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A Knowledge-based Product Design Assistance for the Advanced Circular Economy

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Abstract. Information is crucial to establishing a circular economy. For example, the design engineer must access information regarding recycling processes. Other stakeholders need information on the former use and design to treat the product according to the intended purpose within a circular economy. This article will describe the impact on design decisions and their effects on the circular economy. It will further describe how to extract and provide data and information from the design process and use phase of the product, finally transfer this into knowledge provided for other stakeholders. The approach is illustrated using a product example and information flow within the system and how to generate valuable knowledge out of the whole product lifetime phase.

1 Motivation and introduction

Products could have been easily designed more suitable for the circular economy if the engineering designer had proper access to the correct data, information, or knowledge. By providing those, the products can fulfill more needed factors for a circular economy. Nevertheless, the designer has to have that information and several other stakeholders to enhance the products if they are well informed. An advanced information exchange could be the basis for more sustainable product flows, and accordingly, an advanced circular economy [1]

1.1 The Circular Economy

Within a circular economy, more stakeholders have to depend on each other compared to the linear economy. The product itself goes around, and the information around the product is shown in Figure 1 [2]. Figure 1 sketches the circular economy product itself, with the associated product information, around relevant stakeholders like the Original Equipment Manufacturer (OEM), Raw Material (RM) Supplier, and different kinds of users.

There are many different approaches to designing a product suitable for the circular economy [3]. The authors' work's main focus lies in *Reuse*, *Repair*, *Remanufacturing*, and *Recycling*. Those approaches are standard, *Reuse* is often the case for long-lasting products

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(e.g. cutlery), more valuable investment goods are likely to be repaired by the user or company (e.g. cars). *Remanufacturing* can be a practical option for companies that produce machines with many parts where newer technology is possible for different modules (e.g. lathe). Recycling is important for all products since each product has to be recycled at some point. The other three approaches will prolong the core parts' lifetime of the product. The increased lifetime will also generate more information regarding each product within the circular economy. Hence, it is even more necessary to provide information to all relevant stakeholders.

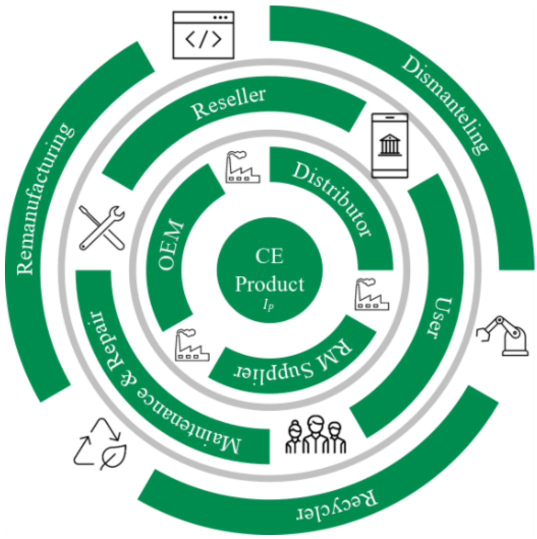

Figure 1 : Overview of involved stakeholders for a circular economy (CE) product. [2] *RM: Raw Material; OEM: Original Equipment Manufacturer;* I_p*: Information regarding the product.*

1.2 Problems and Objective to Promote the Circular Economy

As already pointed out in our previous work, the necessary information is often available, but the motivation to exchange this information is missing for several reasons [2]. Exemplary reasons are missing incentives, protecting internal company secrets, or even the fact that dynamic information is not tracked and stored. This problem leads to a knowledge gap inside the circular economy and limits the implementation of the circular economy at several points. Products are not designed for the circular economy when the engineers do not understand the requirements of a recycler or recycler has no access to information about used materials inside a product. The same problems appear for best practices examples and other stakeholders like a repairer or remanufacturer. In conclusion, one of the main problems for the circular economy is *the lack of information* between all stakeholders.

Accordingly, this paper aimed to present a knowledge-based product design assistance to circulate information and knowledge between all stakeholders in the circular economy. The rest of the paper is structured as follows: Section 2 presents the overall approach of a knowledge-based product design assistance, while Section 3 concludes the paper.

2 A knowledge-based Product Design Assistance for the Advanced Circular Economy

The systematic approach to developing products considers important information at specific points within the process. Crucial points are sketched in the following subsections.

2.1 A Database to assist the Design Engineer with Information

The database development focuses mainly on chemical elements, materials, joint technology, and recycling technology. The different factors are influencing each other. Mechanical recycling technique (e.g. sorting) can separate materials from each other based on their physical properties. Recycling process technology can extract certain materials from a material mix regarding their chemical properties [4]. Some of the existing material combinations will increase both processes' difficulty or even prevent. That increases the needed monetary resources to extract secondary materials, leading to higher prices, causing the recycled secondary materials to be less competitive to virgin materials.

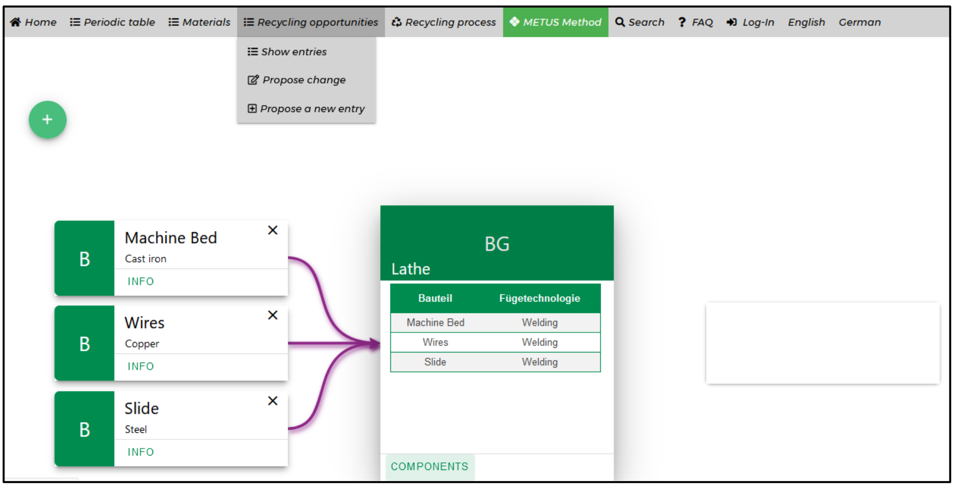

Figure 2 : Overview of the developed database with a structure for a simplyfied lathe as example. *(Note : Work on the database is still in progress.)*

The example from the database, shown in Figure 2, shall assist the design engineer in developing circular products. Since the design engineer is generally the first to work on a certain product, one might assume the first data are generated. Nevertheless, the engineer has to design the product for a circular economy and therefore have access to certain information. This is especially true for the existing recycling technology and which restrictions those might have, for example necessary separation of certain materials. The limits of the recycling technology are directly linked to the possible useable materials and joint technologies between parts and assemblies; for a product to fit into a circular economy.

As mentioned in Section 1.1, multiple approaches to designing a circular economy product exist.

More complex products than the aforementioned simple product could have various materials, making the recycling process more complicated. Furthermore, certain modules could have been designed for another circular approach, like the design for *Reuse* or *Repair*. It might not be evident for the recycler which part/module is designed for another approach than recycling. This will lead to unnecessary recycling because there are well-useable parts that do not have to be destroyed in their existing shape to reproduce them for the next product, in the same shape (see Figure 2, e.g. the machine bed of the lathe). This unnecessary recycling would result in negative effects regarding the aim of a circular economy.

In addition to these possible complications for the recycler, further problems also arise for the owner, user, reseller, or remanufacturer of a product. By gathering information regarding each individual product – not just a product, but every single unit of the product – in a central marketplace, the stakeholder will have access to the needed information to handle the product according to the aim of the circular economy and also fulfill the intended product strategy the engineering designer had in mind while creating the product.

2.2 Extracting the information to provide Knowledge for Stakeholders

The generated knowledge can be used for different scenarios or use cases and differs from the context and specific stakeholder. A repairer could use information about a product's current state to generate knowledge for a repair process. On the one hand, a user needs different information about a product to keep maintenance cycles and use his product as long as possible. On the other hand, a recycler needs information about the components and materials of a product to learn about the recycling processes. A design engineer needs information from a recycler to design more sustainable products. Figure 3 shows a holistic approach for such a system.

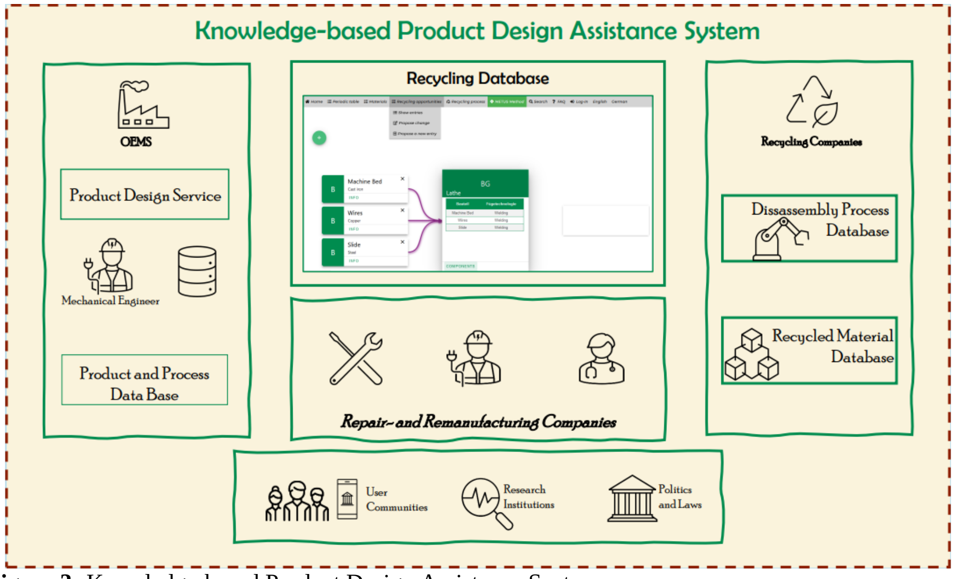

Figure 3: Knowledge-based Product Design Assistance System

2.3 The Value of the Knowledge for the Stakeholders within an Information Marketplace

The literature defines the terms data, information, and knowledge differently. A common understanding is the **D**ata, **I**nformation, **K**nowledge, and **W**isdom (DIKW) [5] pyramid as shown in Figure 4. While data are unstructured information, information is the structured base for knowledge.

Knowledge can be gained based on the extracted information as described in the DIKW pyramid [5] as shown in Figure 4. However, the knowledge depends on different stakeholders' information, who are often unwilling to share their information. This unwillingness to share information creates information gaps within the circular economy [2].

A bridge to overcome these information gaps is a data or information marketplace. An information marketplace provides a legal framework to share information between different stakeholders [6] and therefore creates incentives to these stakeholders to share their information [7]. The idea of an information or data marketplace to bridge the information gaps inside the circular economy was already further described in some previous work, such as: [1], [2], [7], and [8]. Furthermore, as introduced before, the knowledge-based product design assistance system and the information marketplace build the valuable combination to achieve an advanced circular economy.

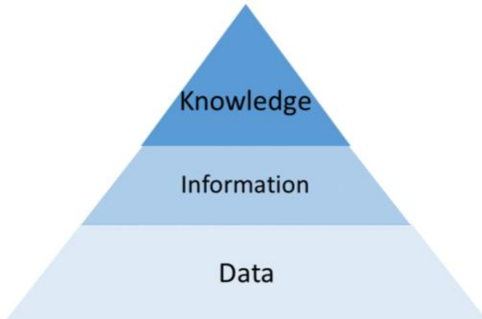

Figure 4: DIKW pyramid based on [5]

2.4 Example

A simple example shall now show how the database can not only aid to establish a circular economy but also how each affected stakeholder can benefit from it. By referring to the lathe example from Figure 2, three exemplary parts are listed. The machine bed, the slide, and wires. The lathe itself shall be designed for R*emanufacturing*, the machine bed for *Reuse*, wires for *Repair*, and the slide for *Recycling*.

Some of the stakeholders from Figure 1 are directly involved in the lathe's use phase. The user has to know which parts are designed for which particular circular approach. Especially if the part is meant to be repaired or recycled, this information must be transferred from the OEM to the user. Later on, after the use phase, the remanufacturer – who might be the OEM again – also has to know what parts were exchanged when and how many operating hours the total machine was in use; so the lathe can be remanufactured accordingly. Again information has to be transferred or be available for a variety of stakeholders. The slide then might be recycled, the recycler will know from his experience it is made out of steel. However, highly specified steel consists out of different alloy materials. By knowing the exact elements within the slide, the recycler can treat the slide more efficiently.

As seen in this example, the circular economy can be assisted by sharing knowledge about the product—static information and dynamic information [2]. The refurbished lathe will also inherent pre-remanufactur product life information. This is important for the reseller; as an example for another benefiting stakeholder.

3 Conclusion and Outlook

This paper aimed to present a knowledge-based design assistance system based on information to achieve an advanced circular economy. While a vast amount of data and information are theoretically available to create such a system, there are still barriers, as discussed in section 2.3. One main barrier is the lack of information between different stakeholders inside the circular economy. We presented an information marketplace that provides a legal framework and incentives to share information, to overcome this lack of information. The database was developed while considering various typical engineering matters. Joint technology is discussed in [9], engineering material in [10], economic influences in [11], and embedment within the design process is further described in [12].

In the next steps, an interface between the engineer design database and the information marketplace will be developed to assist further the communication and exchange of information between all stakeholders. The base for additional services – besides the already presented - and innovations regarding the circular economy is enabled by providing this information exchange. However, the information exchange bears risks, like sharing hidden information. By providing access to information, another stakeholder could gain knowledge, where the owner of the information was not aware of. These problems were already partly discussed in another paper, and a community-driven solution was presented [13].

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