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A Development of an Ontology Framework for Supporting Environmental Product Design

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Abstract

Purpose: Introduction: *Sustainability is divided into three components which are environmental, economic and social. Environmental sustainability requires manufacturer to reduce the impacts of their actions to care for the environment.*

Methodology: *In order to expose the knowledge of environmental product design at early design stage, the ontology for environmental product design are developed. Ontologies serve to a large degree as an approach to make hidden knowledge crystal clear which means it give the ability to designers or manufacturer to recognize the activity they are operating in and to analyse the product sustainability at the early design phase.*

Result and Discussion: *The ontology for environmental product design is developed based on eco-design process module that covered the manufacturing process, end of life strategy and environmental impact. The ontology for environmental product design makes the domain of eco-design process module explicit. Other than that, it can be used to sharing the knowledge among users; can save the user's time to designing and building the environmental product design system since the ontology can be reusable and editable. This study will use table with four legs as a case study to build the ontology for environmental product design. The existing CAD model that has been downloaded is a product of table with four legs.*

Conclusion and Recommendation: *The objectives of this study have been successfully achieved. Sustainability is divided into three aspects which are environmental, economic and social. However, the ontology for environmental product design only covered the environmental aspect. The development of ontology for environmental product design that covers all the aspects of sustainability are recommended for the future research to assist the designers in designing the sustainability product at early design stage.*

Keywords: *Ontology; Environmental; Product Design*

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1. Introduction

In the most recent a quarter century emphasize that the manufacturer puts on environmental sustainability has expanded. Environmental sustainability requires manufacturer to reduce the impacts of their actions to care for the environment. Sustainability are divided into three components which is environmental, economic and social (Khalifa, 2020). Environmental sustainability emphasizes on human well-being by rescuing limited resources from the earth as well as avoiding natural disasters (Khalifa, 2019). Other than that, it also rescuing limited resources from pollutions such as climate change, green house effects, air pollution, and water pollution. For economic sustainability, the monetary development is considered as most imperative arrangement objective of countries (Alharthi, et al., 2020). It is hard to recognize the relationship in the middle of sustainability and financial development. Social sustainability has hazy definition. It is influenced by the local attributes like monetary, social, and social condition. It is also can be defined as a process for making sustainable and effective areas that advance prosperity (Alseiari, et al., 2019). It can be made by understanding what individuals need from the area they live and work (Alsaadi, et al., 2019). All of this components have become the basis for product innovation (Gharama et al., 2020; Khalifa et al., 2021).

Design for sustainability target at creating green products. It delivers the most ideal approach to meet consumer's needs in a sustainable way. As to create a more sustainable product, the implementation of sustainability considerations should be used at the beginning possible phase of product design. Sustainability product design determines important characteristics and properties of a product. It is parallel with the boundary conditions sets for next life cycle phases such as manufacturing and product use. Thus, the design phase has a large impact on the sustainability performance of a product.

Life cycle assessment (LCA) is a precise arrangement of techniques for collecting and inspecting the inputs and outputs of materials and vitality. It is also gathering and examining the related ecological effects which deal directly with the product or by system functions throughout its life cycle. In other words, LCA are used for estimate a product's environmental impact. Truly LCA could only be done once a product was in production because it need to first measure the whole supply chain. This is a missed opportunity for product designers who realize that the best potential for problematic innovation is early in the design process. Other than that, it can save big on costs when upgrades are worked out early. Sustainability has turned out to be constantly important in product design. This study is to enhance a framework for supporting sustainable product design in early phase by using ontology technique that will show the relationship of product sustainability.

Ontologies serve to a large degree as an approach to make hidden knowledge crystal clear which means it give the ability to designers or manufacturer to recognize the activity they are operating in and to analyse the product sustainability at the early design phase. Ontologies represent conceptualizations of disciplinary domains in which concepts symbolize topics. Symbolize topics are relevant for the considered domain and are associated each other by means of specific relations.

2. Literature review

2.1 Related Work

Eco-design as defined in ISO 14062 is a design approach aiming to reduce the environmental impacts of products and services throughout the whole life cycle, while assuring similar or improved services to the end customer. Pigosso et al. (2013) understood that an eco-design is environmental management approach which systematically embeds environmental considerations (EC) into an organization's generic product development (PD) practices.

In the 1990s, concepts such as eco design and green product design were introduced as strategies companies could employ to reduce the environmental impacts associated with their production processes. Ramani et al. (2010) described that product design is one of the most important sectors influencing global sustainability, as almost all the products consumed by people are outputs of the product development process. Quality Function Deployment (QFD) was originally developed in 1960s by Professors Shigeru Mizuno and Yoji Akao in Japan.

QFD goals is to develop a method to build the products which meet the customer's need. According to Crow (1998) QFD is a structure approaches that interpreting the customer requirements. QFD translating the customer requirements into specific plans to produce products that meet the customer's satisfaction. Romli et al. (2015) proposed an Eco-HOQ model as a platform of eco-design features that can be accessed by all QFD phases. The Eco-HOQ used to act as a practical guide to assessment of the product. Then, Romli et al. (2015) developed an integrated eco-design decision-making (IEDM) by using adapted Eco-HOQ to support the improvement in the sustainability of a product.

2.2 Ontology

In this study, the intention is to develop ontology for environmental product design. In order to develop ontology for environmental product design, framework as shown in Figure 1 is proposed. This ontology is developed based on Eco-process model as shown in Figure 2 that has been proposed by Romli et al. (2015). It translates the parameter in the Eco-process model to become ontology for environmental product design.

There are three parts in the framework as shown in Figure 1 which are part 1, part 2 and part 3. Part 1 is Life cycle assessment that consists of four steps. While part 2 is the process of the environmental profile data. Part 3 is the steps to develop the ontology which consists of four steps and the storage of the ontology itself.

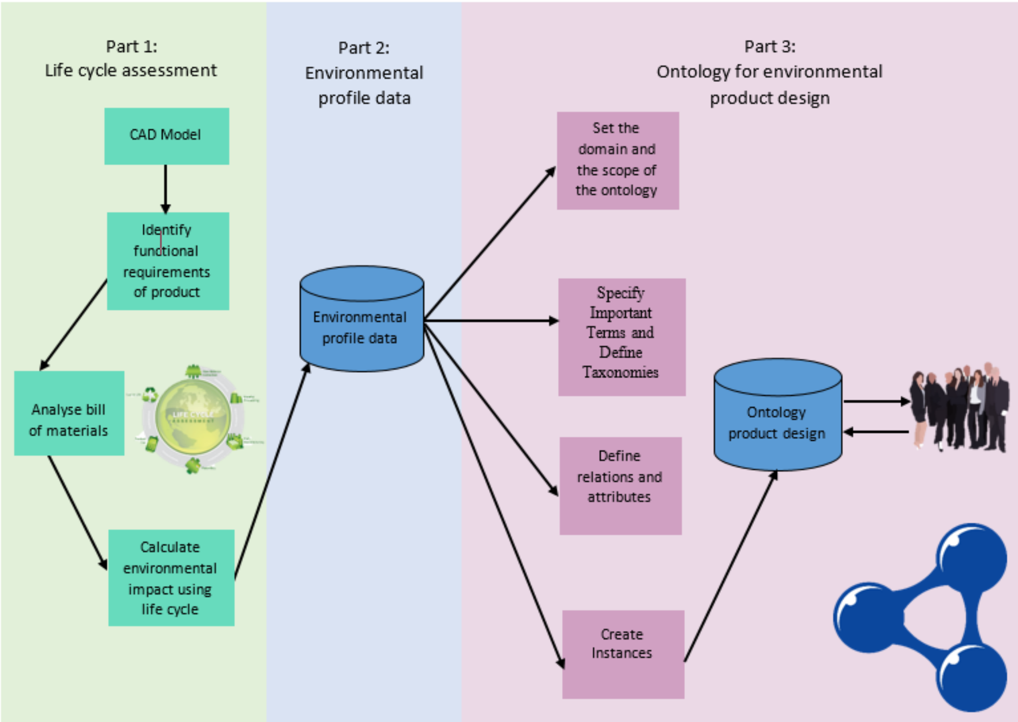

Fig. 1 Framework of Ontology for Environmental Product Design.

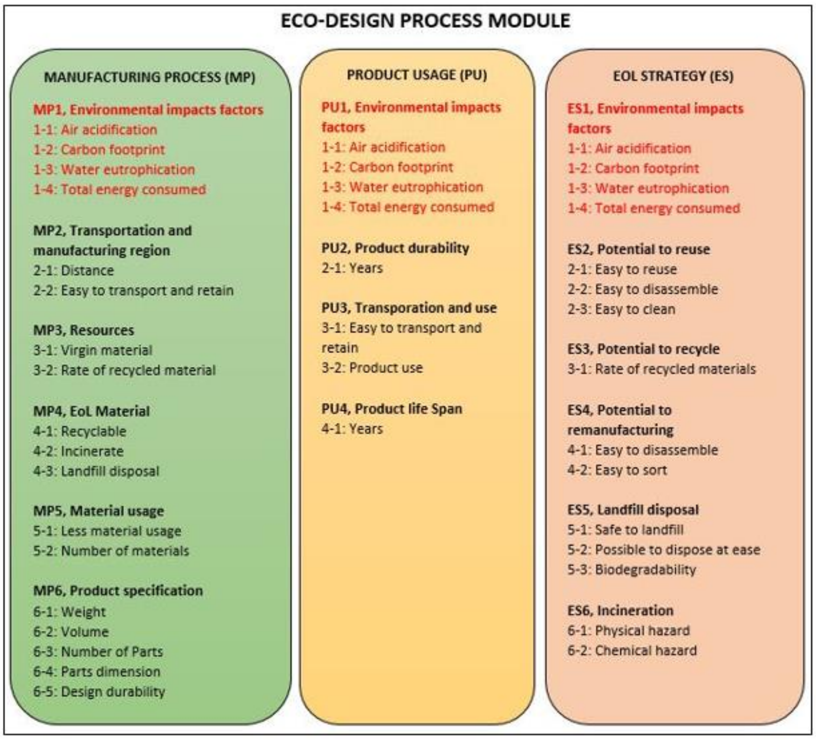

Fig. 2 List of Eco-Design Process Parameters (Romli et al. 2015)

A. Part 1: Life Cycle Assessment

In part 1, there are four steps of LCA process as shown in Figure 1. LCA is used for estimate a products environmental impact. The existing product specifications and details is downloaded from the GRABCAD website (https://grabcad.com/). Then, the model will be exported to Solid Works 2014 software for LCA details. The next activity is identify functional requirements of the products, followed by next activity which is analyses bill of materials, and lastly calculate environmental impact.

These activities will produce an environmental results assessment. An environmental results assessment is product using quantitative information and an objective analysis of the detailed product design. The functional requirement are features or function that are built to help user solves the particular problems. There are two types of functional requirements which is operational functional requirements and general functions requirements. The operational functional requirements provide the criteria or parameter that has to be achieved in order to meet the product's intended function. General functional requirements are the parameter that guides the designers to evaluate whether the design meets its intended satisfactions. This study will use kitchen table as the case study that aim is to improve the environmental product design. The example parameter that will include as the operational functional requirement are weight, height, thickness, edges, etc.

Bill of materials (BOM) is a list of the components or raw materials that are used to build a product. It provides the quantity needed for each parts or components. Both functional requirements and BOM can be integrate in the production of environmental impact assessment. The functional requirements and BOM integrate using quantitative information and detailed product design object analysis that exist in this stage.

In order to calculate the environmental impact, Centre of Environmental Science (CML) methodology is used in Solid Works sustainability. There are four key environmental indicators which is carbon footprint, total energy consumed, impacts to the air, and impacts to the water to assess the environmental impacts. The measuring units for carbon footprint is Kilograms of carbon equivalent (Kg/CO2e), the total energy consumed is mega joules (MJ), the air acidification is Kilograms of Sulphur dioxide equivalent (Kg/SO2e) and the measuring unit for water eutrophication is Kilograms of phosphate equivalent (Kg/PO4e).

The LCA results are influenced by material extraction, manufacturing process, product usage, End of Life strategies and transportation. The material and the manufacturing process are consists of material usage, manufacturing process, recycle content, material cost and product specification. In product usage, there are product durability and product life span. While End of Life strategies consist of reuse, recycle, remanufacturing, incinerate, and landfill disposal. The transportations are including the manufacturing region, use region, types of transportation and distance. The outputs from part 1 will keep in as environmental profile data in part 2 and the data will be used in the part 3.

B. Part2: Environmental Profile Data

The next step after the life cycle assessment complete is the environmental profile data process. In this part, the data from part 1 will be stored or will be organized in order to be use in part 3 which is developing the ontology for environmental product design. To organize the environmental profile data, Microsoft Excel will be used. All the data are stored in the Microsoft Excel according to the elements in the Eco-process module.

After the data has been stored and organized, it will be easier to be used in part 3 as the values in the ontology for environmental product design. Part 3 which is the last part of the framework, will be explained in the next section.

C. Part 3: Ontology Framework for Environmental Product Design

Part 3 consist of 4 steps and the ontology for environmental product design storage. The first steps to build the ontology for environmental product design is set the domain and scope of the ontology. The next step is specify the important terms and define taxonomies. Then, define relations and attributes, and the last steps is create instances.

Figure 3 shows ontology framework for environmental product design result. In the sketch, there are product, product parts, manufacturing process, end of life strategy and environmental impact as the classes of the ontology. Moreover, each classes have their own attributes and instances. From this Ontology for the environmental product design, the product designer, developer and any people can share the knowledge or views about the environmental product design. They also can use the domain of ontology for environmental product design to develop software tools. The steps in part 3 will be explained in the next section.

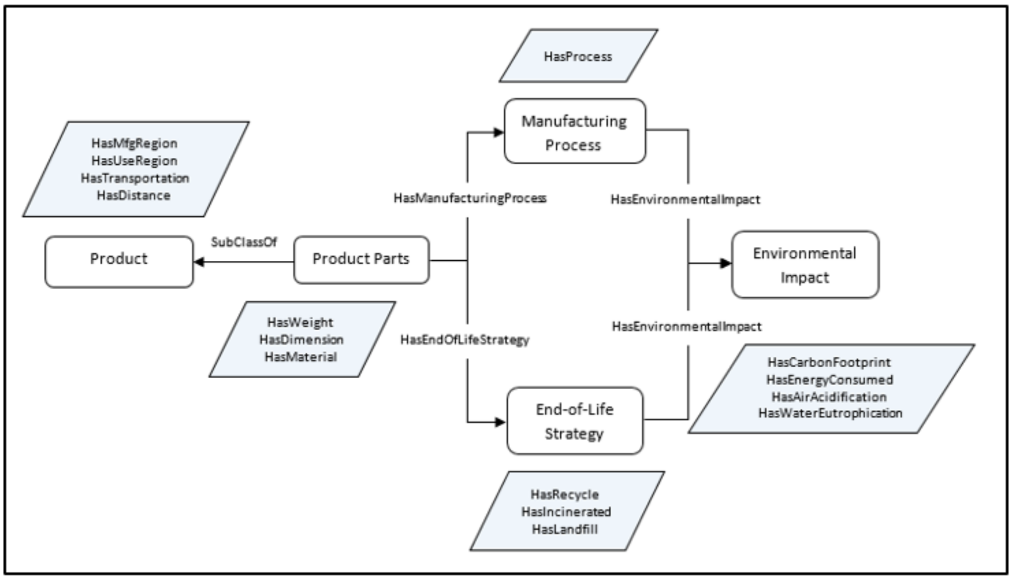

Fig. 2 Ontology Framework for Environmental Product Design

i. Set the Domain and Scope of the Ontology

Domain ontology is the concepts that own part of the world. It is formal description of the classes of the concepts and relationships among the concepts of the application area.

The domain and the scope of the ontology must be defined first to specify what the domain of the ontology will cover. In this research, the domain ontology is product design that will cover the Eco-design process module which consist of manufacturing process, product usage, and end-of-life strategy. The uses of the ontology also need to be clear in this step which are this ontology will be used to share the knowledge among product designer and developer, to enable reuse of domain knowledge for saving the designer or developer time, and to make the domain of eco-design process module explicit. Other than that, in order to set the scope, the question that will be answered by the ontology must be determined such as what is the most less impact material for the environment.

ii. Specify Important Terms and Define Taxonomies

Taxonomy in ontology can be described as a complex hierarchical arrangement of entities that has relationships, for example, class and subclass or parent-child relationships. Other than that, each class of taxonomy in ontology has intern several restrictions its relationships to other classes.

After the domain and the scope of the ontology are determined, the taxonomies will be defined. In other words, the concepts need to be classify in a hierarchy. The terms that will be used in building the taxonomies will be identify first such as basis for class names and attributes names. For example, the important product design terms will include product, product parts, manufacturing process. The terms for content of product is product parts. While the terms for content of product parts is manufacturing process.

iii. Define Relations and Attributes

Between the concepts, there will be relations. To describe the relations, the name, source concept, target concept has to be defined. For example, the product parts have relationship with manufacturing process and end-of-life strategy. Other than that, the relations will be define depending on a type such as classes and individuals that can be related to one another. For example, the manufacturing process class and end-of-life strategy class are related to environmental impact class.

Attributes represent information about an object. The classes without attributes are not provided enough of the information to answer the competency questions. After defining the classes, the internal structure of the concept must be described.

The classes are already being selected from the list of terms created before. The remaining terms will be the attributes of the classes. The terms include process, landfill and recycle. Then, each of the attributes will be determined in which classes it describes. For example, the process is belongs to manufacturing process class. While recycle and landfill are belongs to end-of-life strategy class. The value of each attributes will be defined. For example, the product parts has weight, dimension and material as attribute. The value of weight and dimension will be classified as integer. While the value of material will be classify as string.

iv. Create Instances

The last step is to develop an ontology for environmental product design by creating instances of classes in the hierarchy. This steps requires to choose a class, create individual instances of the class and fill in the property values to describe in detail relevant instances that appear. For example, the product parts class has attributes weight, dimension and material, each of the attributes has a value such as weight and dimension the value will be in kilograms and inch. While the material, the value will be the raw material of the product.

After all the steps are done, the ontology for environmental product design are stored in the ontology library. The software named Protégé is used to represent, handle, and retrieve the information data.

3. Results

This study will use table with four legs as a case study to build the ontology for environmental product design. The existing CAD model that has been downloaded is a product of table with four legs as shown in Figure 4. It is simple basic table that has three parts which are table top, table frame and table legs.

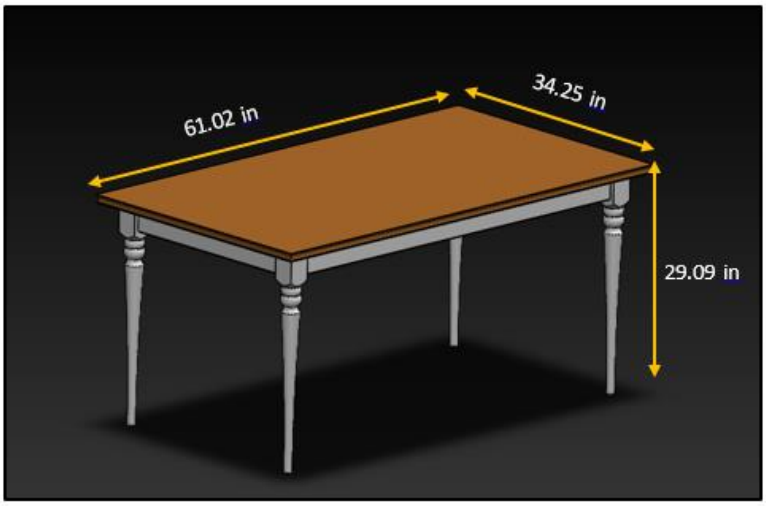

Fig. 4 Table Model.

The output from the activities in Figure 1 are exported in Protégé software to show the ontology for environmental product design in explicit view. Figure 5 shows the ontology for environmental product design with using table with four legs as a case study.

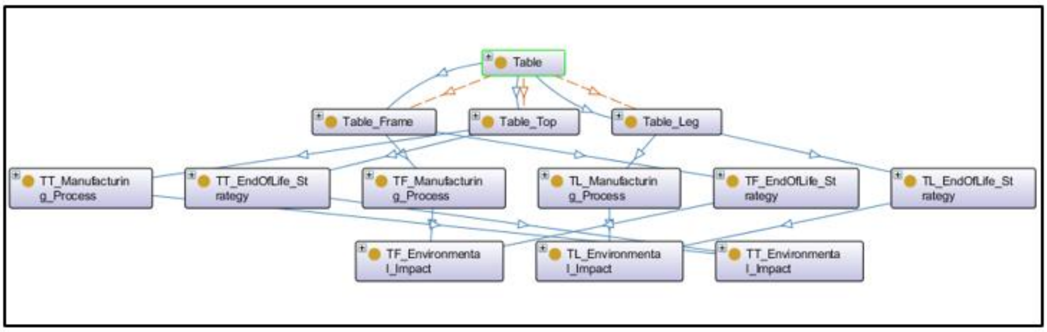

Fig. 5 The Ontology for Environmental Product Design using Case Study

By using the Protégé software, user can choose any classes to see the instances or the subclasses of the selected class. Since the ontology shows the explicit knowledge of the table design, it will help the designers to discussing or sharing the knowledge at early design stage of design the products. To view more details and clearer of the classes and instances, the ontology can be expend. Figure 6 shows the expended ontology for environmental product design using table with four legs as a case study.

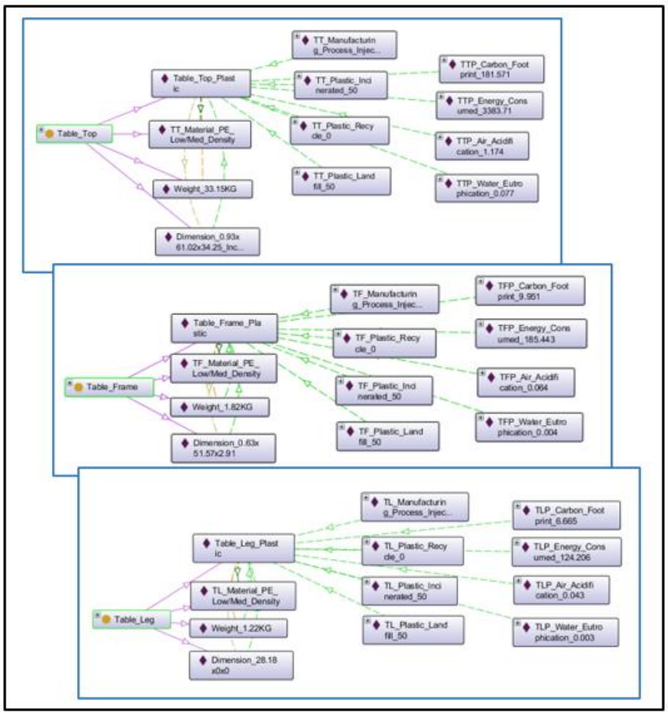

Fig. 6 Expended Classes and Instances

Furthermore, from the ontology for environmental product design, users can also query the instances of the classes using DL Query in the Protégé software. For example, if the user wants to know the weight, dimension, manufacturing process, end of life strategy and the environmental impact of the products part, user can query “Table_Top and isPartOf value Table_Top_Plastic”. Figure 7 shows the query and the outputs. From the output, user will know the details of the product parts and user can also make a change of the details and discusses the knowledge among the users.

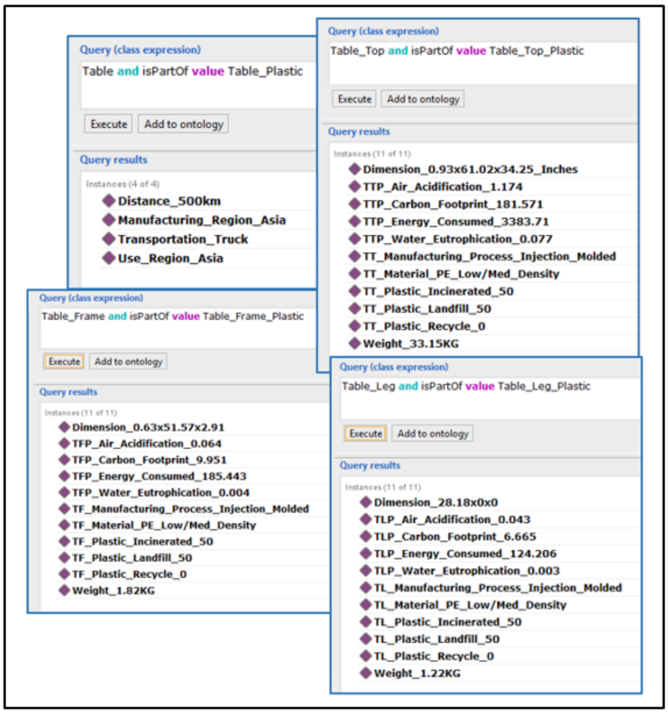

Fig. 7 Query and the Outputs

4. Conclusion and Recommendation

In conclusion, the objectives of this study have been successfully achieved. For the first objective of this study was to adapt an existing framework for supporting sustainable product design in early design phase. From the adapting framework, the parameters in eco-design process module have been translated to become ontology for environmental product design.

The second objective was to develop an ontology for environmental product design. The ontology for environmental product design has been successfully developed by completing the activities in the ontology for environmental product design's framework which has three parts. The first part is the life cycle assessment, the second part is the environmental profile data and the last part is the ontology for environmental product design.

For the third objective was to validate the effectiveness of the ontology through case study. The case study in this research was table with four legs. The case study has been applied to the ontology for environmental product design and the results were successful. The ontology for environmental product design was developed to help users sharing knowledge and views, reusing the domain and understanding the knowledge explicitly.

The sustainability is divided into three aspects which are environmental, economic and social (Alharthi et al., 2020). However, the ontology for environmental product design only covered the environmental aspect. The development of ontology for environmental product design that covers all the aspects of sustainability are recommended for the future research to assist the designers in designing the sustainability product at early design stage.

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