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Method for determining the Circularity Score of ICT goods

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Abstract: This research contains a three-step methodology for identifying the design guidelines that need to be incorporated into an existing ICT good design in order to improve its product's circularity in six dimensions. This research is intended to support ICT goods designers in determining the best circular design guidelines to be incorporated at the early stage of design in order to improve product design from a circular economy perspective. The method includes a mathematical algorithm for alternative quantification.
Keywords: Circular Economy, Criteria for Circular Design Guidelines, E-waste, ICT Goods

1. INTRODUCTION

The principles of circular economy (CE) aim for zero waste at all stages of a product's lifecycle [1, 2, 3, 4, 5]. This requires incorporating design elements that support reducing, reusing, recycling, and recovering to keep products, components and materials circulating in the value chain for as long as possible. To achieve this objective, Criteria for Circular Design (*CCD*) design guidelines that aim to reduce, reuse, recycle and recover should be considered and corresponding design guidelines integrated from the early stages of product design. This is particularly relevant to ICT goods and small household electrical and electronic equipment (sEEE) as rapid innovation and the lack of consumer awareness of considering repairing have accelerated the generation of waste.

To date the implementation of circular economy principles has largely focused on developing new businesses models, such as integrating extended producer responsibilities into business practices, rather than evaluating *CCDs* and proposing design guideline to incorporate circular elements into product design. Multiple design for X (DfX) approaches exist including design for disassembly (DfD), Design for Recycling (DfR), and Design for Remanufacturing (DfRe) [6]. They are applicable to improve ICT goods' and sEEE circularity if they are applied at the early stage of product design.

Therefore, the objective of this research – building on the ideas presented in [6] for sEEE - is to present a methodology for designers of ICT goods and systems to align product design to the most relevant *CCDs* enabling development of more circular ICT goods. ICT goods are much different than sEEE and can often use different business models, therefore the method described in [6] needs to be adapted to reflect ICT goods.

Questions explored in the present research:

- Which *CCD* within existing methods are applicable to ICT goods?
- Which new *CCDs* are necessary?
- How does existing methods need to be improved to be practical for ICT good manufacturers and ICT good customers?
- Can a mathematical algorithm be formulated by which a Circularity Score (CS) for each *CCD* can be calculated?

The falsifiable hypothesis tested in the present research is:

The present CS method gives clearer, more relevant, and more accessible conclusions than [6] method for circularity scoring of ICT goods such as blade servers and set-top boxes.

The originality of this research compared to [6] is:

- the proposal of a new evaluation model – including mathematical algorithms
- four scoring levels instead of three
- possibility of putting non applicable *CCDs* to zero
- and several new specific *CCDs* applicable to ICT goods

2. MATERIALS AND METHODS

The methodology contains a three-step approach to support product designers in determining the most relevant *CCDs* to incorporate in their product design . Bovea and Pérez-Belis [6] proposed which existing DfX guidelines are most relevant in product design from a circular economy perspective. These DfX guidelines were then reorganized based on CE principles as shown in Table I adapted from Table 2 in [6]. DPS9, CR3 and CR4 are additions to the original list in [6].

Table I. DfX guidelines relevant for circular product design

Circular Design Guidelines Group (*CDGG*)	**Code**	**Criteria for circular design (*CCD*)**
Extension of lifespan (ELS)	ELS1	Timeless design
	ELS2	Adaptability
	ELS3	Upgrading
Disassembly of connection means (DC)	DC1	Use standardized joints
	DC2	Use joints that can be disassembled rather than fixed joints
	DC3	Use screws with the same metrics
	DC4	Minimize the type of joints
	DC5	Use easy accessible joints
	DC6	Minimize the number of joints
	DC7	Minimize the number of tools to be used to disassemble connectors
	DC8	Use standardized tools to disassemble connectors
Disassembly of product structure (DPS)	DPS1	Adopt modular designs
	DPS2	Minimize the number of components
	DPS3	Be able to quickly identify disassembly joints
	DPS4	Minimize length of wires and cables
	DPS5	Size components to make their handling easier
	DPS6	Facilitate the accessibility of essential components (for their potential reuse/recycling)
	DPS7	Avoid the disassembly of parts in opposite directions
	DPS8	Design to make disassembly automatic
	DPS9	Time required to disassemble the product
Product reuse (PR)	PR1	Design to avoid dirt from accumulating
	PR2	Use materials that overcome cleaning processes
	PR3	Minimize the use of parts that require frequent repairs/replacements
	PR4	Use components with a similar life span
	PR5	Incorporate systems to monitor failing components
Components reuse (CR)	CR1	Use standardized components
	CR2	Minimize variations in the appliance
	CR3	Use materials with good scratch resistance for housing parts
	CR4	Promote design that allow to reuse components to supply the refurbishment process
Material recycling (MR)	MR1	Use materials compatible for recycling
	MR2	Unify materials in the components joined by fixed joints
	MR3	Use materials with a low environmental impact (recyclable/low energy content/etc.)
	MR4	Promote monomaterial designs
	MR5	Avoid using surface treatments

	MR6	Label materials that are used
	MR7	Minimize using hazardous materials

Noticeably, the far left column of Table I - "Circular design guidelines group (*CDGG*)" - contains a list of circular principles that put all the *CCDs* into different groups. The description of each *CDGG* is as follows:

⇒Extension of life span (ELS): It includes *CCDs* related to promoting the life span and durability of products by adapting their design and studying the possibility of upgrading new version or via timeless designs by ensuring the product can be used for as long as possible.

⇒Disassembly: It includes *CCDs* related to the product's structure and access to its components by distinguishing between;

○ Connector (DC): It includes *CCDs* related to connecting systems to facilitate disassembly.

○ Product structure (DPS): It includes *CCDs* related to the location of the main parts and components to facilitate their access.

⇒Product reuse (PR): It includes *CCD* that facilitate the product's complete reuse by facilitating maintenance or cleaning tasks and its components.

⇒Components reuse (CR): It includes *CCDs* facilitating the reuse of the product's components or parts by using standardized components, minimizing parts, etc.

⇒Material recycling (MR): It includes *CCDs* that facilitate the identification, separation and recycling of materials.

Each of these *CDGG* contains a set of *CCDs* that directly address the *CDGG's* topic. Each criterion is also assigned a code with the group's initials followed by a numerical number.

CCDs directly addressing produce reuse, components reuse, and extending life span are crucial to keep all components of a product in the value chain. Yet there is a significant lack of *CCD* dedicated to those areas. Therefore, further *CCD* should be identified in those *CDGG*.

The proposed methodology involves three main steps which shall be followed:

○ The first step involves determining the margin of improvement of each guideline *CCD* based on degree of compliance.

○ The second step is to estimate the relevance of each guideline *CCD* to the product at hand based on customer relevance or other relevance characteristic for the product category.

○ The third step involves calculating the circularly score (*CS*) of the product at hand and creating a hexagon to summarize the result.

Through this graphical representation - resulting from the third step - designers will be able to easily determine the *CCDs* they need to incorporate in order to improve the products' circularity.

The next section gives a detailed look at each step. Section 3 reports example applications of methodology.

2.1 Step 1 – Evaluation of the margin of improvement (*MI*) for a product design

This step is to evaluate the Margin of improvement *MI* value of a specific *CCD* found in Table I for a product design.

MI evaluates the level of compliance of the *CCD*. It assesses to what extent a product design has incorporated circular design into the product.

MI is defined based on 4 grades (Table II). If a certain *CCD* is not met the *MI* of that product design will be very bad, and the grade 4 will be assigned. Conversely, if a product design fully meets the *CCD*, the *MI* will be very good, and the grade 1 will be assigned. The lower the *MI*, the better it scores for the *CCD*.

Table II. Description of *MI* levels for each guideline

Code	Grade of MI	Description
MI4	*VERY BAD* {4}	The *CCD* is not presented in the product design. The *MI* of that aspect will be *VERY BAD*.
MI3	*BAD* {3}	The *CCD* is slightly met in the product design. The *MI* of that aspect will be *BAD*.
MI2	*GOOD* {2}	The *CCD* is fairly met in the product design. The *MI* of that aspect will be *GOOD*.
MI1	*VERY GOOD* {1}	The *CCD* is fully met in the product design. The *MI* of that aspect will be *VERY GOOD*.

2.2 Step 2 – Estimate the relevance (*R*) of each guideline to the product at hand

The level of relevance (*R*) might appear somewhat ambiguous as there are many criteria/viewpoints which can be used to determine *R*. However if the criteria/viewpoints are clearly set, defining *R* is not an insurmountable task.

R evaluates the degree of relevance of each *CCD* for a product category according to its function, life span, durability, performance etc. *R* is defined based on four grades (see Table III). The *R* of a *CCD* is considered *HIGH* when the significance (i.e. to the customer) of incorporating the aspects included in that group is essential when taking into account the tasks, life span, durability, performance, etc. that characterize the product category to which the product belongs. Conversely, the *R* of the *CCD* is considered *LOW* whenever it is not significant to take into account the tasks, life span, durability, performance, etc. that characterize the product category to which the product belongs.

The *R* of each *CCD* given in Table I can be identified in a number of ways. The most appropriate way is to put the customer of the product at hand in the center of the *R* level determination. Relevance is here determined by the business model used or customer preference. Such customer focused examples are shown in Section 3.

Table III. Description of levels of relevance (*R*) of guidelines

Code	Grade of *R*	Description
R4	Very HIGH {4}	The significance of incorporating the aspects considered in this *CCD* will be *VERY* HIGH when taking into account the functions, life span, durability, performance, etc. of the product category.
R3	HIGH {3}	The significance of incorporating the aspects considered in this *CCD* will be *HIGH* when taking into account the functions, life span, durability, performance, etc. of the product category.
R2	LOW {2}	The significance of incorporating the aspects considered in this *CCD* will be *LOW* when taking into account the functions, life span, durability, performance, etc. of the product category.
R1	Very LOW {1}	The significance of incorporating the aspects considered in *CCD* will be *VERY LOW* when taking into account the functions, life span, durability, performance, etc. of the product category.

Importantly, compared to [6], the proposed method set different *R* to different *MI* of each *CCD*. As one of the main objectives of this research, the comparative *CS* scores will be calculated for smartphones using the proposed method and Bovea's [6] method.

2.3 Step 3 – Calculating the circularity score (*CS*) of the ICT good at hand and creating a polyhexagon to summarize the result

To identify the *CCD* that are most important to be incorporated into a ICT good design, it is necessary to calculate the *CS*.

The values assigned to *MI* and *R* are used to calculate the *CS* of an ICT good, which would allow designers to identify which *CDGGs* listed in Table I are most important to be incorporated – more than others - in their product design in order to improve its circularity.

Once the values of *MI* and *R* are decided following steps 1 and 2, it will be possible to derive the *CS* of an ICT good design for each *CDGG* using (1):

$$CS = MI \times R \quad (1)$$

For instance, if an ICT good does not meet a *CCD,* then its *MI* is very bad. Therefore, a numerical value of 4 is assigned to the *MI*. If this *CCD* belongs to a *CDGG* that is very relevant – either from the viewpoint of the customer or another viewpoint - for this product category, then the numerical value of 4 is assigned to *R*. In this case, the *CS* for this product is 4(*MI*)×3(*R*)=16.

Differently, if an ICT good has slightly met a *CCD*, then its *MI* is bad. Therefore, a numerical value of 3 is assigned. If this *CCD* belongs to a *CDGG* that is not at all relevant for this product category, then its *R* is very low and the numerical value of 1 is assigned. In this case, the *CS* for this product is 3(*MI*)×1(*R*)=3. This scoring present some challenges for several combinations of *R* and *MI* so that that the best score (100%) is not attributed to the combination [*MI*=1; *R*=4] but to the combination [*MI*=4; *R*=4]. As shown later the numerical values of 16 and 3 will not be used for the *CS* scoring but just the 16 possible value pairs, e.g. 4×4 and 3×1.

As such, the present method wants to reward ICT goods which have a "good" circularity with a high *CS* (%) value and an ICT good with a "bad" circularity with a low *CS* (%) value. This requires some development of the scoring compared to the baseline method [6].

The first step of the approach is to fill a matrix of combinations with some pertinent values. To facilitate this process, 5 levels from A (the best score) to E (the worst score) are considered. Fig. 1**Error! Reference source not found.** shows the completed matrix.

		R			
		1	2	3	4
MI	1	C	B	A	A
	2	C	B	B	A
	3	C	D	D	E
	4	D	D	E	E

Figure 1: A to E matrix for *MI* and *R*

The progression is linear from the lowest score to the highest (for example with the best scoring located in the top-right corner and the worst one in the bottom-right).

Then each level in a range of 20% was translated as followed:

A = [100%; 80%]

B = [80%; 60%]

C = [60%; 40%]
D = [40%; 20%]
E = [20%; 0%]

Once again, the matrix is filled with appropriate scores for each letter A-E (Fig. 2)

		R			
		1	2	3	4
MI	1	55	75	90	100
	2	50	60	70	80
	3	40	35	30	15
	4	25	20	10	0

Figure 2. 0% to 100% matrix for *MI* and *R*

2.4 The mathematics of the present Circularity Scoring method

An additional objective is to create a mathematical model that can deliver the scores displayed in Fig. 2 for the different combinations of *MI* and *R*. First the *CS* values from Fig. 1 and the {*MI* ; *R*} combinations are plotted on a scatter-chart. To facilitate its interpretation, the combinations of *MI* and *R* are sorted by ascending *CS* values (Fig. 3).

{MI ; R} combination	Combination abscissa value	Circularity Score value
{4 ; 4}	1	0
{4 ; 3}	2	10
{3 ; 4}	3	15
{4 ; 2}	4	20
{4 ; 1}	5	25
{3 ; 3}	6	30
{3 ; 2}	7	35
{3 ; 1}	8	40
{2 ; 1}	9	50
{1 ; 1}	10	55
{2 ; 2}	11	60
{2 ; 3}	12	70
{1 ; 2}	13	75
{2 ; 4}	14	80
{1 ; 3}	15	90
{1 ; 4}	16	100

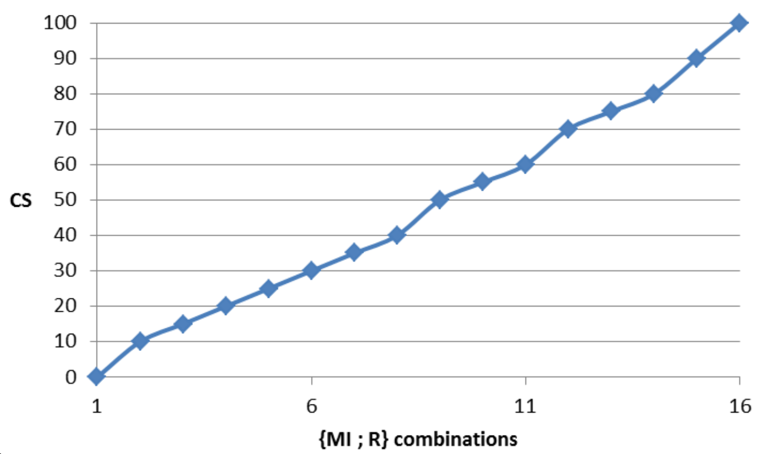

Figure 3. Circularity Score (CS) according to {*MI* ; *R*} combinations

The shape of the curve shown in Fig. 3 is similar to a f(x) = A × x function. However, to obtain *CS*, the function must take into account two variables, *MI* and *R*. Hence the appropriate equation is: CS = f(*MI; R*). The use of both variables allows the result to be obtained in a two-dimensional plane. Hence, f(*MI; R*) = A × x = *CS*. In addition, it can be noted that the median of this distribution is 45 (%).

Each variable *MI* and *R* are isolated to check their influence on the *CS* value. Fig. 4 shows the *CS* values sorted according to increasing *R*. Considering the four values (with *R* = 1 – highlighted by the red rectangle in Fig. 4), the range of values is relatively limited. With *R* = 4 (values highlighted by the green rectangle in Fig. 4), the range is wider (80 with *R* = 4 instead of 30 with *R* = 1). The more *R* increases, the more the range increases. The *CS* values are also further and further away from the median. In addition, it can be noted that for each group, there are two values on each side of the median 45(%).

R	MI	CS
1	1	55
1	2	50
1	3	40
1	4	25
2	1	75
2	2	60
2	3	35
2	4	20
3	1	90
3	2	70
3	3	30
3	4	10
4	1	100
4	2	80
4	3	15
4	4	0

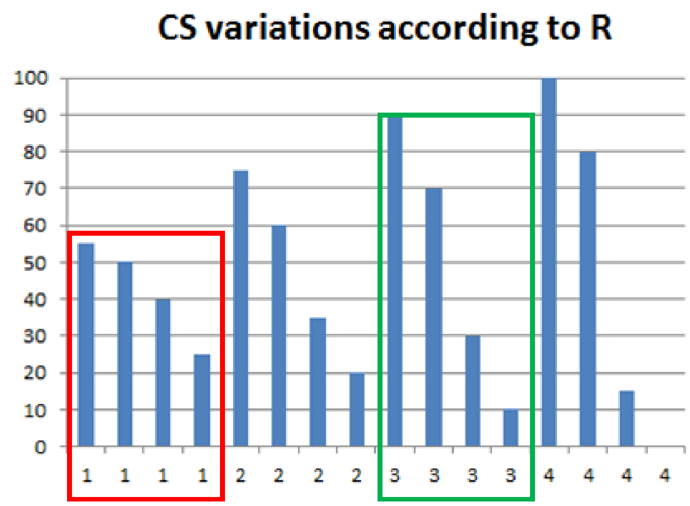

Figure 4. Influence of *R* on the *CS* values

Similar observations can be done from analyzing the influence of *MI* on the *CS* values (Fig. 5).

MI	R	CS
1	1	55
1	2	75
1	3	90
1	4	100
2	1	50
2	2	60
2	3	70
2	4	80
3	1	40
3	2	35
3	3	30
3	4	15
4	1	25
4	2	20
4	3	10
4	4	0

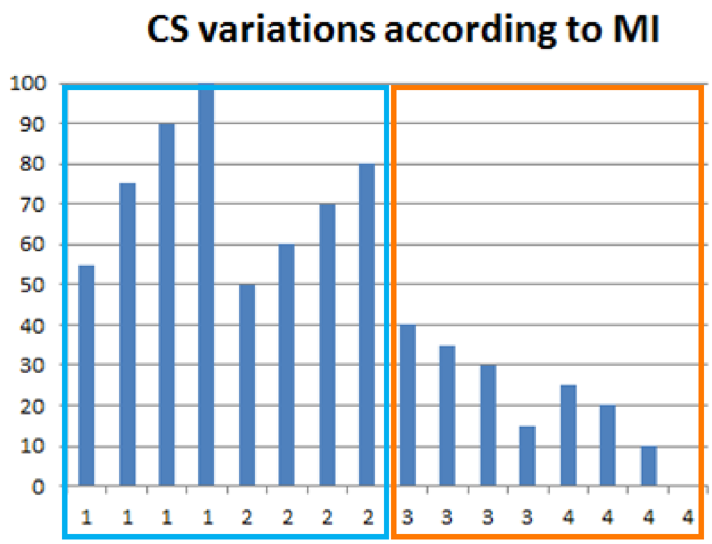

Figure 5. Influence of *MI* on the *CS* values

Hence, if *MI* is equal to 1 or 2, then *CS* is above the median and for increasing value of *R* the *CS* values are also increasing (highlighted by a blue rectangle in Fig. 5). If *MI* is equal to 3 or 4, then *CS* is below the median and for increasing value of *R*, the *CS* values are decreasing (highlighted by an orange rectangle in Fig. 5). Finally, the more *MI* increases, the more the *CS* decreases.

Next step is to find a coefficient that express *MI* variation above and below the median. Fig. 6 shows the required values. By using the trend curve function of Excel®, the equation - to be used as a coefficient - is obtained.

MI	Coeff. A
1	2
2	1
3	-1
4	-2

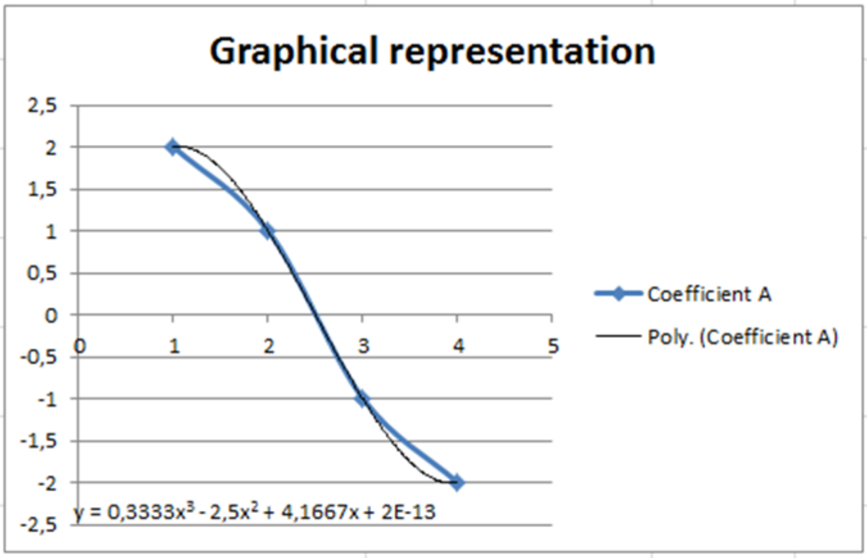

Figure 6. MI coefficient calculation graphical representation

Hence, the simplified (2) is:

$$x = \left(\frac{1}{3} * MI^3 - 2{,}5 * MI^2 + \frac{25}{6} * MI\right) + \frac{45}{MI} \quad (2)$$

In this way, if *MI* is equal to 1 or 2, the coefficient remains positive. On the other hand, ff *MI* is equal to 3 or 4, then the coefficient becomes negative. Considering the observations made previously on *R*, (2) can be extended to (3):

$$f(MI\,;R) = A * \left[\left(\frac{1}{3} * MI^3 - 2{,}5 * MI^2 + \frac{25}{6} * MI\right) * R^2 + \frac{45}{MI}\right] = CS \quad (3)$$

Several iterations of calculations are then carried out to obtain the best value for A (Fig. 6). These calculations also consider the fact that the minimum value for *CS* has to be 0 and the maximum 100. (4) includes all these corrections:

$$CIS = \left[\left(\frac{1}{3} * MI^3 - 2{,}5 * MI^2 + \frac{25}{6} * MI\right) * R^2 + \frac{45}{MI} + 20{,}75\right] * \frac{100}{97{,}75} \quad (4)$$

It should be noted that if the range for *R* and *MI* is susceptible to be changed (e.g. using a 1 to 5 range for both metrics) a new formula - to calculate the scores for the new combinations (e.g. [*R*=5; *MI*=5]) - is required.
The *CS* values calculated with (5) are displayed in Fig. 7.

		R			
		1	**2**	**3**	**4**
MI	**1**	70	76	86	100
	2	45	48	53	60
	3	35	32	27	20
	4	30	24	14	0

Figure 7. CS values calculated with (5)

The extreme values are always in the same categories (*CS* = 100 for {*MI* = 1 ; *R* = 4} and *CS* = 0 for {*MI* = 4 ; *R* = 4}) and the value distribution remains consistent with Fig. 2. However for some values (e.g. {*MI* = 1 ; *R* = 1} or {*MI* = 2 ; *R* = 4} the difference between the *CS* value in Fig. 2 and Fig. 7 is significant. Thus the recommendation would be to use the values form Fig. 2, unless the method has to be implemented in a specific software tool that requires a formula to deliver results.

In the current situation - with fixed ranges for *R* and *MI* - one could consider the scores in Fig. 2 directly. Fig. 8 shows the translation of *(MI)* and *(R)* combinations – using (2) - to values between 0% and 100%. combinations

This means that (1) is no longer used.

		R			
		1	2	3	4
MI	1	55	75	90	100
	2	50	60	70	80
	3	40	35	30	15
	4	25	20	10	0

Figure 8: *CS* matrix with scores for *MI* and *R*

2.3.2 Calculation of *CS* of individual *CDGG*

The average *CS* (%) for a $CS_{CDGG,average}$ is calculated by (5):

$$CS_{CDGG,average}\,(\%) = \frac{\sum_{i=1}^{n} CS_{CDGG,i(j)}}{n} \qquad (5)$$

For instance

$$CS_{ELS,average}\,(\%) = \frac{CS_{ELS_1} + CS_{ELS_2} + CS_{ELS_3}}{3}$$

where

$CS_{CDGG,average}\,(\%)$= Average % Circularity Score for applicable *CCD* in a *CDGG*

$CS_{CDGG,i(j)}$= Circularity Score *i* Circularity Design Guideline Group *j*

$CS_{ELS,average}\,(\%)$= Average % Circularity Score for applicable *CCDs* in the *CDGG* Extended Lifespan

i= Circularity Score *i*

j= Circularity Design Guideline Group *j*

n= number of Criteria for Circular Design in Circularity Design Guideline Group *j*

With the *CS* determined, it will be possible to identify the *CCDs* which most help to improve a product's circularity. For instance, if the *CS* of an ICT Good is 0 in the ELS category (i.e. Very Bad *MI* =4 and Very High *R*=4), it means that it is very important to redesign the product by improving the *CCD* (incorporating the corresponding guidelines) from the ELS category found in Table I. Conversely, if the *CS* of the ICT Good is 100 in the DC category (i.e. Very Good *MI* and Very High *R*), it means that no immediate action is needed to improve the product design from a DC standpoint.

In addition at this stage it is possible to review the list of *CCD* applied to the equipment. Indeed, some of them might not be relevant (R = 0), due to the ICT good design or business-model, whereas some might be missing to describe the effort done to improve its circularity. For example, for an ICT good that will undergo a refurbishment process during its lifespan it could be interesting to consider the scratch resistance of the housing parts, as they might be reused a spare parts. This exercise is carried out on a set-box (see Table VI). The R metric is set at 0 for the three least relevant *CCD* and three new *CCD* are introduced within the already existing *CDGG*.

As the final exercise of the third step, it is also possible to create a graphical representation to illustrate the $CS_{CDGG,average}$ results. Figs. 9-10 show examples.

Each axis represents the $CS_{CDGG,average}$ for the six circular design guidelines groups defined in Table I. The wider the polygon appears to be, the more circular is the product. The smaller the polygon appears to be, the greater the need for improvement before the product can be considered circular.

The scale in the hexagon (Figs. 9-10) simply represents the level of circularity for a particular product design and the urgency to incorporate different *CCD*. They are graded differently depending on the $CS_{CDGG,average}$. This graphical representation provides designers a simple visual clue of a product's circularity performance, allowing them to refer to the guidelines found in Table V and improve the *CCD* that have the lowest % scores.

Table V. The level of urgency of circularity score for each circular design guidelines group.

Circularity Score (CS), %	Urgency level explanation
81-100	Does not require any specific action
61-80	Does not require significant design changes
41-60	Efforts should be made to redesign the ICT good
21-40	It is highly recommendable to redesign the ICT good
0-20	It is urgent to redesign the ICT good

The next section will illustrate three examples of applying this methodology to ICT goods.

The priorities might be different if Bovea and Perez-Belis [6] approach is used and the same R is used for all MI within a *CDGG*. This is explored in section 3.1

3. RESULTS

The following are three generic examples of applying the present three-step method to ICT goods. The first example is a Set-top box (Table VI and Fig. 9), the second one a Blade server (Table VII and Fig. 10) and the third one a smartphone (Table VIII).

Table VI. Method applied to a Set-top box

		Set-top box (present method)			12/30/2019
Circular Design Guidelines Group (*CDGG*)	**Code**	***MI***	***R***	**CS**	**Average score**
Extension of lifespan	ELS1	1	2	75	81.67
	ELS2	1	4	100	
	ELS3	2	3	70	
Disassembly of connection means	DC1	1	4	100	98.75
	DC2	1	4	100	
	DC3	1	3	90	
	DC4	1	4	100	
	DC5	1	4	100	
	DC6	1	4	100	

	DC7	1	4	100	
	DC8	1	4	100	
Disassembly of product structure	DPS1	1	3	90	
	DPS2	2	2	60	
	DPS3	2	4	80	
	DPS4	2	2	60	
	DPS5	1	3	90	78.89
	DPS6	2	4	80	
	DPS7	2	3	70	
	DPS8	2	4	80	
	DPS9	1	4	100	
Product reuse	PR1	2	0	Deleted	
	PR2	2	0	Deleted	
	PR3	2	3	70	86.67
	PR4	1	3	90	
	PR5	1	4	100	
Components reuse	CR1	1	4	100	
	CR2	1	2	75	88.75
	CR3	2	4	80	
	CR4	1	4	100	
Material recycling	MR1	2	4	80	
	MR2	2	2	60	
	MR3	2	2	60	
	MR4	1	2	50	71.67
	MR5	2	0	Deleted	
	MR6	1	4	100	
	MR7	2	4	80	

The set-top box is very well designed from a disassemble-ability viewpoint.

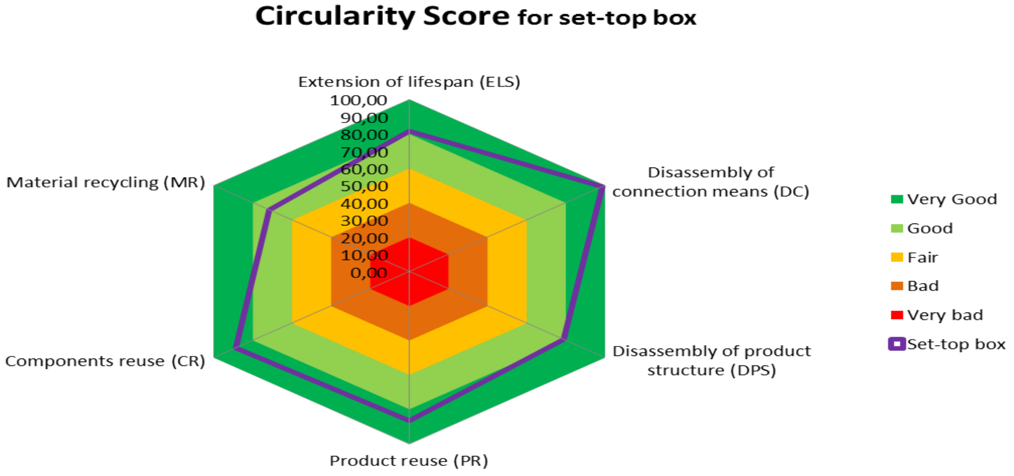

Figure 9 Example of a graphical representation of the circularity improvement score of a set-top box.

Table VII Method applied to Blade Server

		Blade server (present method)	**12/30/2019**

Circular Design Guidelines Group (*CDGG*)	**Code**	***MI***	***R***	**CS**	**Average score**
Extension of lifespan	ELS1	3	1	40	70.00
	ELS2	1	4	90	
	ELS3	2	3	80	
Disassembly of connection means	DC1	2	3	70	84.38
	DC2	2	3	70	
	DC3	1	2	75	
	DC4	1	4	100	
	DC5	2	3	70	
	DC6	1	3	90	
	DC7	1	4	100	
	DC8	1	4	100	
Disassembly of product structure	DPS1	1	4	100	79.38
	DPS2	1	2	75	
	DPS3	2	3	70	
	DPS4	2	3	70	
	DPS5	2	3	70	
	DPS6	2	4	80	
	DPS7	1	3	90	
	DPS8	3	4	80	
	DPS9	0	0	Deleted	
Product reuse	PR1	2	1	50	75.00
	PR2	1	1	55	
	PR3	1	4	100	
	PR4	2	3	70	
	PR5	1	4	100	
Components reuse	CR1	1	4	100	87.50
	CR2	1	2	75	
	CR3	0	0	Deleted	
	CR4	0	0	Deleted	
Material recycling	MR1	3	4	15	38.57
	MR2	4	1	25	
	MR3	3	2	35	
	MR4	1	2	75	
	MR5	2	1	50	
	MR6	3	2	35	
	MR7	3	2	35	

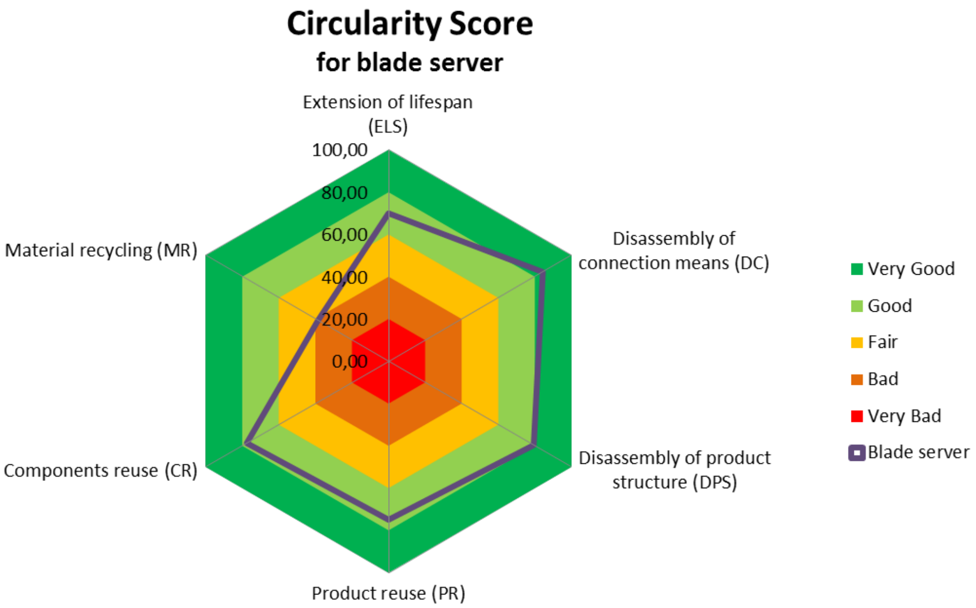

Figure 10 Example of a graphical representation of the circularity improvement score of a blade server.

3.1 Comparison of the present *CS* method and the original Bovea-Perez method

Here follows the comparative analysis of a generic smartphone of the original Bovea-Perez method [6] and the present *CS* method (Table VIII). The main differences concern the scoring methodology. The present method also emphasizes extension of lifespan more than [6]. The method in [6] promotes low scores (1 is best and 9 is worst) and the present *CS* method high % scores.

Table VIII. Comparison of present Circularity Scoring method and [6].

Smartphone (present method)			**12/30/2019**		**Smartphone (using [6])**			
MI	**R**	**CS**	**Average score**	**Code**	***MI***	***R***	**CS**	**Average score**
2	2	60	63	ELS1	2	2	4	4.00
2	1	50		ELS2	2	2	4	
2	4	80		ELS3	2	2	4	
2	2	60	40	DC1	2	2	4	5.00
3	2	35		DC2	3	2	6	
2	2	60		DC3	2	2	4	
4	2	20		DC4	3	2	6	
4	2	20		DC5	3	2	6	
2	1	50		DC6	2	2	4	
3	4	15		DC7	3	2	6	
2	2	60		DC8	2	2	4	
2	1	50	43	DPS1	2	2	4	4.75
1	2	75		DPS2	1	2	2	
3	2	35		DPS3	3	2	6	
2	2	60		DPS4	2	2	4	
4	2	20		DPS5	3	2	6	

4	2	20		DPS6	3	2	6	
2	2	60		DPS7	2	2	4	
4	1	25		DPS8	3	2	6	
3	1	40		*DPS9*	0	0	0	
2	4	80		PR1	2	3	6	
4	2	20		PR2	3	3	9	
2	3	70	51	PR3	2	3	6	6.60
1	2	75		PR4	1	3	3	
4	3	10		PR5	3	3	9	
1	3	90		CR1	1	2	2	
2	1	50	55	CR2	2	2	4	3.00
3	1	40		*CR3*	0	0	0	
3	1	40		*CR4*	0	0	0	
4	1	25		MR1	3	1	3	
2	1	50		MR2	2	1	2	
4	1	25		MR3	3	1	3	
4	1	25	38	MR4	3	1	3	2.57
4	1	25		MR5	3	1	3	
4	1	25		MR6	3	1	3	
1	3	90		MR7	1	1	1	

4. DISCUSSION

The proposed method is a practical complement to the material efficiency standards recently developed [7]. ICT good manufacturers and operators can use the present *CS* method for design for circularity. Table VIII shows that the present method is more versatile than [6] as it gives different relevance to different *CCDs* and can flexibly add new *CCDs* and set *CCDs* to zero if irrelevant for an ICT good. ICT operators may use the present *CS* method as a criteria within the eco-rating [8] of smartphones and other ICT goods. The *CS* method is similar to Life Cycle Assessment methods as it can be adapted by each user. LCA is performed differently by each individual organization. A company can choose which *CCD* is relevant to its products. An ICT goods vendor and an ICT operator can agree on which *CCD* to evaluate for a specific ICT good. The present *CS* method does not replace forthcoming material efficiency standards for ICT goods, just like eco-rating cannot replace full LCA [8].

5. CONCLUSIONS

The present method for Circularity Scoring give reasonable results and can be used in a parallel by both manufacturer and customer. The method is flexible and can be customized for different ICT goods. The present *CS* method is more flexible and gives more informative results for smartphones than the method on which it is based.

6. NEXT STEPS

A recent megatrend in product development is to use multi criteria optimization. Fuzzy theory [9] could be used to weigh the *CDGGs* as a fourth evaluation step. More *CCDs* could be added and arguably the number of *CDGG* might not be optimal.

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