

DESIGNER FOCUSED QUICKSCAN RECYCLABILITY ASSESSMENT METHOD

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Abstract: Recycling crosses the fields of resource engineering, metallurgy and materials sciences, and designers cannot be expected to master all these knowledge areas. However, designers need to have access to this knowledge in a simple and clear form, to be able to design products that allow an optimal recovery with minimum quality losses. This is achieved by developing a QuickScan recyclability assessment method based on an exploded view of a product, in which material compatibility and ease of separation of parts are indicated with a simple color scheme. The requirements for the method is derived based on understanding of the design process and learnings from existing recycling tools. The QuickScan recyclability assessment method was tested on a MR16 LED Lamp for method enhancement.

1. INTRODUCTION

Many tools have been created to make it possible for designers to integrate recycling information during the design process. However, most of them poorly suit the requirements at early design stage. First, the majority of existing tools are simply not usable at the early design stage because they require too detailed product data. Secondly, they are rarely integrated in the actual design activity and existing tools and methods and therefore constitute an extra work load. Another major concern is linked to the complexity in the decision making process during the design phase. Designers have to deal with multi-criteria decisions, and recyclability is often considered as a less relevant and relatively complex parameter [2].

Designers need simple, easy to use and heuristic methods, which can be adapted to their daily tasks, existing tools in the design process and their competences. Therefore, the aim of this paper is to draw the outline for a QuickScan recyclability assessment method for designers. The ultimate aim of the QuickScan recyclability assessment method is to enable designers to take recycling information into account in a straight forward way. By using this method a designer should be able to gain a fast(er) understanding of how well a product can be recycled and on which design aspects to focus for improvement. With this information designers will be able to optimize material choices and connections in

products in order to limit loss of materials in actual recycling of the product at its end of life.

The QuickScan tool is developed focusing on the one hand on the recyclability information needed by the designer in the early stages of design process, and on the other hand on the way in which the information can best be presented to be useful to a designer.

We first present a literature overview to establish which product attributes directly affect recycling and recovery of materials and how these are addressed in existing recycling tools.

The design process and especially the role and responsibility of the designer/engineer was analyzed to determine the type of information that is most relevant to include recyclability aspects in the decisions taken at a particular design stage. Special attention is given to a QuickScan recyclability assessment method that can be used in the stages of conceptual design and embodiment design to optimize design with respect to materials and joints. The proposed outline for QuickScan recyclability evaluation is illustrated on a MR16 LED Lamp.

2. METHODOLOGY

We conducted four interviews with two senior design engineers in Philips Lighting to understand how recycling information can best be presented to designers. During these interview sessions possible input and output data for the QuickScan recycling

method were discussed. As concluded from literature review and interview sessions the input data should compose of materials and connections (product attributes), and simplified information on recycling and recovery of materials and joints. Output should be a simple visualization for conceptual design stage that takes only 1 to 2 minutes to scan. A designer should be able to gain a fast(er) understanding of how well a product can be recycled and which materials and connections cause losses in current design concept.

By finding the input data, immediately ideas began to emerge on how to visualize and present the data using assembly trees, cutaways, explosion diagram, liaison diagram, precedence diagram or AND/OR trees instead of a typical excel file or look up tables. The novelty of the approach was to use existing product modelling in the design process to present recycling information, since product modelling can be easily understood by designers. As a result, it has been concluded that exploded view is a good way to visualize and present recycling information.

The various stages in product design and decision taking are well described by Roosenburg's design process (see Figure 1).

Next we have disassembled various MR16 LED Lamps to learn about the product architecture, materials, weight, connections, fabrication methodology (deep-drawn or die-casted). At the same time we applied some of the existing Ecodesign and recycling tools such as QWERTY/EE, EcoScan, Fast Track LCA to evaluate the environmental and economic impact of various MR16 LED lamps. The purpose of impact assessment was to understand if environmental scores are a right indicator for recyclability. For the QuickScan recycling method, the economic value of materials for recyclers will be the indicator for recyclability. For example we know that aluminium has higher value for a recycler than glass. Therefore, when a product contains aluminium the product has to be designed such that aluminium parts can be easily disassembled/ liberated. This is because aluminium has a higher economic value for recyclers.

Next, we conducted a literature search to compile a list of attributes that impact the recycling process and should be included in the QuickScan recyclability tool. Finally the outline of the Quickscan tool presented for experts in the course of Green Electronic progress meeting [3]. Experts were added to validate the findings of our study and to prevent bias. Experts were asked to indicate if they see the QuickScan recycling method useful for designers. In addition, they were asked to test the method for their products for the purpose of method validation and improvement of the method.

3. LITERATURE REVIEW ON EXISTING RECYCLING TOOLS

Prior to the QuickScan tool development it is important to understand "What recycling information does a designer need in the early stages of design process?". There are many domains and trends discussed in recycling namely as: legislations, recovery and recycling technologies, process configurations, collection rate, disassembly, sorting, shredding, separation, smelters, material fractions and liberations. In addition, waste management principles such as Extended Producer Responsibility, take back system organisation, legal compliance requirements, consumer behaviour, and other external drivers affect product recycling performance [4, 5].

The recycling information relevant to product designers, deals with the selection of materials, connections, shapes, surface treatment and life time of a product.

To develop the QuickScan recycling method we have focused on a product centric approach [5] in which break-down of connections and separation and recovery of materials are most essential, that is those aspects that are directly in the hand of a product designer.

3.1. Methods applied for recycling assessment

Recyclability information is commonly translated to designers through a set of design guidelines, tools or techniques either as qualitative/semi quantitative or quantitative methods. Qualitative or semi-quantitative methods are quick, fairly simple to use and can be applied at the early design stage [2]. Examples are the metal wheel [5], compatibility tables of materials [6], joints look up tables and design guidelines [7].

On the other hand, quantitative methods require a lot of data about the product before it is designed and enters the design process at a fairly late stage. These methods often work best to upgrade or redesign a product. Well known quantitative methods are Quotes for environmentally WEighted Recyclability and Eco-Efficiency (QWERTY/EE) [8], Electronic Product Environment Assessment Tool [9], Take back advisor (TBA)[10], SYstem iNtegration Approach for Product reSource Efficiency (SYNAPSE) [6] and Physics based modelling [5, 11].

3.2. Comparison of existing recyclability tools

Existing recyclability tools have some similarities in common. They all address “product attributes” and “end of life attributes”. Product attributes are design parameters that describe aspects of a product such as materials, connections, shape, surface treatment and product life time [4]. While end of life attributes are parameters that describe the end of life processes and the way in which product attributes behave in end of life processes, namely as: collection, transportation, sorting, depollution, dismantling, shredding and secondary processing.

Table 1 is a summary table of recycling tools and techniques that shows: a) the attributes that different recyclability evaluation tools and methods have in common, and b) the way in which recyclability is indicated in various tools. As shown in Table 1, QWERTY/EE takes into account the Bill of Materials (product attribute) and transportation, dismantling, fragmentation and secondary processing (end of life attributes) while it does not implicitly cover connections, shape, surface treatment and life extension from product attributes and sorting and collection rate from end of life attributes. However, interestingly all the tools and techniques presented in Table 1 have materials in common. This means that material is an important variable that needs to be considered in any design for recycling tool development followed by connections.

On the other hand, in end of life attributes the knowledge related to “secondary processing” are also considered in majority of existing tools and techniques followed by “dismantling” and “shredding”. The analysis of Table 1 shows that variables such as “shape”, “life time”, “surface treatment”, “sorting”, “collection”, and “transportation” are less enforced into existing recycling tools and techniques for designers. That is mainly because these variables are more consumer and process related and not in the hand of a designer.

It is also important to note that each tool indicates recyclability in various forms. In some tools recyclability is calculated based on recovery yield (% separated, % wasted) or environmental and economic values, while in some other tools and techniques recyclability is not an indicator but lessons learnt from actual recycling runs (practice) which are presented as do’s and don’ts statements. Moreover, some tools have a specific focus on dismantling and shredding, while some others on secondary processing or in some cases like QWERTY/EE on both. Requirements for the QuickScan tool is summarized in section 6.

4. DESIGN PROCESS

4.1. What decisions are made at each stage?

Figure 1 shows the stages of a product development process (PDP) as depicted by Roozenburg [1]. Interview with product engineers at Philips lighting confirmed this description. The PDP starts with a business idea. A business idea is a concept which can be used for commercial purposes. It typically focuses on a product or service that can be sold.

The second stage is mainly sketching where designers freely and widely generate as many ideas as possible. Moreover, designers obtain a clear understanding of the assignment, allocate resources and agree on the initial project plan.

In the “clarification of the task” stage various sketch ideas will be judged based on a criteria list by an expert team. Members of an expert team vary for different products. For example for the case of MR16 LED Lamp the expert team consists of a mechanical engineer, an electrical engineer, a thermal engineer, an optical engineer and a product architect with further input from marketing and a compliance officer.

The evaluation criteria for finding the best ideas are value chain analysis, bill of materials, mechanical, electrical properties, etc. In fact each expert will evaluate and rank the various design options based on a number of criteria but usually not on all. The sketched ideas with the highest scores will be further developed.

The “conceptual design” is the stage at which the ideas that underlie the root solution are created and matured in a manner that is consistent with the requirements. Morphological chart is a well-known conceptual design technique to evaluate various design concepts.

The “embodiment design” stage is the part of the design process which is concerned with the production of the design concept, the engineering and the economic feasibility. The production contains the parts making and the product assembly.

The detailed design includes specification of the materials, the dimensions and the shape of parts, positions of the attachment and assembly holes, etcetera. Many alternatives and options are considered during this part of the engineering design processes. The outcome of this stage gate is a prototype.

At “commercial release” stage a product becomes available to the general public. Mass production refers to the process of creating large numbers of similar products efficiently. In the last stage the business case will be evaluated.

4.2. Which stage to incorporate?

Referring to Figure 1, there are three stages in the design process where recycling information can be best incorporated: 1. Product planning, 2. Clarification of the task, and 3. Conceptual design.

During the product planning stage 'design guidelines illustrated with examples (e.g. images) of dismantled and shredded products can be used to increase awareness. In this way, designers can observe "what is working" and "what is not working" in actual recycling runs considering the materials and connections. This can be used to improve sketching and idea generation. A booklet of inspiration at this stage would help designers to create new ideas.

On the second stage of the design process so called "clarification of the task", it is often the case that there are no criteria in the requirements list related to recyclability. To enforce implementation of tools and methods for improved recyclability such requirements should be in the criteria list. There are 3 ways to do this: 1. Define a new role/add a new recycling expert to the team for selection and scoring of the ideas considering recycling, 2. Train one of the existing experts in evaluation team e.g.: the mechanical engineer, or 3. Have a checklist. Adding a recycling criteria to requirements list is not part of the tool development, however having a recycling criteria in the criteria list is important to put recycling tools into implementation.

At the third stage of the design process various design concept will be generated and evaluated. At this stage product concepts are not in production yet and changes can be made relatively easy. At this stage a more detailed recyclability assessment is most useful as during this stage the basic choices with respect to materials and joints between parts are made. In section 7 we will describe a QuickScan recyclability assessment method to accomplish this.

4.3 Eco Design and Recycling tools positioned in design process

In the past two decades, various Ecodesign tools and techniques are developed to integrate sustainability into the design process. Namely as green product road map, value engineering tools such as quick LCA, EcoMap, Green Logos, BOM check, SimaPro, GaBi and many more.

Referring to Figure 1, these tools are used at various stages of the product development process. For example legislations, policies and standards and green product road map works best before getting into the details of design process. Design guidelines suits best at early design stage. While value

engineering tools are more functional when more detailed data about the product is known and that is during "embodiment" and "detailed design" phases. And lastly, Life cycle assessment tools such as Simapro are more operational at the end of product development process when detailed profile of a product is selected and only minor or no changes are possible. Tools like Simapro will help to indicate which parts have the highest impact and should get specific attention in redesign and upgrade of a product.

This layout is also accurate for recyclability assessment methods. Some tools are more appropriate for early design stage such as joints look up tables, metal wheel, materials compatibility table, while other tools like Physic based modelling, SYNAPSE, QWERTY/EE become more functional at a later stage when the product design is frozen.

Referring to Figure 1, "things didn't really work" or in another word lessons learnt from the implementation of various tools should become a feedback loop to the design process.

5. PRODUCT ANALYSIS MR16 LED LAMP

Deep-drawn MR16 LED lamp has resulted in the development of a LED lamp optimizing recyclability [12, 13]. The prime concern was to enable separation of the electronic parts during recycling as this is important from a resource efficiency point of view. Although the value to recyclers might be less than that of Aluminum due to the higher processing cost associated with electronics recycling. Further, use materials that can be recycled, i.e. aluminum parts instead of plastics; simultaneously lowering the total amount of aluminum (i.e. the value to the recycler) by going from die-casting to deep-drawing. Therefore the main requirement for new design was: 1. Enable contamination/free separation of electronics (in a shredding process), 2. Use recyclable materials. This led to a design in which: a. Avoids internal fixed connection (everything is stacked internally) b. Used aluminum instead of engineering plastics where possible.

As it is shown in Figure 2, the deep-drawn MR16 LED Lamp consists out of the following main components: sleeve, heat sink top, collimators (lens), LED printed circuit board (PCB), two heat spreaders, driver PCB, driver clamp and housing.

Table 1-Summary table of recycling tools comparing product and end of life attributes

Existing techniques	Product attribute					End of life attributes					Indicators
	Materials	Joints	Shape	Surface treatment	Life extension	Collection	Transportation	Sorting	Depollution Dismantling Shredding	Secondary processing	
LCA tools	x						x			x	Environmental impact (mPt)
Design guidelines	x	x	x	x	x	x	x	x	x	x	Lessons learnt from actual recycling runs
Metal wheel	x									x	% liberated, recovery yield
Compatibility table	x									x	% liberated, recovery yield
Product modelling I	x	x							x		Disassembly sequence and depth
Product modelling II	x	x	x						x		Disassembly
Physic based modelling	x	x								x	% liberated, recovery yield
QWERTY/EE	x						x		x	x	Environmental impact (mPt) and economic value
TBA	x			x			x	x	x	x	Environmental impact (mPt) and economic value
EPEAT	x				x					x	Environmental impact (mPt)
Frequency of application in various tools per attribute	10	4	2	2	2	1	4	2	5	8	

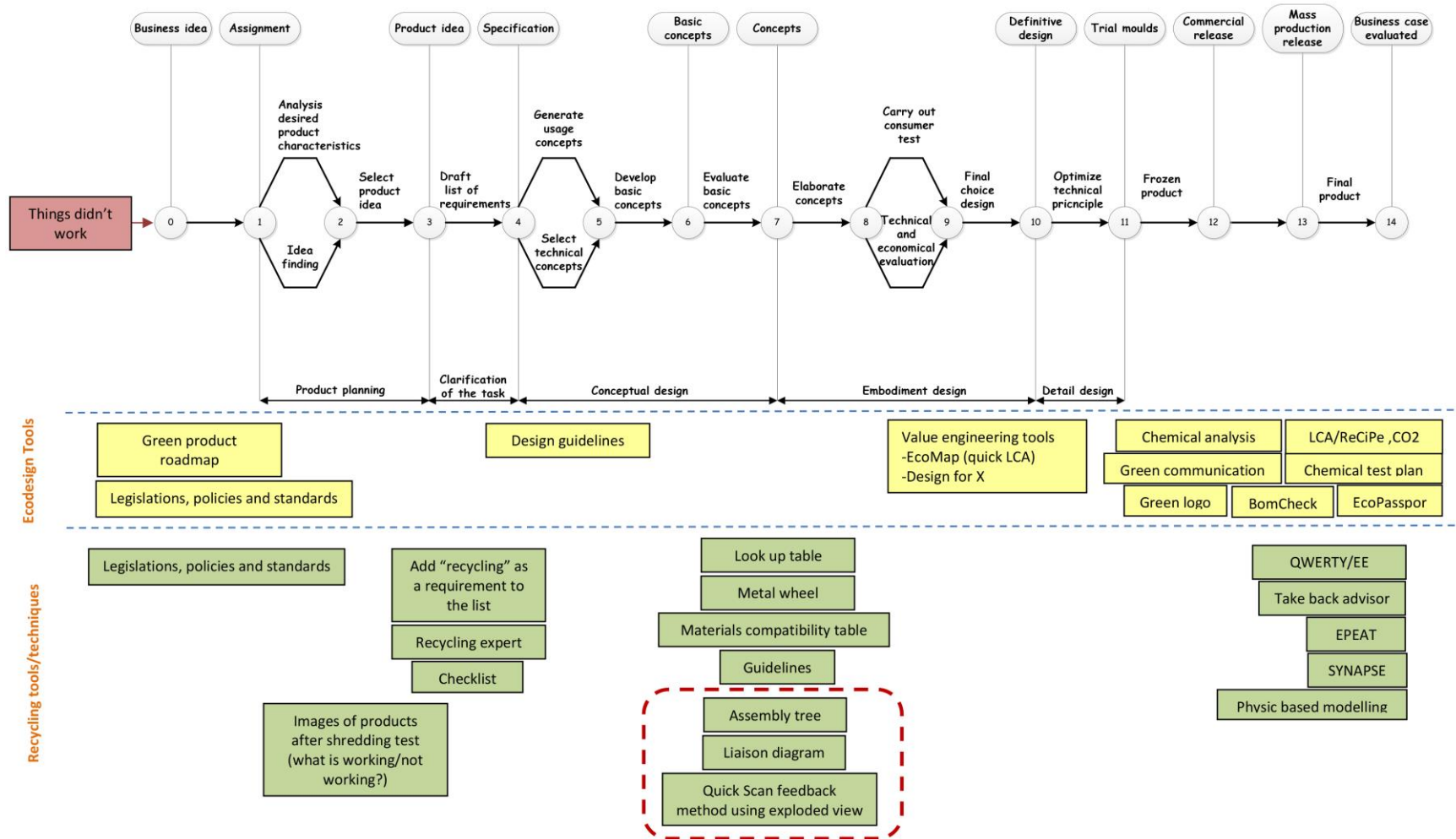


Figure 1-Ecodesign and Recycling tools positioned in the product development process of Roozenburg [1]

Deep-drawn MR16 is a good example to show that design for recycling is doable. This has been proved in an actual recycling test. Therefore QuickScan recyclability assessment method and development of the color scheme is enhanced based on this design.

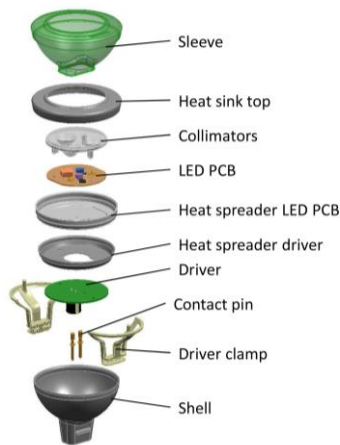


Figure 2- Exploded view of a Deep-drawn MR16 LED lamp

6. QUICKSCAN RECYCLABILITY ASSESSMENT REQUIREMENTS

Understanding the design process, existing recycling tools and analysis of MR16 LED lamp results in a draft specification for a QuickScan recyclability method:

1. The QuickScan tool must be integrated in the actual design activity and implemented in existing tools and techniques. (exploded view)
2. It should be quick, easy to use and applicable at the early design stage.
3. It should be heuristic, qualitative or semi-quantitative.
4. It should focus on materials and connections as product attributes and disintegration (either manual disassembly or mechanical methods like shredding) and secondary processing as end of life attributes.
5. The Quickscan tool visualize existing recycling knowledge to designers, while hiding in-depth insight in recycling.
6. Economic value of materials after recycling will be the indicator to prioritize parts and materials for better (re)design.

7. FINDINGS: QUICKSCAN RECYCLING METHOD

Figure 3 illustrates the QuickScan tool applied to the deep-drawn MR16 LED Lamp. The figure is an exploded view of a Deep-Drawn MR16 LED Lamp split into several layers that represent the disassembly sequence.

As shown in Figure 3, in the first layer the disassembly task is to peel off the lamp sleeve. The connections between parts at this layer should be easy to break down, otherwise the liberation of embedded parts in layer II will not be possible. The parts at first layer are visible to a user while the parts in layer II and III are only visible after disassembly/breakage. The parts at layer II and III are embedded in the housing, upper and lower parts of the lamp.

In order to present recyclability information to designers using exploded view and disassembly sequence we created a language based on lines and colors.

The yellow dashed lines highlights the most valuable parts of the lamp either from an economic or environmental perspective. In this case the LED PCB, the driver PCB and pins are circled by yellow dashed lines. These parts should be separated from the product at end-of-life.

We use a dotted line to indicate compatibility of materials in a secondary processing. When the dotted line is green it means that the two materials connected are compatible. However, a red dotted line means that the two materials connected are not compatible, and an orange dotted line means a designer is not sure if the two connected materials are compatible. As shown in Figure 3 heat sink top and housing in layer two are compatible therefore a green dotted line has been drawn.

We use a solid line to indicate the breakdown of a joint during shredding. A green solid line means the joint is well liberated during shredding (such as a snap fit). A red solid line means that the joint is not liberated during shredding and orange means a designer is uncertain how this joint will behave in a shredding, that is because of lack of recycling information provided. A dashed green line means two parts are only touching each other but not connected. Touch means laying on top of each other. Touch is always good for recycling. As shown in Figure 3 the connected parts are linked with two lines. In two vertical lines, the line on the right shows the material compatibility and the line on the left shows the connections.

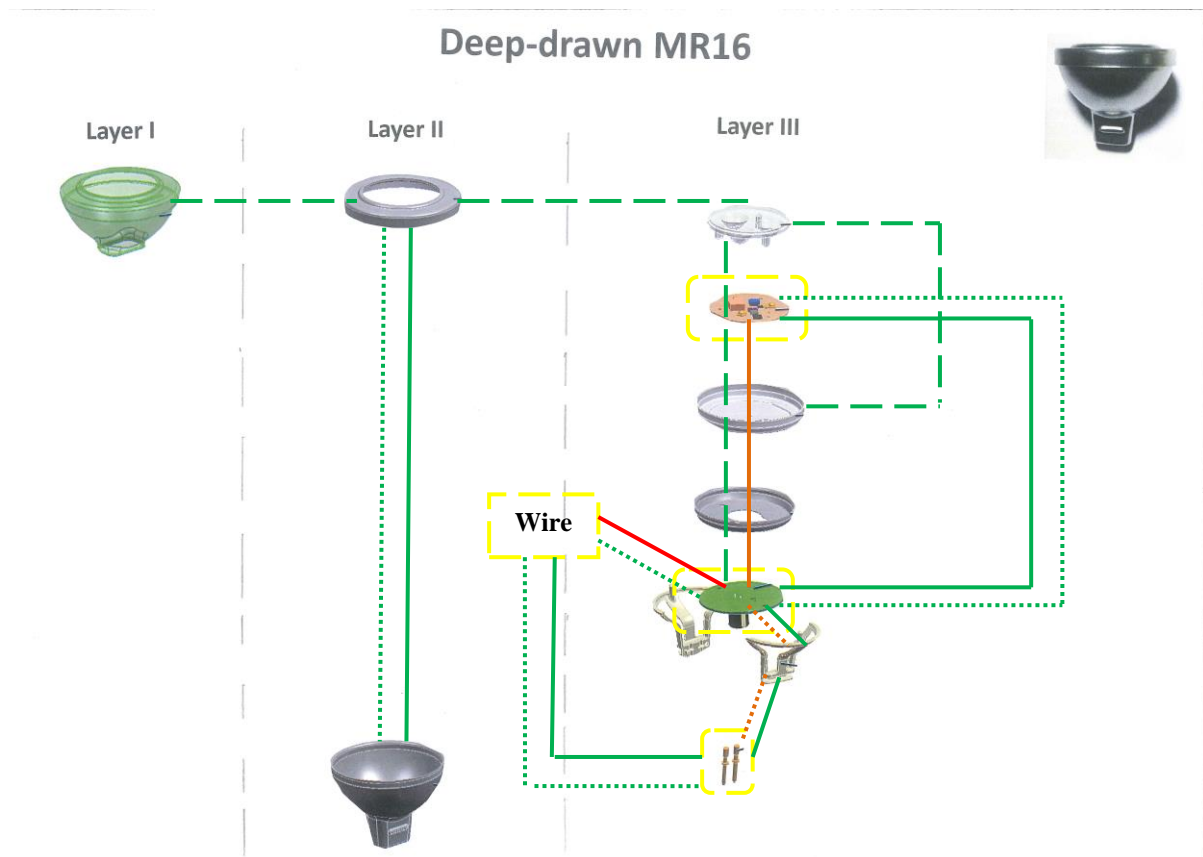


Figure 3- Testing QuickScan recycling method on Deep-drawn MR16 LED lamp

While in two horizontal lines, the line on top shows the material compatibility, and the line below shows the connections. The recycling tools presented in Figure 1 –so called recycling toolbox- can be used to provide the recyclability information. It is important to note that material compatibility and connection lines can end up to 9 possible combinations as shown in Figure 4.

1) green dotted lines with green, orange or red solid line, 2) orange dotted lines with green, orange or red solid line or 3) red dotted lines with green, orange or red solid line. For example, in the first case, when two materials are compatible any joint is fine.

		Material compatibility		
		OK	Uncertain	Bad
Connection break-down	OK	good —	good —	good —
	Uncertain	good —	warning —	warning —
	Bad	good —	warning —	bad —

Figure 4 Possible combinations of materials compatibility and connection

The elements present in the recyclability toolbox can be linked with the QuickScan recyclability assessment method. For example the metal wheel and materials compatibility table can be used for coloring the compatibility of materials (dotted lines), and a joints look up table can be used for coloring the joint solid lines. The intention is that in a next stage the QuickScan recyclability assessment method will be directly linked to more complex quantitative tools such as Physic based modelling or QWERTY/EE for information on compatibility.

The recyclability of Deep-drawn MR16 using QuickScan shows that in the layer tree LED PCB is connected to Driver PCB through the heat spreaders. This single connection is connecting three other parts. Therefore it is not clear how this connection will react in shredding. Also the wire is soldered to Driver PCB, the joint as such is not good for recycling but since the two materials are compatible during secondary processing therefore this is a good connection. Moreover the clamps are connected to Driver PCB and connection pins. Although the material compatibility is orange dotted line (meaning uncertain) but the connection is good for shredding and therefore the parts can get liberated.

8. CONCLUSION

Designers need simple, easy to use, heuristic and semi-quantitative methods to assess recyclability of a product, which fits into their daily tasks, based on existing tools in the early design stage and building on their competences. As a result, the first version of a QuickScan recyclability assessment method has been developed based on an exploded view of a product, in which material compatibility and ease of separation of parts is indicated with a simple color scheme. The tool is based on understanding of the design process and learnings from existing recycling tools.

Through a comparison of existing recycling tools we have seen that materials and connections are two commonly addressed product attributes which have a high influence on recovery and recycling of products. We have also seen that disassembly, shredding and secondary processing are commonly addressed end of life attributes.

By studying the design process, we came to the conclusion that there are three stages in the design process where recyclability information can be most usefully incorporated. A booklet of inspiration before/at the sketching phase will help designers to create new ideas. Adding a recycling criteria to requirements list during “clarification of the task” stage is important to put recycling tools into

implementation and a QuickScan recyclability assessment tool during the conceptual design stage will help to evaluate various recycling design concepts.

To develop the QuickScan recyclability assessment method, the novelty was to expand existing design tools to present recyclability information. This is because design tools can be easily understood by designers and existing recycling tools are good enough to provide recycling information, and therefore their results can be used. For developing the QuickScan recyclability assessment method, product modelling (exploded view and disassembly sequence) is used.

The QuickScan tool presented in this paper is the first version. The method needs to be tested and validated in actual product design. In addition, further studies will be needed to test the tool for more complex products such as medical display and televisions. Doing this will help to improve the method and its language. It is important to note that there is no “one-size-fits-all” tool which can address and translate the complexity of recycling, but rather there is a need for a toolbox. A recycling toolbox consists of individual elements which can be applied upon specific demands. In the future, it is necessary to link QuickScan recycling method directly to some existing elements in the recycling toolbox.

8. ACKNOWLEDGEMENT

The authors would like to thank Ruud Balkenende, Maurice Aerts, Vincent Gielen and Peter Bukkems from Philips Lighting for their contribution. We would also like to thank ENIAC for providing us with research funding.

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