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ANALYSIS OF CIRCULAR DESIGN METHODS IN PRODUCT DEVELOPMENT FOR A CIRCULAR DESIGN TOOLKIT FOR SMALL AND MEDIUM-SIZED ENTERPRISES

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ABSTRACT
This contribution deals with circular design methods, which were identified and pre-selected with the help of a systematic literature research on the scientific database *Scopus* based on the requirements developed in a previous contribution for small and medium-sized enterprises and small development teams. Both design methods and design tools were identified, which are summarized in this contribution under the term *circular design methods* (CDM). The CDM are analysed, categorized, and elaborated upon with respect to these requirements to support product development in increasing the circularity of a product. The analysis provides insights on the status of CDM and which activities in the product development process are supported by them. The contribution follows the overarching process for method selection according to Ernzer and Birkhofer [1], whereby existing CDM are first identified and then analysed. Afterwards they are organized in the context of a strategic level, resulting in an initial draft of a catalogue of methods, which forms the foundation for the creation of the Circular Design Toolkit, with 21 CDM. The aim of this contribution is to provide product developers with a preselection of methods suitable for circular product development by analysing the existing CDM from circular design to support their work and activities in the direction of circular economy and circular design. This contribution derives an application-oriented multi-mode catalogue based on the needs of small and medium-sized enterprises using previously developed criteria. The paper also helps with the further development of methods for the circular economy.

Keywords: Circular design, design methods, product development, circular economy, circular design toolkit, SMEs

1 INTRODUCTION
Due to political and economic interests, the circular economy (CE) is gradually becoming more relevant for companies and their product development projects. small and medium-sized enterprises (SMEs) in particular are facing adaptation challenges due to limited resources and capacities, as can be seen from studies on current transformation processes of SMEs towards a CE orientation. Students are confronted with similar challenges in their studies and practical projects, such as limited time and resources, lack of knowledge about the methods and constantly changing requirements. At this level, a comparability can be derived that allows the context of the contribution to be extended to students. The main challenges are changes that require rethinking of product development processes (PDP), new skills and knowledge of new methods and a lack of resources (cf. [2], [3] [4] [5]). The development of circular products is a complex task that the use of new methods is necessary [6]. However, such methods are particularly advantageous for SMEs and small development groups like student projects as they are simple and easy to apply compared to complex LCAs which are therefore increasingly used by large companies. However, the acceptance of such methods in practice appears to be low [7]. It is primarily the consideration and inclusion of the complete product life cycle that makes a product development (PD) with a focus on the circularity of the product comprehensively complex, whereby several usage cycles may have to be included in the consideration. In addition, an understanding of the topic of CE is required within some method applications and a broader range of skills is necessary in PD [5].
For this purpose, design methods with a focus on the circularity of PD are useful and can support the accomplishment of complex tasks [8]. However, the growing number of CDM developed in recent years

represents a further challenge for users, as there is a lack of knowledge about design methods, their application and intercompatibility [9].
The contribution therefore addresses the question of which existing design methods from circular design support circular PD in the context of SMEs. It also provides an overview of existing design methods with a focus on circularity and thus a preselection of suitable CDM. In addition, the detailed examination of the content of the design methods from Circular Design provides further information on the spectrum of CDM and helps developers of new design methods to identify and address existing gaps. This will serve to help select such CDM and thus be integrated at first into the teaching of integrated design engineering (IDE) and furthermore become thus disseminated as a teaching aid.

2 RESEARCH APPROACH

In order to obtain an overview of existing product development methods that can be assigned to circular design, a systematic literature search will be carried out on February 18, 2023, using the scientific database *Scopus*. Search queries are formed from search terms that relate to topics of circular design, product development methods and product development. The search terms are specifically „circular design", „design for circularity", „Kreislaufdesign“, „tool*”, “method*”, “Methode*”, “Werkzeug*, “circular*”, “zirkulär*”, "Zirkularität", “product*”, “produkt*”, “tool*”, “method*”, “Methode*”, “Werkzeug*”, „design", "product development", „Produktentwicklung“. A two-stage narrowing down and screening of the content of the 178 hits identified six design methods, six tools and two method catalogues that are relevant to the research field shown in Table 1.

Table 1. Overview of the identified methods, tools and method catalogues

Title	Type	Year	Reference	Cross-reference
Circular Product Readiness Method	T	2022	[10]	
Use2Use-Toolkit	MC	2021	[11]	
Circular Economy Assesment Tool (CCET)	T	2013	[12]	[13]
Multi-Criteria Evaluation Method of Product-Level Circularity Strategies	M	2020	[14]	
Circular Business Model Planning Tool	T	2018	[15]	
Consumer Intervention Mapping	M	2018	[16]	
Circular Composites Design Method	M	2022	[17]	
Circular Design Guide	MC	2017	[18]	[19]
Spider Map	T	2015	[20]	[19]
Disassembly Map	M	2021	[21]	
Concept Circularity Evaluation Tool	T	2020	[22]	
Emotional Durability Design Nine	M	2018	[23]	
Time-based Disassembly Method	M	2018	[24]	
Circularity Potential Indicator	T	2017	[13]	

M = Method, T = Tool, MC = Method catalogue

A total of 45 relevant CDM are thus identified, including the design methods from the method catalogues. Furthermore, the identified CDM are evaluated and assessed using a qualitative utility analysis [25] of evaluation criteria from the areas of circularity, integrability and applicability [9] and grouped into content-related categories.

3 METHOD ANALYSIS OF CIRCULAR DESIGN METHODS

The CDM identified from the literature review are analysed using a three-stage method selection process according to Ernzer and Birkhofer [1]. According to Figure 1, first, the identified CDM are evaluated

using a utility analysis. This creates a pool of relevant methods that can be embedded in the context of the PDP. Accordingly, a preselection of categorized CDM is created at the strategic level, from which SMEs can make a project-related selection.
To carry out the utility analysis, this contribution is based on a set of evaluation criteria that are subordinate to the requirements for CDM - circularity, applicability and integrability [9]. The design methods which meet the requirements are then assigned to activity-related categories of the PDP. At this point, the activities of the IDE approach according to Vajna [26] provide the basis for the content-related categories.

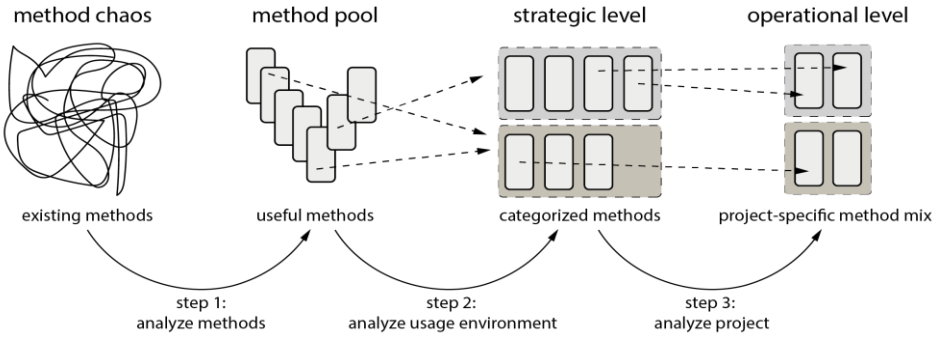

Figure 1. Three steps to select methods (according to [1], S. 1306)

The 45 CDM are evaluated according to the three requirements of circularity, applicability and integrability, and their subordinate evaluation criteria, which have been explicitly formed for the evaluation of CDM [9]. The evaluation of the assessment criteria results in both partial utility values and total utility values, which provide an indication of the suitability of the CDM for SMEs. In order to only consider CDM that are fitting the requirements, a minimum value is set at 2.5, which is the arithmetic mean of the highest possible score of 5. Table 2 shows results from the evaluation. By exclusion, 24 design methods that do not meet the requirements can be identified. This leaves 21 CDM that are considered relevant for the creation of an application concept. The examination of the methods shows that the reasons for exclusion are in most cases due to insufficient focus on the CE, lack of information and material for implementation or prototype status.

4 SETTING UP THE CIRCULAR DESIGN TOOLKIT

The evaluation of the CDM provides information on which CDM can be integrated into the PDP. In order to create a generally applicable catalogue of methods, the methods need to be assigned at an operational level. The IDE approach is used here due to its interdisciplinary nature and versatility [26]. The aim of the categorization is to group CDM with similar goals and application purposes in order to support developers in selecting the most suitable CDM for their project. For this purpose, the CDM are classified into categories that show which tasks and activities are supported in the PDP. This provides an overview of the tasks or activities for which a CDM can be used effectively. To create content-related categories, the activities in the IDE approach are used as a guide [27]. The classification of CDM into categories derived from the activities that occur during a product development results in six categories shown in Figure 2.

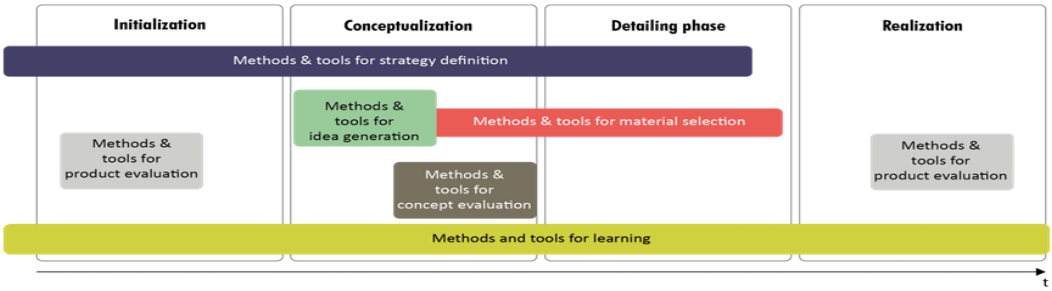

Figure 2. Method categories classified in the context of the phases of the IDE approach

The identified CDM are used conclusively at different stages in the product development process and support different goals and activities during the PDP.

Table 2. Results of the utility analysis of circular design methods

	Circularity	Applic-ability	Integrat-ability	Utility value
Circular Opportunities	4,17	4,14	3,86	**4,06**
Circular Designs Ideation Pack	4	4	4,14	**4,05**
Concept circularity evaluation tool	4	4,29	3,86	**4,05**
Circular Brainstorming	3,17	4,43	4,43	**4,01**
Circular Flows	4	4	3,71	**3,9**
Spider Map	3,5	3,71	4,29	**3,83**
Use2Use Thinking Activation Pack	3,67	3,86	3,71	**3,75**
Insides Out	3,5	3,86	3,86	**3,74**
Service Flip	3	4	4,14	**3,71**
Disassembly Map	3,5	3,29	4,29	**3,69**
Circular Designs Evaluation Pack	3,17	3,86	3,86	**3,63**
Materials Journey Mapping	4	3	3,86	**3,62**
Safe & Circular Product Redesign Workshop	3,33	3,71	3,57	**3,54**
Circular Product Readiness Method (CPR)	4	3	3,57	**3,52**
Circular Journeys Exploration Pack	3	3,29	4,14	**3,48**
Smart Material Choices	3,5	3,57	3,29	**3,45**
Circularity Potential Indicator (CPI)	3,17	3,86	3,29	**3,44**
Multiple Use-Cycles Exploration Pack	2,83	3,57	3,71	**3,37**
Product Journey Mapping	3,67	3,14	3	**3,27**
Circular Business Model Planning Tool	3,17	3,43	3,14	**3,25**
Material Selection	4	2,86	2,86	**3,24**
Multi-Criteria CE evaluation method	3,33	3,14	2,43	
Regenerative Thinking	2,83	2,86	2,43	
Moving Forward with Materials	3	2,29		
The Circular Economy Assessment Tool (CET)	3,5	2,28		
Consumer Intervention Mapping Tool	3	2,43		
Circular composites design method	3,17	2		
Emotional Durability Design Nine	3,33	1,57		
Learn from Nature	2,33			
Time-based disassembly method	2,17			
Digital Systems	1,83			
Imagine New Partnerships	1,83			
Align your organization	1,83			
Continuous Learning Loops	1,67			
Circular Buy In	1,5			
Circular Business Model	1,5			
Concept Selection	1,5			
Launch to Learn	1,5			
Create your Narrative	1,5			
Building Teams	1,33			
Create Brand Promise	1,33			
Define your Challenge	1,17			
User centred Research	1			
Embed Feedback Mechanism	1			
Rapid Prototyping	1			

The architecture of the Circular Design Toolkit (CDTK) is created by developing the categories and assigning the CDM to them. Figure 3 shows the classification of the relevant CDM into six categories based on their content. Assigning the 21 circular CDM to the six categories results in a method catalogue that offers product developers a preselection of relevant CDM to develop products holistically for a CE and allows them to select CDM on a project-specific basis at an operational level.

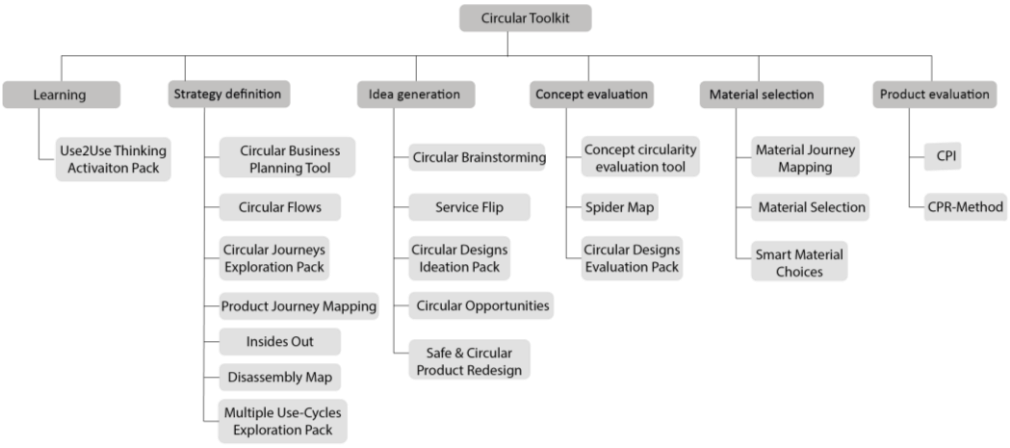

Figure 3. Categories and design methods of the Circular Design Toolkit

5 DISCUSSION AND OUTLOOK

This contribution identifies similar application hurdles which, as shown at the beginning (section 1), are lamented in the industry. Some CDM only exist in a prototype state and are not readily applicable for product developers. Furthermore, some CDM do not focus sufficiently on the principles of circular design and therefore cannot be used for the intended purpose. It should be noted that the utility value analysis is a subjective assessment. Accordingly, a further evaluation of the CDM by experts and users makes sense to counteract the subjective nature of the evaluation. Nevertheless, the analysis shows that CDM exist in order to be able to focus on a development towards the CE and support the work of product developers throughout the entire PDP. The contribution thus provides a selection of relevant CDM, as well as their content-related categorization for product developers in SMEs. However, methodological gaps were identified in the analysis of the CDM. For example, the methods for generating ideas largely relate to the concept of brainstorming and the CDM for strategy alignment are mainly aimed at technical cycles. There is a lack of methods that focus on the development of biological cycles. In addition, there are no methods that focus primarily the social dimension of sustainability. This raises the question of the balance between the dimensions of sustainability in the discussion about circular design and which methodological means can be used to enable a more targeted consideration of the social dimension in PD. In view of the results, the analysis serves as a prerequisite for the creation of a mature method catalogue, in which the categories and the CDM contained therein are visually prepared so that they quickly and easily convey the essential information that is relevant for product developers when selecting methods. In the following contributions, the CDTK will be finalized to create a basis for a continuous expansion of methodological knowledge and will be provided to the master course of the IDE to disseminate CDM-knowledge.

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