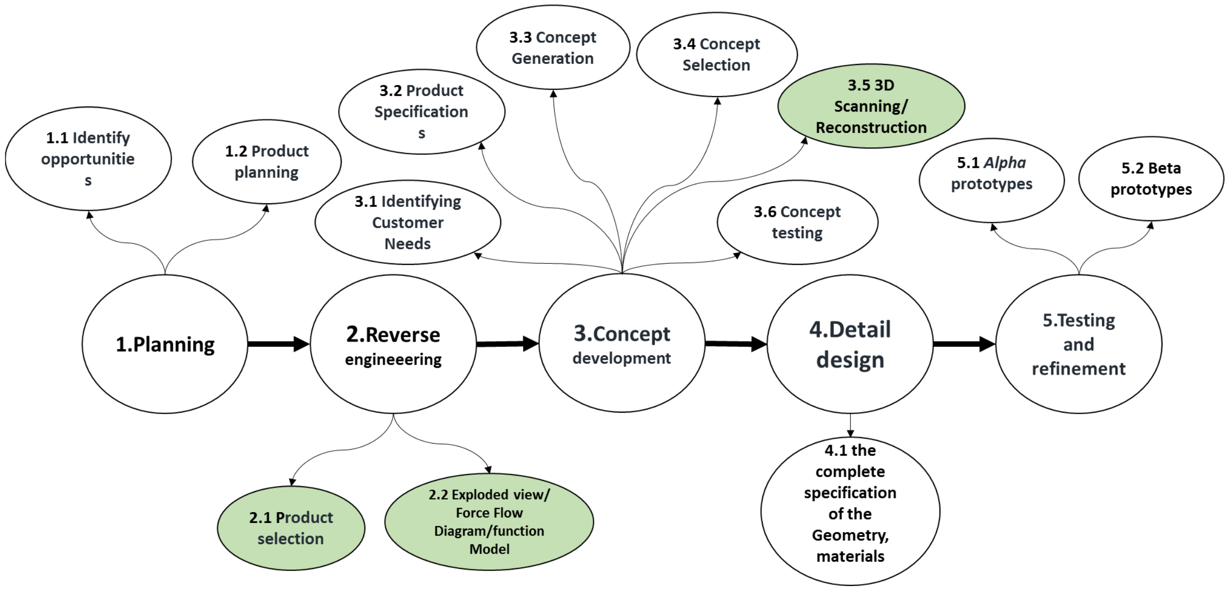

Figure 3. New Product development process including reverse engineering activities

3. Process application

The proposed process, illustrated in Figure 3, was used by a class of students during a course on engineering design at the master degree. Students were instructed to follow thoroughly the process. 10 projects have been launched (4 to 5 students per project). In the following, we choose a project as an example to explain each process phase with a real case.

In the first phase, the group of students identified several opportunities. Then by a multi-vote, they chose to work on the improvement of a hand blender. For the second phase, students selected to dissect a hand blender. Figure 4 shows the Exploded view, Force Flow Diagram and Functional Model done by the students.

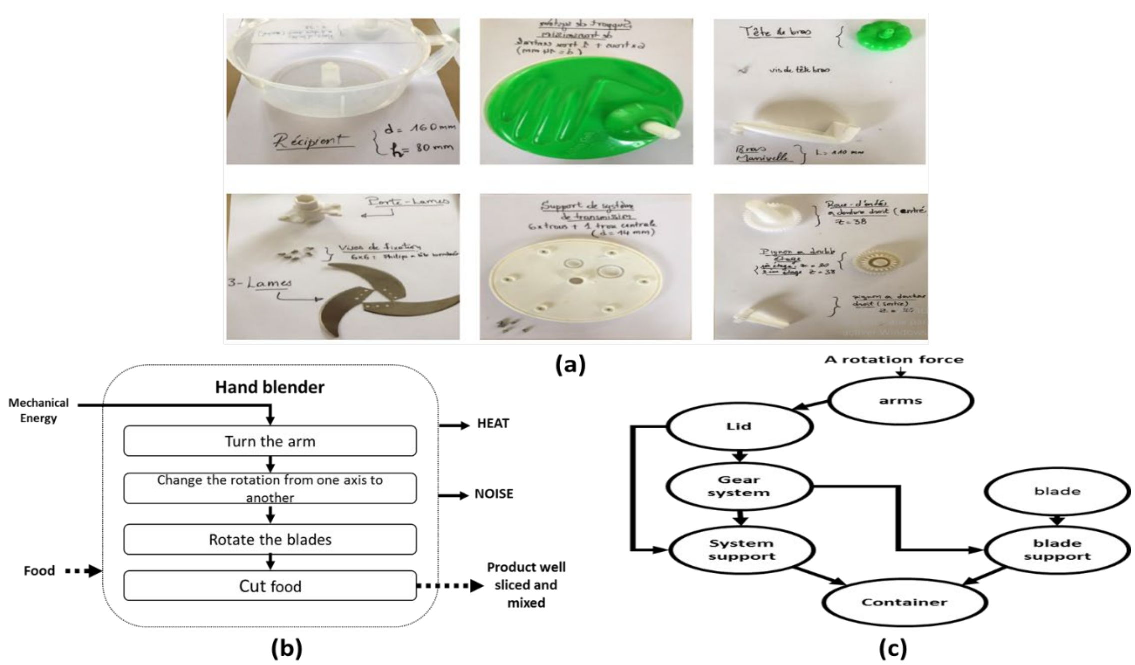

Figure 4. (a) Exploded view (b) Function Model (c) Force Flow Diagram

In the third phase, students identified needs by several methods: intuitive method, SAFE method and the teardown. Examples of needs are:
ND1: facilitate arm grip
ND2: increase efficiency and reduce slicing time
ND3: facilitate cleaning
ND4: resist external stresses

After the identification of the needs, engineering specifications were generated by the students. These specifications illustrate the engineering measures that must be respected during the design of the new product. Table 1 shows some specifications with their measurements.

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Specifications	**Level**
Have a light weight	0,35 kg
Resist the temperature	Material : PP/ T=298,15 K
Achieve the maximum speed of rotation	600 tr/min

Students generate concepts that meet the obtained needs. Figure 5 shows some concepts generated by students.

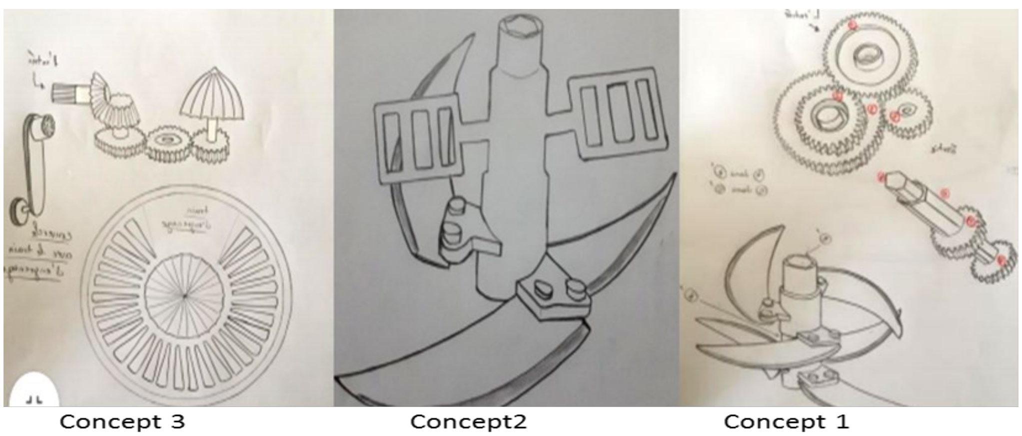

Figure 5. Some concepts generated by students.

The students selected the best concept according to design criteria. In this case, the final concept is concept number 3 which better meets the desired needs and specifications. Several parts were chosen from the dissected product to be used in concept number 3. And because of the lack of technical documentation for these parts, it is necessary to use the 3D scanning tool. The 3D contact scanning machine is "MODELA MDX20". It was used in this step. Figure 6 shows the point cloud recovered from a pinion with an accuracy of 0.1 mm in both axes (x and y).

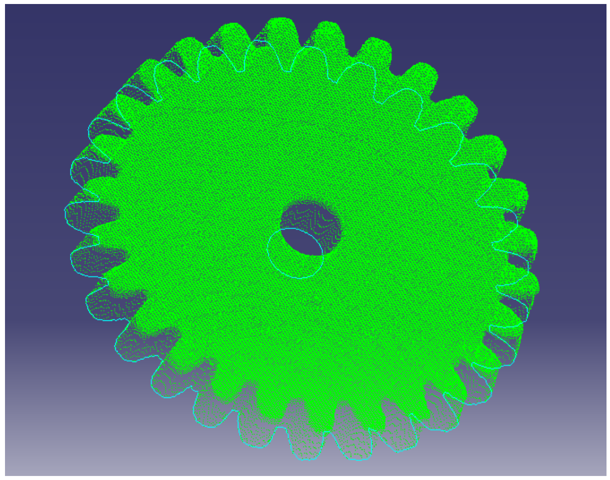

Figure 6. Point cloud in CATIA V5.

In order to use this digitized part in design software, the point cloud must be transformed into a solid modifiable part. For this, the students used Catia as reconstruction software. Figure 7 shows the solid part.

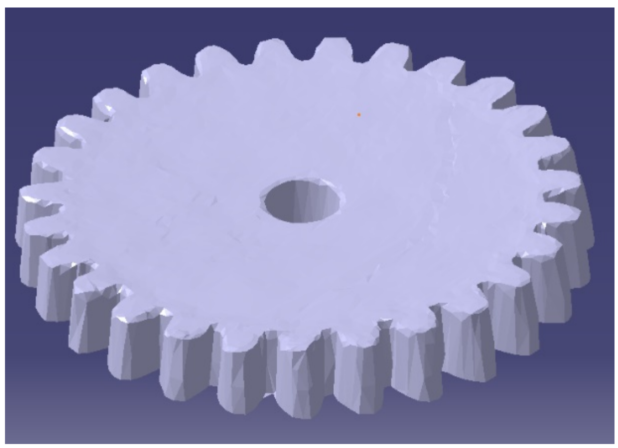

Figure 7. Solid part.

The students made modifications after the reconstruction to realize exactly the chosen concept.
Figure 9 shows the concept drawn by Catia software. This concept has been tested to validate the technical feasibility.

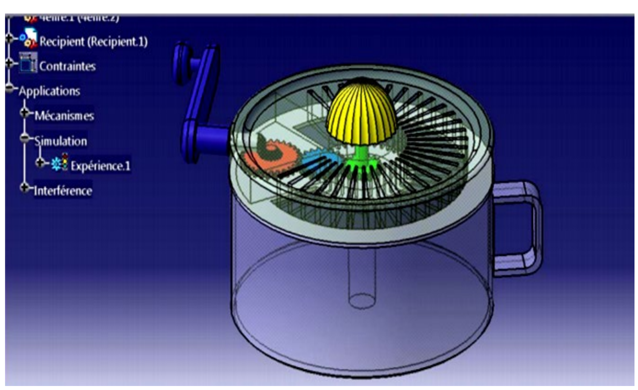

Figure 9. Modeling the new system with innovative functionality on CATIA software.

After the realization of the virtual concept on Catia, and After a solid 3D model was generated, the students created the STL model for the production of the prototype of the new design in ABS material by a 3D printer. Figure 10 illustrates a real part by 3D printing.

Figure 10. Real part by 3D printing

4. Results

Towards the end of the semester, the students were evaluated according to the following criteria: the quality of the final concept (functionalities, technical feasibility, customer desirability...), understanding of the process, the completion of reverse engineering steps and other criteria. After the evaluation and feedback from the students, we concluded that there is an improvement in the level of practical learning of students. Also, a decrease in development time compared to previous years. This reduction in time is characterized by a remarkable progress in the final stages of the process. Despite this reduction in development time, most groups encountered several problems during the last phase of prototyping.

5. Limitations and perspectives

During the application of the process, we observed problems that limited the exploitation of the potential of the process. Among these problems:
- Lack of rapid prototyping resources
- Time constraint
- Complexity of the process
-Limited financial resources of our faculty

These problems lead us to plan to improve the process by adapting it to emerging countries context of limited resources and technical knowledge. In our future work, we intend to develop a new redesign process based on reverse engineering and patent circumvention methodologies and the use of open hardware.

6. Conclusion

This work was devoted to the integration of reverse engineering into a generic product development process. The goal was to help students design new products and acquires practical skills. To evaluate the relevance of the proposed process, an example was illustrated from idea to prototype. Our future goal is to develop a more efficient process particularly for the context of emerging countries.

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Biographies

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