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## Using Design Requirements for Environmental Assessment of Products: A Historical Based Method

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### Abstract

Due to the increasing pressure on industries for more environmentally friendly processes, the environmental assessment of products emerges as a key indicator to determine if created goods align with the organization's targets. A review of published literature reveals that the tools available for such assessments can be applied primarily when at least an embodiment of the product design is achieved. However, the environmental impacts of the product may be determined in earlier design stages. The objective of this research is to study if the environmental performance of a product can be predicted from the requirements list elicited early on in the design process. For this purpose, an environmental assessment tool (SLCA) is used to estimate the environmental performance of final products, while a rubric is developed to evaluate the requirements list of those same products in terms of environmental impacts. Artificial Neural Network (ANN) structures (18,900) are used to relate the information gained from the rubric to predict the SLCA scores calculated for corresponding products. The products used for training and testing are drawn from student design projects. The results show that the predictions are stable, with residual errors of less than half the range of target values. The maximum prediction error was found to be 27% while the average prediction error was 10%. However, the accuracy of the predictions depends on the selection of the training and test sets. Moreover, the scalability of this approach to industrial applications should be explored. Opportunities for future work are identified to improve the method for early assessment of environmental impacts of products.

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### 1. Motivation

The technological development and the initiative of companies to capture portions of the markets leads to an always growing development of products [1]. The creation of products have an impact on the environment because of the selection of the materials they are made of, the energy involved in the manufacturing processes and transportation, the way customers use them, and the wastes generated during these stages or in their final disposal [2–4]. These environmental impacts, like other aspects of products, such as functionality, cost, quality or attractiveness [5,6], are primarily determined during the *design process* of the product [7]. The systematic approach of the design process is typically organized in the following stages: clarification of the task, conceptual design, embodiment design, and detailed design [5].

Studies have indicated that the greatest impact on the different traits of a product is determined during the early stages of design process – that is, clarification of the task and conceptual design. This is because at this stage the main decisions that lead to the chosen design concept are made [8]. An important part of the clarification of the task involves turning the objectives and properties intended for the solution into a requirements list, which is a specification that can be used to judge the success of the design project [5].

The objective of this work is to study if the environmental impacts of a product can be anticipated or predicted from the requirements list generated during early stages of the design process. For this purpose, an environmental assessment tool, Streamlined Life Cycle Assessment (SLCA) [3], is used to estimate the environmental performance of final products, while an assessment tool for requirements based on a rubric with a series of questions is developed to evaluate the

requirements list of those same products in terms of environmental impacts. The discovery of relationships between the data obtained from the requirements rubric and the SLCA scores is performed through an artificial neural network (ANN) analysis employing 189 architectures evaluated 100 times each. The products used for the analysis were selected considering the availability of information needed: final products for performing the SLCA and requirements lists to be assessed. Fifteen projects developed by students in the ME 4010-Mechanical Engineering Design senior level course at Clemson University are used for the study, for which the elicitation of requirements were explicitly requested as a design task. This course and the products developed throughout by the students have been used in previous research for studying different aspects of engineering design [9,10]; given the results obtained from those experiences, it was decided that these design projects are sufficient for this work.

### 1.1. Predictions using earlier design representations

The work presented in this paper explores the potential to use requirements as early stage design representations to predict later stage performance factors – in this case, the environmental impact. This is similar to work done using function structures or assembly models to predict assembly time or market prices [11–14], as seen in Figure 1. These previous research efforts show that the market price and assembly time predictions generated using functions structures are not as accurate as those obtained using assembly models. This can be explained by the fact that function structures are earlier representations of the problem – typically used during the conceptual design stage, while assembly models take place later in the design process – typically in embodiment design stage; therefore, the former involves larger uncertainty about the understanding of the design problem than the latter.

Following this reasoning, using requirements as even earlier representations of the design problem to predict a particular cost of the product like the environmental cost, should lead to larger errors on the estimations. This is illustrated in Figure 1, where it can be seen that the earlier the stage in the design process, the higher the uncertainty about what the final features of the product will be, and the higher the error in the predictions of those features based on current information. Therefore, as more detailed information is available about the design, the predictions accuracy improves.

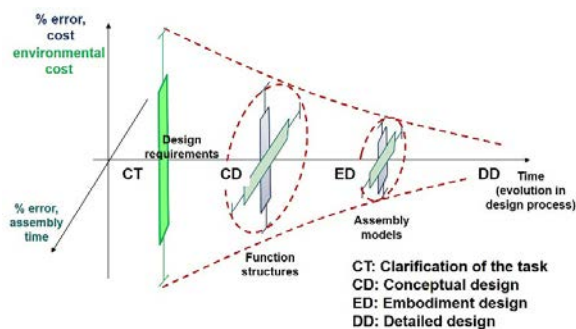


Figure 1: Errors of predicting features of a product using representations at different design stages

### 1.2. What would be the importance of this tool?

To illustrate the relevance of the work presented in this paper, we present a motivating use case of using a tool to predict environmental impact early in design (Figure 2). Considering a product design problem, one of the first efforts of the design team as part of the clarification of the task design stage is the elicitation of requirements. This requirements list can then be assessed using the assessment rubric, and a prediction of the environmental performance of the product is calculated. If the prediction is not aligned with the organization's target, then the team can keep working on the requirements and re-think different aspects of the design that perhaps did not receive the deserved attention. The improved requirements list can be assessed again, and if the prediction is now closer to the objectives of the organization, then the team can move to the next design task. Without this iteration in the elicitation of the requirements, the design project would have progressed to the next design task, and the flaws would have been discovered later in the process, with the consequent cost and time involved in making the required changes.

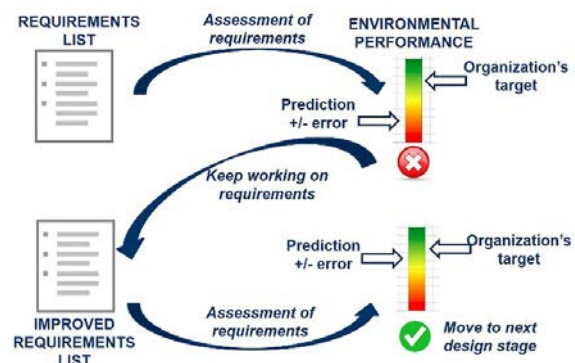


Figure 2: Motivating use case for the tool to predict environmental performance of products from design requirements

## 2. Frame of reference

The three basic engineering resources used for this study are design requirements, streamlined life-cycle assessment (SLCA), and artificial neural networks (ANN).

### 2.1. Design requirements

A requirement can be defined as a condition or capability that must be suitably addressed by the system being designed [15]. Requirements support in translating the stakeholder's expectations into a definition of the problem through the elicitation of statements which can be used for defining a solution for the problem in question [16]. Some authors such as [15] and [16] specify that requirements are expressed as "shall" statements organized in a requirements document, but in [17] it is argued that, requirements are more than a list of statements of what a system must do, they are a network of related elements containing definitions, goals, rationale and measurements. According to the stages defined by [5] for the systematic design process, the requirements elicitation takes place following the clarification of the task and prior to the conceptual design.

This structuring is consistent because one of the main purposes of the requirements list is the generation of ideas for

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