TECHNICAL PRODUCT OPTIMISATION A NEW COURSE INTEGRATING DFA AND LCA

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ABSTRACT
Technical Product Optimisation (TPO) is a second year course of the Bachelor of Industrial Design Engineering [1] at Delft University of Technology. The course has a DfA and a LCA practical exercise. The results of both exercises were poor on content and enthusiasm. Two important aspects play a role in it: *the time pressure and same tasks for both exercises*.
The integrating DfA with LCA is necessary for better results and has a side effect that the students come from passive to active involvement.
The integrated exercise was carried out in groups of four students. The student groups are doing tasks together and also a reasonable time separated in two couples of two. The student groups get a consumer product to make the DfA and LCA analysis for making a redesign. The experiment was an overwhelming success. The quality of reporting was high. Active student involvement in the exercise leads to creative solutions.
A key aim of technical education is motivating students through interesting and engaging tasks. Moreover the objective is also to ensure that doing alone is not emphasized but writing on reflective note on the experience.

Keywords: DfA, LCA, optimization, design education

1 INTRODUCTION
The reason of integrating DfA (Design for Assembly) with LCA (Life Cycle Assessment) was the dramatically bad results of LCA practical exercise and to lesser degree the results of DfA. LCA was boring, students had to fill in numbers and they got meaningless answers back as result. The computer programme was opaque, the results were not related to a size that one may justify. During filling in the form on the computer a satisfaction point may be reached if a reasonable number of parts have been filed in at certain moment. The motivation drops to almost zero at that point, so the students don't learn the goal of this exercise.
Two aspects play an important role in the bad results: the time pressure and same tasks for both exercises.
DfA and LCA are two methods for coming to a more optimized product. The methods are used for analyzing an existing product or a detailed design. Everything is already known of the parts and their relation, but using the methods may give insight to make change in the final product design that may have the same performance with an effective detailed design and sustainable too.
DfA is an optimisation method which evaluates an existing product by means of disassembly or analyzing a detailed product design. Boothroyd and Dewhurst [2], have described their method for manual and automated assembly. In this study we use the manual assembly description.
LCA is a well defined method to calculate the environmental burden of a product or service [3].
The goal of integration will be a better usage of time, which can lead to an improvement in quality by reducing time pressure. Time pressure shall be reduced by avoiding doing the same task twice. The students have to come from passive to active involvement which is defined as a sub-goal. Likewise the quality of reporting should be improved which is unfortunately the sub-sub-goal. The aim of integrating of DfA with LCA is to motivate students with interesting tasks. Interesting tasks are not filling in big forms, calculating formulas etc. Instead the students have to discuss the problems to be solved and to make decisions for making progress in the project. Therefore the integration has a side effect; the students come from passive to active involvement.

2 INTEGRATING OF DFA WITH LCA

The DfA and LCA exercises should be integrated. However, at first the DfA analyzing process and secondly the LCA [4] method need explanation in the same order before the integration can take place. For both methods the essentials are to come to the improvements goals, which lead to discussion of the goals with the best opportunity. For this, the students need already technology knowledge of a high level. In these types of projects they can use the information that is already generated in the Industrial Production course which is also a practical exercise.

2.1 DFA

The Boothroyd and Dewhurst method is used to analyze and a redesign the product. In another course of Industrial Production (IP) they are using the same product so that the students have to evaluate which IP-report they are using to optimize the product. The optimization conclusion should be done on the basis of parts tables. The main issues are to research the parts on the following points:

- Integration or leave out
- One way assembly direction
- Symmetry

Three goals have to be formulated on the research of the parts for optimization. They should not be trivial but focus on innovation. For instance, hydro forming may be an innovation of production process for junctions which can not be disassembled without destroying the junction.

Teams of four students make first an individual redesign with the three goals for optimization. The individual redesigns should be weighed and the best one chosen or the best solution out each or less individual redesign. This is the starting points for final redesign [5], [6], [7].

2.2 LCA

The environmental burden of a product or service has to be calculated for the optimization of the product. The basic calculation system is based on a systematic approach of production and consumption. The systems have boundaries, indicating what is included or excluded. A clear description of the system boundary should be made, so the calculations could be used by others. For example: a coffee maker will include the coffee and the filter bags.

The tree is a system approach that lays an emphasis on materials, production of product systems. A pitfall could be the production phase, which is often calculated in much detailed. For example: materials of all parts may be different. Then look for parts with the same material and weight the influence on the total. Parts below 1% of the weight should be neglected in the calculation, but parts of the same material and process should be included.

The functional unit is a combination of the functionality of the system and the unit in which this functionality is expressed.

Quality aspects of LCA are an obstacle for the designers which have to deal with three manners basically [8]:

- Measurable in a unit of power, lumen, decibel, watt, kcal etc.
- Lifespan in a unit of time (hour, day, week, month year etc.)
- Market value in a unit of money (€, £, $ etc.)

2.3 Integrating of DFA with LCA

The integrating of DfA with LCA is logical step to improve the bad results. Many students groups have to redo the separate parts, it is hard to accept that nearly 50% is just sufficient or doubtful but 5% have to redo that the specific project part. The analyzing phase should be more fun for the student; the student groups choose their product from the set of offered products, but the challenging products are first gone. There are still products to choose that recall resistance from the student team. In the course that is now running, the student team may bring in its own product, which has to fulfill certain criteria such as: number of parts, different material use, and different production. All the tasks of the integrating of DfA with LCA exercise is defined and structured in project steps. The projects steps are on integration and General, Specific DfA and Specific LCA. Integration may be done on every step but the steps 5, 6, 7 are integration steps in particular (see Table1).

Table 1. Project steps for Integration and General, Specific DfA and Specific LCA [9]

<table>
<tr><th>Specific (DfA)
Design for Assembly</th><th>Integration and General</th><th>Specific (LCA)
Life cycle assessment</th></tr>
<tr><td colspan="3">1.Orientation</td></tr>
<tr><td>• DfA lecture
• Choose a product and download IP report</td><td>• go trough LCA-DfA Syllabus
• collect the product
• register for a team</td><td>• LCA lecture
• determine product chain
• determine life cycle
• determine functional unit
• determine the boundary</td></tr>
<tr><td colspan="3">2. Disassembly, investigation the product and parts</td></tr>
<tr><td>• documentation assembly
• explode view of all parts using picture(s)
• Draw an assembly scheme</td><td>• disassemble the product
• documentation using table(s) and picture(s)
• put results in report</td><td>• determine the weight (if this is unknown)
• determine material
• determine manufacturing process</td></tr>
<tr><td colspan="3">3. Calculation</td></tr>
<tr><td>• fill in the work tables with assembly and handling times (DFA-Manual) [10]</td><td>• put results in report</td><td>• make an LCA using Ecoscan</td></tr>
<tr><td colspan="3">4. Define design goals</td></tr>
<tr><td>• analyze the bottlenecks at assembly and handling
• define clear and unambiguous three goals for optimization of the redesign</td><td>• put results in report
• identify conflict situations between DFA and LCA goals</td><td>• analyze the bottlenecks at LCA, the environmental impact
• define clear and unambiguous three goals for optimization of LCA, the environmental impact</td></tr>
<tr><td colspan="3">5. Redesign</td></tr>
<tr><td>• two students of the team make an individual redesign with sketching on the base of DFA goals</td><td>• put results in report
• all individual redesign must be put in the report</td><td>• two students of the team make an individual redesign with sketching on the base of LCA goals</td></tr>
<tr><td></td><td>6. Synthesis redesign</td><td></td></tr>
<tr><td colspan="3">• Discuss the individual redesign and make the final redesign which may be best one or best elements out all the redesigns [11].</td></tr>
<tr><td colspan="3">7. Evaluation redesign</td></tr>
<tr><td>• make an assembly scheme & tables redesign
• discuss redesign results with comparing original</td><td>• put results in report
• discuss redesign with regard to DFA and LCA</td><td>• make a LCA with Ecoscan
• discuss redesign results with comparing original</td></tr>
<tr><td colspan="3">8. Report and presentation</td></tr>
<tr><td colspan="3">• finish the report, with conclusion, discussion, evaluations and recommendation
• make a presentation of 20 minutes with 10 minutes for questions</td></tr>
</table>

3 DESIGN EDUCATION

For the integrated DfA and LCA practicum only 24 study hours is available. The 24 hours should not equally be divided over the eight steps, but in such a way that the time is efficiently spent. A student team consists of four students who carry out the tasks together and also in teams of two. The teams may choose as their product which they may have analyzed in the Industrial Production course carried out previously in the last quarter. For high motivation the consumer products which are offered should be meaningful for the exercise which leads to high grades. The grading was directly done with

sufficient and insufficient, but the insufficient grades could be filled up with a partial task to experience on a sufficient level.
The teams may discuss each project step, so every team member knows about the assembly, design and environmental aspects of the considered product on each step. This means that the team members are learning from each other the ins and outs of the product. Steps 5, 6, 7 are specific to discuss and the integration should take place here for the project.
The discussion is not without engagement because at the end of the discussion conclusion(s), should be drawn, and these are mostly requirements or wishes for the redesign or verification. These inputs are the basis for evaluations and recommendations. Before redesign one should discuss the goals for optimisation of DfA and LCA, and decide which aspects should be improved in the redesign. Here could one get conflicting aspects, but decisions have to be made not only on rational bases but also optimal. The comparison of the results concerning the redesign and original design shows the improvement of the product design that the team has reached.

4 RESULTS

The results are presented in a PowerPoint™ presentation with a discussion of the DfA and LCA contribution to the final redesign. The students directly hear whether it is sufficient, insufficient or they have to fill up with a partial task. All teams with a partial task finally delivered a sufficient fill up report.
About 350 students have formed 90 teams; each team which presented the redesign in about 20 minutes with 10 minutes for discussion. The discussions are very interesting for judgment, because it is possible to directly find if the student understood the DfA and LCA optimization and how valuable the redesign is. Besides the presentation, the teams have to deliver a report in a hardcopy, digital the digitally presentation and a digitally poster. The poster was an aid for making the presentation, because it clearly unfolded the story of the redesign.
The improvements of integrating DfA with LCA are divided into qualitative and quantitative aspect of this practical exercise.
The qualitative improvements occurred in redesign, report hardcopy and presentation. The redesigns have improved from marginal to valuable, because the changes in design were based on the goals of DfA and LCA. The hardcopy reports have improved from poor to good and 20 % of the reports were excellent. The quality improvements were realized by the clear structure. The presentations have grown to high level, because the students had to make a poster which gives directly the structure for the presentation.
The quantitative improvements for DfA are found in shorter assembly time, better design efficiency and for LCA in reduced environmental impact, reduction in CO2 emission and eco-cost reduction. The DFA quantitative improvements are found in shorter assembly time, the time reduction varies form 2% to 30 % but few teams have made a design efficiency improvement from 2 % to 20 %. Reduction of eco-cost lies between 5% - 20% and few teams also show CO_2 reduction by 3% to 25 % this in the environmental impact.
The improvements lead mostly to success which comes easier to a flow when the project progress take place in a satisfied time for the students. That is a valuable experience which drives the teams to a high creativity level.
Experience is researched from the personal evaluation of the individual students. The following criteria are used at the observation research: teamwork, technical knowledge, estimation, documentation, processes and materials.
The team work stimulated the teams to do task on the planned time, but the organization of the practical exercise was not clear and chaotic. The first four steps were done separately by couples that made the discussion in the next steps tougher. Another remark is that is the technical knowledge was doubled for DfA in the analysis phase, because students did not make use of information from the IP-report.
Because estimation is working with uncertainty, it gives students an unsatisfied feeling. The databases used do not have all the needed information. The documentation cost time to read; most students look only to do task but they avoid understanding the lessons.
Processes and material knowledge required to analyze consumer product was poor, because the experience learning and doing was lacking.
One of the redesigns is reflected in a Figure 1, with the original product and the redesign concept.

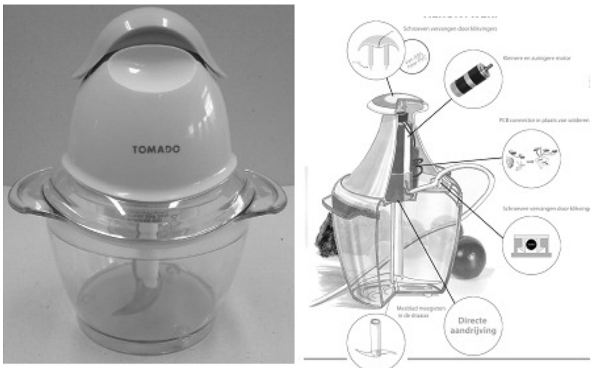

Figure 1. A vegetable chopper: original (left) and redesign (right) with another drive and material use

5 DISCUSSION

The forming of DfA-LCA teams was good for the redesign task. However, for the first four steps should be recommended to discuss the results by explanation of the goals to reach for DfA and LCA to the other couple. This feeds the product knowledge enormously which founded the motivation of the teams to finish the redesign on the highest level that the team can reach. The discussion costs time, however a good analysis will accelerate the synthesis, and avoid iterations which cost more time then the extra time needed for the proper analysis. A good understanding of the product cost time but with the optimisation methods you passed on it is possible to make a good analysis and the first time right redesign concept. Learning from each other would save time in all stages of the process because the learned product knowledge is shared with the team members.

The qualitative improvements comes by mastering of the product knowledge which are expressed in a clearly report with conclusions from which the team is convinced that it has a contribution to their own competencies. The explode view is always a good aid to learn a product: first by disassembly the product, second by making the exploded view of the product with digital camera (see Figure 2) and third by assembling all the part and sub-assemblies to a working product.

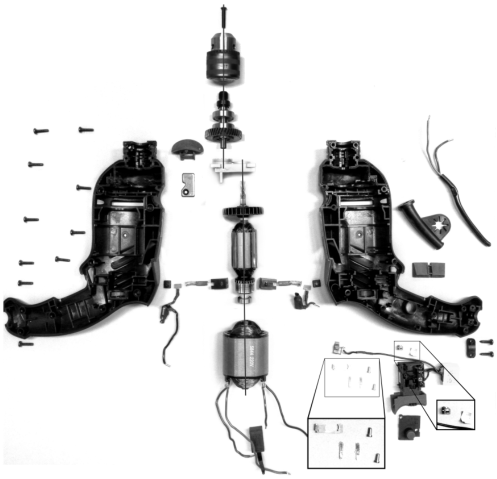

Figure 2. Exploded view of an electric power drill

The quantitative improvements could be small. To small improvements could be experienced by team members as not reaching the goal which disturb the coherence in the team. These phenomena should be recognized and solved, however there is lack of time to coach the teams more intensively. If the improvements are substantial then the team will come in a flow. The flow can be disturbed by worse functioning of the team.

Estimation is always unsatisfied and discounted the motivation; only by experiences you learn to handle the uncertainty which is connected on estimation. Designing is always looking forward to a design solution which is a compromise between all the requirements and wishes. You can’t calculate the most optimised product concept, so dealing with uncertainty should be one of the competences the students have to learn.

6 CONCLUSIONS

The integrating of DfA with LCA is carried out successfully, because the presentation, hardcopy report has strongly gained to a high level. The improvements may fall higher out if the integration is also done in the first four steps. The environmental impact now shows to better advantage, because the process is given more direction with the step structure.

The teams are so successful that they experience the flow of the redesign process, but bad team communication lead to slowing down the process and the team inspiration and motivation. Also here it goes about improvements on product design but the calculations are not sufficient because the product is assembled out of part and sub-assembly.

Technical education can motivate student’s trough interesting tasks that lead to brisk project. Nevertheless some teams get lost by perfectionism, too long discussion took much planned time away. So also the planning could much better with products which are interesting for the competence of the students.

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