MRM STANDARD

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MAJLIS REKABENTUK MALAYSIA

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Circular design practice

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For further information on MRM Standard, please contact:

Malaysia Design Council
Lot PT5285
Off Lebuhraya Puchong-Sungai Besi
57000 Bukit Jalil
Kuala Lumpur
MALAYSIA

Tel: +603 89926043
Website: www.mrm.gov.my

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Foreword

This standard was developed by the Project Committee on Circular Design established by SIRIM Berhad.

This standard was developed with the following objectives:

a) developing a guidance document for individual or organisations that has interest in design or applied design disciplines of tangible goods and products; and

b) as the basis for recognition or the certification of Good Circular Design Award.

Information to assist users of the standard

For the purpose of this standard, the following ISO definitions have been adopted regarding verbal forms for the expression of provisions:

a) **"shall"** indicates an auditable **requirement**: it is used to indicate requirements strictly to be followed in order to conform to the document and from which no deviation is permitted;

b) **"should"** indicates a **recommendation**: it is used to indicate that among several possibilities one is recommended as particularly suitable without mentioning or excluding others, or that certain course of action is preferred but not necessarily required, or that (in the negative form) a certain possibility or course of action is deprecated but not prohibited;

c) **"may"** indicates a **permission**: it is used to indicate a course of action is permissible within the limits of the document; and

d) **"can"** indicates a **possibility** or a **capability**: it is used for statements of possibility and capability, whether material, physical or causal.

Compliance with this standard does not by itself grant immunity from legal obligations.

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Circular design practice

1. Scope

This standard proposes a method to define good circular design practices. This standard specifies requirements and guidance for organisation in integrating circularity into the design and development process of tangible products based on subject chosen by an organisation within circular strategies (refer to 4.2.2, 4.2.3 and 4.2.4).

Having the life cycle thinking as a core principle, this document provides guidance on how to reduce environmental impacts, and how to deal with challenges such as trade-offs during circular product design, without compromising functions and safety.

This standard can be applied when no product-specific or product group standard exist. Where such documents are developed, this standard can be used as reference to ensure consistency and harmonisation across the different product areas and supply chains or networks.

2. Normative references

The following documents are referred to in the text in such a way that some or all their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Environmental Quality (Scheduled Waste) Regulation 2005, Department of Environment

IEC 60050-901:2013, *International Electrotechnical Vocabulary (IEV) - Part 901: Standardization*

ISO/IEC 29142-3, *Information technology - Print cartridge characterization - Part 3: Environment*

ISO 6707-3, *Buildings and civil engineering works – Vocabulary - Part 3: Sustainability terms*

ISO 14009:2020, *Environmental management systems - Guidelines for incorporating material circulation in design and development*

ISO 14021:2016, *Environmental labels and declarations - Self-declared environmental claims (Type II environmental labelling)*

ISO 14050:2020, *Environmental management - Vocabulary*

ISO 56000:2020, *Innovation management - Fundamentals and vocabulary*

EN 1325:2014, *Value Management - Vocabulary - Terms and definitions*

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EN/IEC 62430:2019*, Environmentally conscious design (ECD) - Principles, requirements and guidance*

EN 45552:2020, *General method for the assessment of the durability of energy-related products*

EN 45554:2020, *General methods for the assessment of the ability to repair, reuse and upgrade energy-related products*

SIRIM 30:2019, *Design for Environment*

3. Terms, definitions and abbreviated terms

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardisation at the following addresses:

a) ISO Online browsing platform: available at https://www.iso.org/obp

b) IEC Electropedia: available at https://www.electropedia.org/

3.1 Terms and definitions relating to circular product design

3.1.1 circular economy

Economic system that contributes to sustainable development whereby value of products, materials and other resources is kept as high as possible for as long as possible, keeping the resources in a circular flow and minimising waste, harmful emissions and pollution.

3.1.2 circular strategies

Practices chosen by an organisation to design products that are aligned with the principles of a *circular economy* (refer 3.1.1).

3.1.3 circular goals

Goals aligned with the principles of a *circular economy* (refer 3.1.1).

3.1.4 circular product

Product aligned with the principles of a *circular economy* (refer 3.1.1).

3.1.5 circular product attribute

What needs to be addressed to align a product with the principles of a *circular economy* (refer 3.1.1).

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3.1.6 circular product design

Process of creating products that are aligned with the principles of a *circular economy* (refer 3.1.1).

NOTE. The concept can be applied to existing products through redesign.

3.1.7 circularity (of a product or part)

Intentional design for multiple cycles.

3.1.8 material efficiency

Minimisation of the use of (natural) resources by maximising the lifetime of products through optimised material circulation strategies.

[SOURCE: ISO 14009:2020, 3.1.12, modified]

3.1.9 value

Gains from satisfying needs and expectations, in relation to the resources used.

EXAMPLE. Revenues, savings, productivity, sustainability, satisfaction, empowerment, engagement, experience, trust.

NOTES:

1) Value is relative to, and determined by the perception of, the organisation and interested parties.

2) Value can be financial or non-financial.

3) Value can be created, realised, acquired, redistributed, shared, lost, or destroyed.

4) The value of an entity is generally determined in terms of the amount of other entities for which it can be exchanged.

5) The word “value” sometimes refers to a (numerical) unit of data, e.g. the output from measurement and “values” sometimes refers to principles or standards of behaviour, e.g. included in the concept of culture. When "value” is used in these senses, it should always be used with some form of qualifier, e.g. “numerical value” or the meaning should be obvious from the context.

6) When a process is inefficient, the amount of resources used can exceed the amount of resources required.

7) The diagram below illustrates the general concept of value assessment.

$$\text{value} \propto \frac{\text{satisfaction of the needs}}{\text{consumption of resources}}$$

8) value for brand identity

[SOURCE: ISO 56000:2020, 3.7.6, modified]

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3.2 Terms and definitions relating to environment

3.2.1 environment

Surroundings in which an organisation operates, including air, water, land, natural resources, flora, fauna, humans and their interrelationships.

[SOURCE: ISO 14050:2020, 3.2.2]

3.2.2 environmental aspect

Element of an organisation's activities or products that interacts or can interact with the environment.

[SOURCE: ISO 14050:2020, 3.2.20]

3.2.3 environmental impact

Change to the environment, whether adverse or beneficial, including possible consequences, wholly or partially resulting from an organisation's environmental aspects.

[SOURCE: ISO 14050:2020, 3.2.22]

3.2.4 environmentally conscious design (ECD)

Systematic approach which considers environmental aspects in the design and development with the aim to reduce adverse environmental impacts throughout the life cycle of a product.

[SOURCE: IEC 62430:2019, 3.1.1]

3.3 Terms and definitions relating to product and resource

3.3.1 product

Goods, service, or combination thereof.

[SOURCE: ISO 14050:2020, 3.5.12, modified]

3.3.2 resources

Anything that is required to satisfy the needs.

NOTE. Resource can be physical, financial, intellectual, and social. Resource can also include skills and time.

[SOURCE: EN 1325:2014, 2.1.9, modified]

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3.4 Terms and definitions relating to recycling

3.4.1 recovery

Operation that gives value to end-of-life products, parts or materials which otherwise would be disposed.

NOTE. Recovery can result in products, parts, materials and/or energy.

3.4.2 recycled content

Proportion, by mass, of recycled material in a product or part.

NOTE. The proportion is often expressed as a percentage of mass.

[SOURCE: ISO 14021:2016, 7.8.1.1 a), modified]

3.4.3 recycled material

Materials that have been recovered or otherwise diverted from the solid waste stream, either during the manufacturing process or after consumer use.

[SOURCE: ISO/IEC 29142-3]

3.4.3.1 recovered material

Material that has already been processed or used, then separated, diverted from previous use or removed from a waste stream in order to be recycled for usage as a product performing another function, reused for the same purpose or used to substitute primary materials.

[SOURCE: ISO 6707-3]

3.4.3.2 secondary material

Material that has been reprocessed from end-of-life products, parts and material.

3.4.4 recycling

Process of segregating non-usable parts or components for material recovery.

[SOURCE: SIRIM 30:2019, 3.19]

3.4.5 waste

Material or object which does not fulfil its function anymore, or for which the holder has no need, and the holder decides or is required to discard.

NOTE. Triggers for the decision or need to discard include, for example: function no longer available, change in the needs by the user, interoperability with new system elements not supported, loss or unavailability of data or history information about the object (e.g. instruction for use not available; service info; info needed for refurbishment).

[SOURCE: IEC 60050-193:2023]

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3.5 Terms and definitions relating to durability

3.5.1 durability (of a part or a product)

Ability to function as required, under specified conditions of use, maintenance and repair, until the end-of-life is reached.

NOTES:

1) For the purpose of this document, the designer has to specify the criteria for the durability.

2) The criteria is based on predictable aspects (e.g. technical aspects) so that the durability can be estimated.

3) Durability can be expressed in units appropriate to the part or product concerned, e.g. calendar time, operating cycles, distance run, etc. The units should always be clearly stated.

[SOURCE: EN 45552:2020 definition 3.1.1.1, modified]

3.5.2 end-of-life (EoL)

3.5.2.1 end-of-final-use

Life cycle stage of a product starting when it is finally removed from its intended use-phase.

[SOURCE: IEC 60050-901:2013 (IEV 191-07-15)]

3.5.3 end-of-use

Point in time when one user does not want to repair or maintain or does not want to use the product anymore.

[SOURCE: IEC/CD 60050-193]

3.5.4 reliability

Probability that a product functions as required under given conditions, including maintenance, for a given duration without limiting event.

NOTES:

1) The intended function(s) and given conditions are described in the information for use provided with the product.

2) Duration can be expressed in units appropriate to the part or product concerned, e.g. calendar time, operating cycles, distance run, etc. The units should always be clearly stated.

[SOURCE: EN 45552:2020, 3.1.1.2]

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3.6 Terms and definitions relating to lifetime extension

3.6.1 disassembly

Process whereby a product is taken apart in such a way that it could subsequently be reassembled and made operational.

[SOURCE: IEC 60050-904:2014/AMD3:2019 (IEV 904-04-01), modified]

3.6.2 maintenance

Process to retain a product in, or restore it to, a state in which it can perform as intended.

[SOURCE: IEC 60050:2015 (IEV 192-06-01), modified]

3.6.3 repair

Process of returning a faulty product to a state where it can fulfil its intended use.

[SOURCE: EN 45554:2020, modified]

3.6.4 refurbishing

3.6.4.1 reconditioning

Industrial process to return a used product or part to its original specifications.

NOTES:

1) Specifications include form, functionality, performance and safety aspects.

2) The identity of the product or part shall be maintained (e.g. serial or type number).

3.6.5 remanufacturing

Industrial process to create a product by combining different parts from used products and including, where necessary, new parts.

NOTES:

1) Remanufacturing also occurs when at least one change is made which influences the safety or original performance of an existing product.

2) The product shall be given a new identity (e.g. serial or type number).

3.6.6 reuse

Operation by which a product or part is used again.

NOTE. When the product or part is reused for another purpose, it is also called repurpose.

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3.6.7 upgrade

Process to enhance the functionality, aesthetics, or performance of a product.

NOTE. An upgrade to a product can involve addition or replacement of parts.

3.6.8 useful life (of a product)

Time interval from first use until the user requirements of the last user are no longer met due to social, economic, or technical reasons.

NOTES:

1) Concept not intended for measurement.

2) Useful life can only be quantified retroactively.

3) Social, economic, or technical reasons can result in parts obsolescence.

4) Social aspects include trends in fashion.

3.7 Abbreviated terms

AI	Artificial intelligence
CEAP	European circular economy action plan
CE	Circular economy
CRM	Critical raw material
ECD	Environmentally conscious design
ESG	Environment, social and governance
GHG	Greenhouse gas
ICT	Information and communication technology
IP	Intellectual property
ME	Material efficiency
SDGs	Sustainable Development Goals

4. Principles of circular product design

4.1 General

The linear 'take-make-dispose' economic model is reaching its limits, and initiatives to develop alternative economic models are emerging. Circular economy promises an industrial system that is restorative and regenerative by design [23]. As part of the circular economy, material efficiency can be increased through the three principles of slowing down, narrowing, and closing material flows [26].

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Slowing and closing the loops are fundamental principles toward the cycling (circulation) of materials. They are distinct from the other approach of narrowing the flows, which focus ultimately on overall reduction of the material flows and represents a linear flow.

NOTE. These principles are intended as source of inspiration when designing circular products.

Not being exhaustive, Figure 1 shows a schematic representation of these three principles along with representation of a linear flow for comparison. The subclauses thereafter give examples of strategies to be implemented that contribute to these three principles.

Linear flow	Narrowing flows	Slowing flows	Closing flows
			
Materials are transformed into products, which are eventually discarded when they become obsolete.	This principle focuses on using less resources during the production and utilisation of products.	This principle focuses on slowing down the flow of materials from initial production up to post-use.	This principle focuses at closing the loop between the post-use and production, resulting in a circular flow of materials.

Figure 1. Principles of slowing down, narrowing and closing resource flows

4.1.1 Narrowing material flows

The principle for narrowing material flows involve strategies using less materials (and energy) to deliver the same or equivalent function to the user. It also involves strategies such as intensifying the use of products through sharing services.

4.1.2 Slowing material flows

This principle is aimed at using products, components and materials longer through the design of long-life goods (increased reliability and durability) in combination with product-life extension strategies such as maintenance, repair, hardware or software upgrade or software update, and refurbishment. With such strategies, the utilisation period of products is extended, resulting in a slowdown of the flow of materials by reducing the need to replace existing products or by decreasing the need for new products.

The ultimate goal of this principle is to reuse products again and again, which needs complementary activities like planning circular systems around the product inclusive reverse logistics or to develop new business models to rethink ownership.

4.1.3 Closing material flows

Closing the material flows refers to activities that bring post-consumer waste back into the economic cycle. Recycling is the most common strategy to close the material flows. Also, activities such as remanufacturing and repurpose allow for closure of the loop by creating (new) products from already used products or parts.

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Lately, the use of renewable content is becoming popular to close the material loops. However, there are a number of criteria which should be considered so that the material can really go back into the soil at the end and close the biological cycle. A final step to close the biological cycle is the safe return to the biosphere through activities like biodegradation, anaerobic digestion or composting of the material. This asks that the material can be safely returned to the soil and used by living systems, meaning it should not contain any harmful substances to soil organisms or human health. Depending on the remaining quality and functionality of a biological material after use, recycling can be an option to close the loop.

NOTE. Whether a material gets recycled in practice depends on the availability of recycling processes, technology, and infrastructure.

4.2 Material value hierarchy

The material value hierarchy represents the concept of keeping the value of materials as high as possible in the economy. It is intimately related to one of the principles of the circular economy, namely circulate products and materials at their highest value. The material value hierarchy is also a good model to represent material efficiency, that is defined as a relationship of an output of performance, useful life, and material recovery versus an input of material.

Figure 2 below shows the material value hierarchy. This hierarchy represents value loss (or additional value needed) when moving from up to down the ladder.

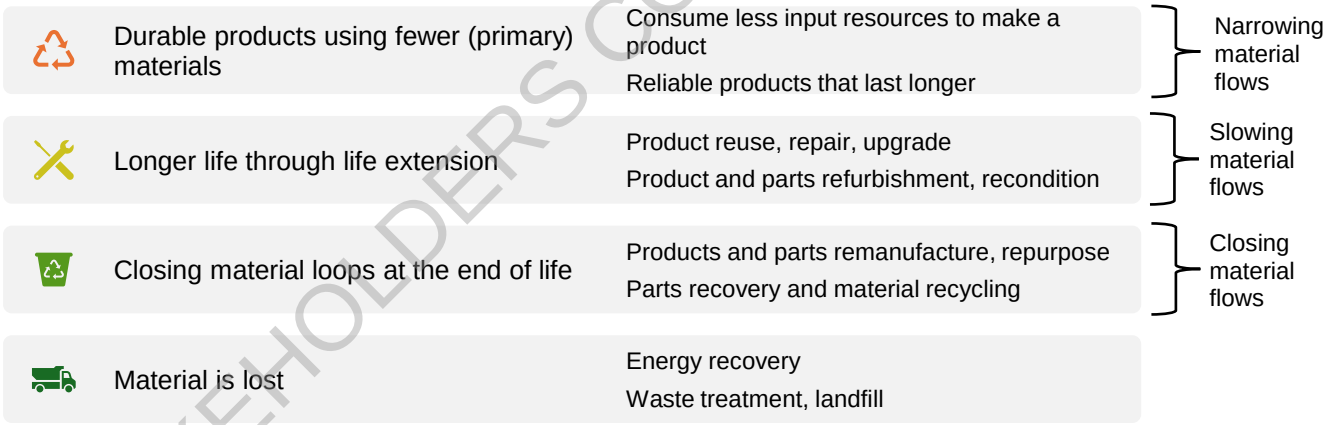


Figure 2. Material value hierarchy

The material value hierarchy can be used as support by organisations that are making the transition to circular economy. Having a good understanding on how the value of materials evolve when applying different circular solutions helps organisations to make a more conscious choice of the circular business category and related circular design strategies. Organisations may use the material value hierarchy as source of inspiration, as relevant.

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5. Transition by an organisation to become circular

5.1 Circular economy as part of the vision, mission, and strategy

Once the organisation has decided that it wants to move from linear to more circular ways to do business or operate, it will adapt its vision, mission, strategy, and goals to express such intent.

The organisation should draft and communicate the vision (the “what and why”), mission (the “how”) and a strategy which includes, at least indirectly, a commitment to circular economy.

EXAMPLES:

1. “Our organisation strives to make the world more sustainable through circular innovations”.

2. “Our organisation aims to grow the organisation responsibly and sustainably. To this end, we have deployed a comprehensive set of commitments across all the Environmental, Social and Governance dimensions that guide the execution of our strategy and support our contribution to UN Sustainable Development Goals 12 ‘Ensure sustainable consumption and production patterns’ and 13 ‘Take urgent action to combat climate change and its impacts”’.

5.2 Goals by the organisation to become circular

Next is for the organisation to set concrete goals in order for it to become circular. In line with the ECD principles from EN/IEC 62430, circular goals shall be made part of the policies and ambition of organisations that wish transforming (part of) their business from linear into circular.

For defining circular goals it is necessary to take into account all stages in the life cycle of products that the organisation can control or can influence.

Typical circular goals by an organisation can be expressed as follows:

a) “Circular product design is applied to X % of our products”.

b) “X % of our revenue comes from refurbished products by year YYYY”.

c) “X % of our internally generated waste will be recycled or reused by year YYYY”.

d) “The minimum recycled material content of our new products is at least X % by year YYYY”.

e) “Alternative technologies using less or fully replacing the use of rare earth elements by more common ones is applied by YYYY".

(Top) management understanding and commitment, availability of resources and engagement of all relevant business functions are key to successfully achieve circularity. Topics to be addressed by the organisation are, for example:

a) understand how the current (linear) business can be modified, incremented or, otherwise, or replaced by (new) circular ones. E.g. consider how circular business models or circular strategies can replace the current business(es) allowing for the transition to circular (for inspiration, see the numerous circular strategies in 6.2);

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b) take into account the supply chain and the expectations of interested upstream to downstream stakeholders, as well as the life cycle of activities and products, which can reinforce (or otherwise, make it more difficult) reaching the circular ambition by the organisation;

c) establish, implement, and maintain an environmental policy, which includes circular goals consistent with the organisation's strategy; and

d) if the companies' goals are to be communicated towards external stakeholders, they should be fully documented and traceable.

5.3 Measuring the organisation's transition towards becoming circular

Circular product design requires a holistic organisational approach including design, innovation, development, marketing, and business leaders, as well as key external stakeholders e.g. backward logistics handling. Transforming a business from linear towards circular requires capacity building in the functions and roles that contribute to the overall product offer. Awareness creation is often not sufficient; a dedicated training per function and role is required to ensure that the circular product design concept is fully understood.

To facilitate improvements in the overall circular design of products, a consistent basis for measuring the different material efficiency aspects of products is necessary. Horizontal in nature, organisations may refer to EN 4555x series of standards which are intended to be used as a framework to develop product or product group and product specific standards. These standards provide general methods of assessment of different material efficiency aspects and should be taken into account to improve circularity in a relevant aspect in material efficiency while designing a new product.

In order for the organisation to measure its transition from linear towards circular, the organisation shall set targets (key performance indicators - KPIs) and shall cascade these KPIs throughout the organisation.

The efforts to become circular can be determined, and their progress can be measured by the organisation based on, for instance, revenues, production volumes, sales volumes, regulatory requirements, stakeholders' requirements, or a combination there-off where value is created. Figure 3 shows examples of circular strategies expressed in terms of revenue KPIs.



Figure 3. Examples of circular strategies by an organisation based on revenues

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5.4 Circular product design trade-offs considerations

Since circular product attributes and other aspects such as performance, etc., may be in contradiction with each other, trade-offs shall be considered, keeping in mind the global circular economy objectives, instead of focusing on specific attributes individually. Such trade-offs shall be considered on a product category base, keeping into account product category specificities.

NOTE. Safety and security are not part of such trade-offs.

Considerations when designing a circular product are:

a) The circular product design should be useful:

   i) focus on the circular product design aspects that are most relevant to the product in question; and

   ii) focus on the redesign effort on products with expected market demand (e.g. do not redesign products that are close to end of technological or fashion life).

b) The circular product design should be effective:

   i) remanufacturing should cost less energy and resources and avoid adverse impact on the environment than making a new product; and

   ii) increasing the overall reliability or durability of the product can be more favourable than repair or refurbishing.

c) The circular product design should be economically viable, as to be sustainable, a company also needs to make profit.

d) The circular product design should consider relevant trade regulations or requirements.

6. Circular product design requirements and guidance

6.1 Circular product design process

Implementing a circular product design in an organisation shall involve the following process steps:

a) integrate the organisation's circular economy and material efficiency ambition into the management system (including KPIs for target setting and measuring the transition from linear to circular);

b) identify and optimise circular strategies (e.g. business models) capable to improve the organisation's products and material recirculation. Circular product design should enable the implementation of a circular business model and the product should make use of all enablers provided by the circular business models. As relevant, consider the principles for narrowing, slowing, and closing the material flows;

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c) for each circular strategy and product range or type identify the circular product attributes:

   i) considering all life cycles and possible design-related barriers hampering the full potential for circularity of the product;

   ii) explore all mandatory and nice to have circular product attributes that need to be met;

   iii) for each requirement determines the questions that can support the design optimisation and respective circular product design requirements. As relevant, consider the material value hierarchy;

   iv) consider the trade-offs between different circular product designs balancing with other environmental impacts, quality, etc. Throughout all life cycle stages of the product taking best practices into account, where available;

   v) consider capacity building and training, including (new) relationships with the users; and

   vi) repeat the above for other products (range or types).

d) build the circular matrix (for details see 6.5) to be used by the organisation as dashboard to track progress, linking circular strategies to circular product attributes.

The above is represented graphically in Figure 4.

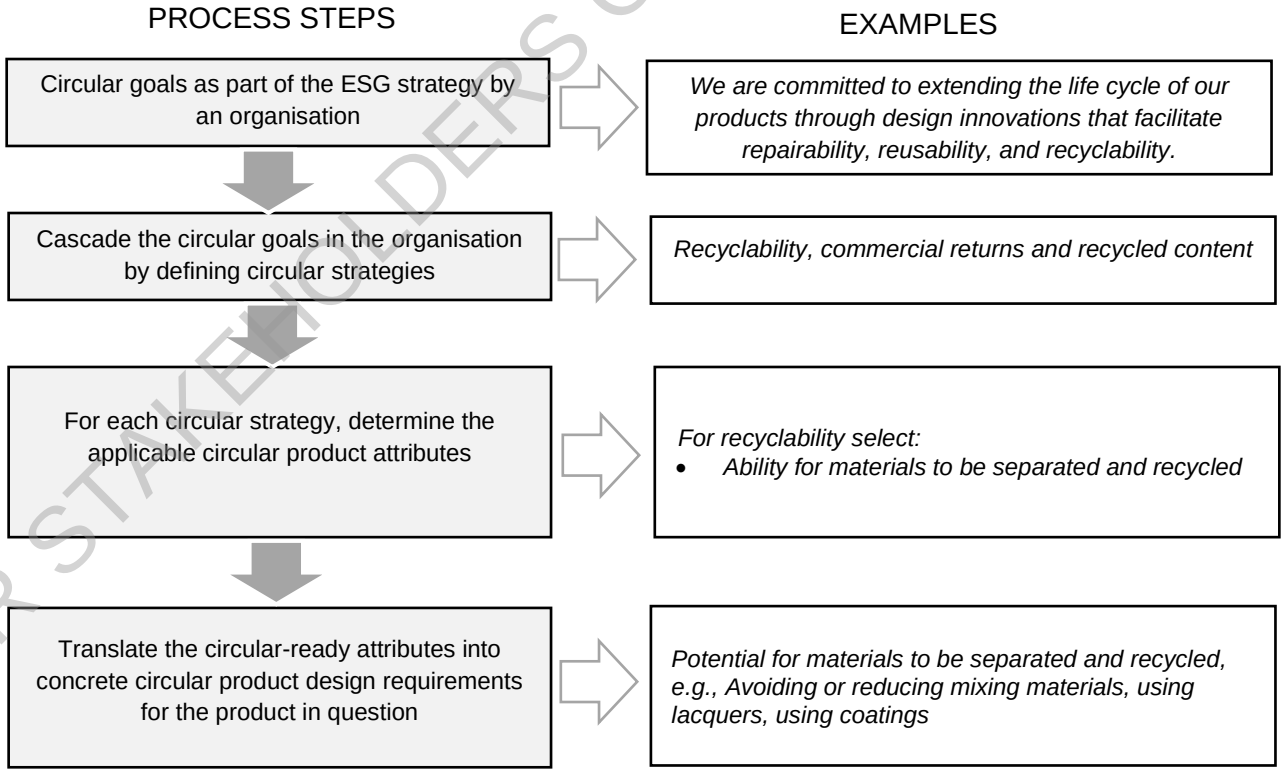


Figure 4. Circular product design process for implementation

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6.2 Circular strategies

6.2.1 Introduction to circular strategies

Circular strategies can be implemented:

a) using less material or narrowing material flows;

b) using materials longer or slow down the material flows; and

c) using materials again or closing the material flows.

The concept of circular product design cannot be separated from circular business models or circular strategy exploration. A circular business model or strategy without a circular designed product is not going to be optimum either. A circular designed product that is not combined with a complementary business model will either not exploit the circular improvements or a third party will be able to take advantage or benefit from these improvements.

Therefore, the transition towards product circularity starts with the identification of circular strategies by the organisation. These are closely linked with the product portfolio of the organisation and can and should give directions on how to improve its products to become circular designed products.

To make the circular economy and material efficiency objectives of an organisation more tangible, the organisation shall determine which circular strategies to focus on. Below is a (non-exhaustive) list of circular strategies that may be chosen by an organisation. The principles of narrowing, slowing, and closing the material flows of 4.1 can support the organisation in this process.

6.2.2 Circular design strategies that use less materials or narrow the material flows

a) Physical to virtual

This category involves using less resources by transforming physical solutions (hardware, software, or services) into digital equivalent. Digitalisation makes use of digital technologies to change a business model and provide new revenue and value-added opportunities that are resource less intensive. Advantages from digital solutions can be:

i) virtualisation or cloud computing - decrease in number of local servers;

ii) increased hardware utilisation rate;

iii) easy access in remote locations; less travelling;

iv) less GHG output by reducing travel;

v) improve traceability of type and origin of materials; and

vii) reduce the need for physical mock-ups for design verification of performance by test by creation of e.g. digital twins.

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NOTE. Sometimes replacing a physical product by a virtual solution could imply in the increased need for energy or other environmental impacts in another location (e.g. data centres cooling requirements, telecommunications). Trade-offs are, therefore, essential.

b) Multiple functions

Involves combining functions from different products into one single product, reducing the material needed to manufacture multiple products. E.g. fax, copy machine and printer in one.

NOTE. Sometimes combining functions require considering that the loss of one function can lead to the loss of all functions, reducing the reliability of the product. Also, the combination of functions in one material such as electrical or thermal insulation combined with fire resistance can reduce the ability for the material to be recycled.

c) Lease or share

Lease or sharing to intensify use of durable assets increases their use over time and reduces the number of products that need to be produced by avoiding the need for each potential user to own a product.

This type of business model facilitates implementation of other circular strategies such as refurbishing or remanufacturing so that the reverse logistics is easily implemented. Advantages from leasing or sharing solutions can be:

i) access to product at its end-of-life gives opportunity to grow customer engagement;

ii) reduce costs; and

iii) secure additional revenues by making use of its residual value via refurbishment or recondition.

NOTE. There might be reasons (costs, hygiene, product lifetime, etc.) for preferring buying to leasing or sharing in some cases.

d) Use less materials

Using less material to deliver the same function is key in an economy that is truly circular.

Additional aspect to consider is the fact that the supply of CRMs is dominated by small group of countries globally, making the longer-term supply of these materials uncertain due to trade barriers/wars for the global supply. This may, therefore, impact the availability of products and concurs to the need to reduce use of these critical materials along with strategies to reduce the amounts of materials to deliver a function.

NOTE. Although stepwise decrease on the use of materials is important, it is expected that ground-breaking innovations are likely to deliver the most significant savings in materials in relation to the function they are expected to deliver.

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6.2.3 Circular design strategies that use materials longer or slow down the material flows

a) Software update

Software updates (or maintenance) that provide fixes (often security) for features that are not working as intended or add minor enhancements and compatibility allow for the extension of the life of the product. For instance, the common operating system update is a security update, which is issued to protect a system against vulnerabilities that might be exploited by hackers and viruses.

NOTE. Update refers to a minor change to a product that does not influence the functionality and/or user experience of the product. For instance, in the case of software, update is used to patching bugs and errors discovered after the product is already on the market (e.g. security update).

b) Hardware or software upgrade

A software upgrade is a new version of the software that enhance functionality over the current version. It is considered as perfective maintenance action. Similar to hardware upgrades, software upgrades often offer additional features to users.

Hardware upgrade involves replacement of certain parts of an equipment in order to bring it up to date or to improve its characteristics, e.g. increase storage capacity of a data server.

Both software (or firmware) and hardware upgrades allows for the user to continue using the product for a longer period before it is considered obsolete.

c) Hardware maintenance

The purpose of maintenance is to ensure the maximum efficiency and availability of an equipment, utility, and related facilities at optimal cost and under satisfactory conditions of quality, safety, and protection for the environment.

Maintenance refers often to routine (planned) and/or corrective or preventive activities done on assets to prevent (long term) damage and prolong its life expectancy.

Condition-based maintenance allows for longer use of replaceable parts, resulting in less material use (e.g. lubricant refresh).

d) Longer life

Designers can incorporate characteristics that enable products to serve their originally intended functions longer. This can be achieved by e.g. applying new high quality or functional materials. This can include strategies to increase both, the physical as well as social useful life (e.g. timeless design that remains desirable for users over a long period of time).

Lifetime extension strategies go often hand in hand with strategies that foster the extended use of products, like design for repair, upgrade, and easy maintenance.

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e) Lifetime extension - Repair

Repair refers to restoration work when an asset breaks, gets damaged, or stops working. The objective is to return it to a condition where it can fulfil its intended use, and so support the product's expected service life.

f) Lifetime extension - Refurbishment

Refurbishment is a process (or combination of processes) applied during the expected service life to restore a product to a condition of safety and performance according to the specification of the manufacturer. Refurbishment can include activities such as repair, rework, replacement of worn parts, and update of software and hardware.

g) Lifetime extension - Product or parts reuse

In a circular economy, nearly all products will be reused again and again. Reusing products or parts over multiple usage cycles is an important measure for reducing resource consumption and increasing value capture from that product.

Reuse of products retains the greatest value in embedded costs such as material, labour, energy, capital as well as lowest environmental impacts such as GHG emissions, water consumption, etc.

6.2.4 Circular design strategies that use materials again or close the material flows

a) Remanufacture and repurpose at end-of-life

Remanufacturing or renew is a process (or a combination of processes) performed on products resulting in a new expected service life, new or modified specifications, intended use(s), or legal claims. Remanufacturing can include using parts (including software) not supplied or specified by the original manufacturer but deemed technically suitable by the entity doing the work.

Effective reverse logistics is key to enabling a supply of high-quality secondary resources to enable circular activities such as remanufacturing, or repurposing.

Repurpose is the use of something (a product or part) for a purpose other than its original intended purpose by modifying or using the item in a new way. Repurposing can be a cost-effective strategy since the reused items can prevent a business from having to purchase new materials. Repurpose, is normally performed as a way to reduce waste and supplant a new, manufactured good contributing to material efficiency and recirculation of end-of-life products and parts.

NOTE. Repurposing might not always be environmentally friendly or cost-effective. For example, an old building could be converted to a new use but not updated enough to reduce energy costs. Or, for example, an old gasoline engine-powered car could be repurposed as an electric car, which would involve a costly conversion and may not lead to greater efficiency.

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b) Parts recovery at the end-of-life

Parts recovery involve reverse logistics to enable transporting of post-use or unsold products, components, or materials back into the organisation or value chain in order to harvest parts that can later be reused in e.g. to make a new product, or in repairs, refurbishment or remanufacturing.

This strategy shall follow relevant national legislation. For example, in accordance with *Environmental Quality (Scheduled Waste) Regulation 2005*, a waste generator should demonstrate the waste they generated did not exhibit hazardous characteristics and shall obtain Department of Environmental approval before it can be reused/reprocessed into other product.

Benefits of parts recovery strategies are:

i) they reduce costs for the users and manufacturing organisation;

ii) grow or maintain market of reusable elements;

iii) enable continuous improvement of design with knowledge from returned elements; and

iv) when taking place is a closed loop system, there is the possibility to retain assets and intellectual property (IP), thereby preventing the organisation's products entering the broker markets.

c) Recycling at the end-of-life and recycled content use

This is the process of recovering materials through proper collection, sorting and high-quality recycling technologies excluding energy recovery. Recycling destroys product integrity and value and requires energy, making it the last resort for the circular economy. Nevertheless, recycling is very important because it keeps the material in use and reduces waste volumes. Materials are best recycled achieving the same quality as they had before or even higher quality (upcycling). Not all materials, however, can be recycled, e.g. when hazardous substances cannot be fully separated and can accumulate during new cycles. Successive use in downward cascades (downcycling) can also be appropriate for technical materials when recycling treatments is not able to achieve at least the same quality or are deemed not environmentally friendly.

Use of recycled content to manufacture new products implies in e.g. value coming from hardware containing a certain % (content) of recycled materials. Typical benefits of using recycled content can:

i) reduce costs by using recycled materials;

ii) stimulate the availability on the market (economy of scale), which leads to further cost reduction; and

iii) counteract depletion of the planet and natural resources scarcity.

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Toxic substances should not be reintroduced in the production cycles. Any measure to increase recycling and recycled content rates should be accompanied by an assessment of health and environmental impacts, as well as an assessment of alternative materials.

6.2.5 Addressing circular service, hardware, and software

The circular strategies describe in the three previous subclauses can focus on the optimisation of software, hardware, services, or a combination thereof to deliver circularity, as follows:

a) Circular service involves often "closing and/or slowing down the loops" by extending the lifetime of products through service offers. Examples are planned maintenance, upgrades, or lease service model, where users pay for use and return the goods so that other users can make use of it.

b) Circular hardware involves "closing the material loops" by the reuse of products, systems, parts, components, and materials. Typical examples are reuse of products, parts and materials, product life extension strategies such as refurbishing or remanufacturing, smart material choices, recycling and use of recycled content.

c) Circular software (including firmware) involves in most cases "narrowing the loops" by replacing or optimising resource usage of hardware with digital solutions. Examples are from analogue to digital, software optimising resource usage, etc.

6.3 Circular product attributes

Product circularity can be assessed and improved through circular product attributes. In essence the circular product attributes address how design and architectural changes of the product can improve its circularity and, in this way, support current and new/ future circular strategies. A list of circular product attributes that are applicable to the product portfolio of an organisation shall be developed in order to drive the circular design of products in structured and harmonised manner throughout the organisation.

The circular product attributes will support the organisation designing products such that the maximum potential for circularity can be achieved. Including circular product attributes already at the design stage enables progress of the circular strategies. The circular product attributes can be grouped in four different groups as follows:

a) User safety or security - identifying, analysing and preventing errors that lead to adverse events.

b) Functional performance - refers to the capacity of the material to fulfil its requirements in the specific device application.

c) Obsolescence/lifetime - refers to the time and state in which a piece of technology or product ceases to be useful, productive, or compatible.

d) Material stewardship - embodies the range of activities required for optimal and appropriate use of minerals, metals and other (natural) resources in society.

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The list of circular product attributes including rationale and objective is further detailed in Table 1. This is a non-exhaustive list. When assessing the potential to improve the circular design of a certain product or groups of products, the applicable circular product attributes given in the table shall be selected, however the user safety or security attribute shall be compulsory. Where relevant attributes are needed that are not included in the table, the organisation shall extend the list with the missing elements. When including such additional elements, reference to, where possible, existing standards shall be made.

To support the process, the product attributes requirements are provided in Table 1 and a series of questions supporting the design are provided in Annex A. Not all attributes or design questions may apply equally to all product sectors, and those applicable to the product(s) or group(s) of products(s) under consideration shall be selected by the organisation. Where relevant attributes or design questions are not included in the table, the organisation shall extend the list in Table A.1 accordingly.

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Table 1. Circular product attribute groups, rationale, and objectives

Circular product attribute	Group	Rationale	Objective
1. Ability to clean, sterilise and restore aesthetic state	Pertains to user safety or security	Helps ensure user safety over multiple use cycles. From a consumer point of view, aesthetic performance is a proxy for hygiene.	Protect users from infection (objective) and maintaining high hygienic perception (subjective). Make easy for the organisation to disinfect and restore aesthetic quality.
2. Ability to guarantee digital security	Pertains to user safety or security	In a digital era, connected products containing sensitive information pose a threat to individuals if not secured. Transferring assets between users creates a threat that should be managed in order to enable product lifetime.	Protect users from cyber-attacks and breaches of data. Certify removal of personal, proprietary, or other sensitive data.
3. Ability to operate safely when given longer lifetimes	Pertains to user safety or security	As products remain in use for longer durations, they are exposed to potential wear and aging, which can impact their reliability and safety. Addressing this ensures that users are protected from hazards that may arise due to prolonged use or aging of components.	Design products that can maintain safe operation throughout extended lifetimes, thereby enhancing user safety and security by mitigating risks associated with prolonged usage, such as structural integrity failures or functional deficiencies.
4. Ability to assess and track performance	Pertains to functional performance	Increases the efficiency and reduces the time required for diagnostics. Enables predictive and remote maintenance and provides usage infom1ation to support use-based business models. Being able to assess and track perfomance is critical in order to estimate the remaining useful life of a product being refurbished or parts being recovered. Where possible, use simulation for verification instead of test.	Allow for diagnostics, remote monitoring, and assessment of the remaining useful life. It covers the following aspects: i) diagnostics ii) remote monitoring iii) remaining useful life assessment.

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Table 1. Circular product attribute groups, rationale, and objectives *(continued)*

Circular product attribute	Group	Rationale	Objective
5. Ability to disassemble and reassemble	Pertains to functional performance	Increases the feasibility, efficiency, and economic attractiveness of repair, upgrade, refurbishment, remanufacturing and parts recovery.	Enable the disassembly and re- assembly of hardware (e.g. to restore or upgrade functionality) without causing damage to the product.
6. Ability of users to accept used products	Pertains to functional performance	Improves the demand for used versions of the product by improving consumer perceptions of the quality or desirability of used versions.	Increase consumer acceptance of a used version of the product.
7. Forward and backward compatibility and use standardised parts	Pertains to obsolescence / lifetime	Makes the execution of circular activities like repair, refurbishment, and remanufacturing easier and less costly. Standardisation of parts helps reduce the size of the overall stock of parts required.	The product is designed as part of a platform/module series, compatible and interoperable with backward and forward releases, as opposed to a standalone SKU. Main objectives are: i) minimises the variety in components within and between products; and ii) maximises the compatibility with other products. previous versions, and potential new versions.
8. Modular design	Pertains to obsolescence/ lifetime	Enables the quick disassembly and replacement of several parts with a similar lifetime. Allows replacement of only the specific part of a device that need to be upgraded or replaced.	Enable the removal and exchange of several parts in a single disassembly step via the use of modules.
9. Product durability and reliability (including parts, components, and materials)	Pertains to obsolescence/ lifetime	Helps delay the technical obsolescence and disposal of products. Increases the total lifetime of product and feasibility of parts harvesting and replacement. Reduces invisible degradation of key components or materials, leading to a loss of performance or protection without creating a visible limiting state.	Elements selected from industry standards (instead of custom), with high lifetimes and reliability Increase the physical lifetime of the product and its parts. Carefully select technologies for components or materials playing a key role in product performance or protection.

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Table 1. Circular product attribute groups, rationale, and objectives *(continued)*

Circular product attribute	Group	Rationale	Objective
10. Potential for adaptability and flexibility	Pertains to obsolescence/ lifetime	Allows the product to adapt to changing user needs, preferences, or environmental conditions which help making sharing and renting more feasible. Helps ensure the product remains relevant to a user, delaying disposal.	Make the product suited for changes in the environment such as different users and different weather. Design for the broadest possible range of environmental and operating conditions.
11. Potential for product attachment and emotional durability by users	Pertains to obsolescence/ lifetime	Pertains to obsolescence. Helps increase product lifetime by having consumers have a strong emotional attachment to the product. This typically results in consumers taking better care of the product and potentially pass it down over generations.	Increase the emotional bonding consumers have with the product. i) Linked to quality ii) Linked to cost iii) Linked to fashion
12. Use of sustainable materials	Pertains to material stewardship	Enables closing the loop at end-of-life by using recycled materials, where those are the sustainable alternative to primary raw materials. Helps defray increasing material costs and address more stringent regulations linked to substances use and recycling. Use of safe materials to enable better recycling and prevent accumulation of substances of concerns.	Use of safe, recycled materials instead of primary raw materials, select pure materials which can be later recycled.
13. Ability for materials to be separated and recycled	Pertains to material stewardship	Enables economical recycling by making separation of the product into pure material streams as easy as possible. The composition, configuration, and method of attachment of components all influence the degree to which material separation is possible.	To enable recycling stakeholders to obtain quality recycling streams (e.g. pure materials) in an efficient manner.
14. Potential for material minimisation	Pertains to material stewardship	Reduced the environmental footprints (energy, materials) of a product by using smart designs to reduce the amount of material needed to achieve the same functionality. This can result in lower product costs as well.	Reduce the amount of material needed while keeping the same functionality and quality (durability, reliability, safety).

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Table 1. Circular product attribute groups, rationale, and objectives *(concluded)*

Circular product attribute	Group	Rationale	Objective
15. Potential for digitalisation	Pertains to material stewardship	Reduces the need for bespoke hardware, typically resulting in significantly less material being needed for the same functionality and therefore a lower environmental footprint (energy, materials). This is commonly achieved with the use of software and generic hardware.	To replace dedicated hardware with generic hardware.

6.4 Determining the relevance of the circular product attributes

Once the organisation has identified the circular strategies it has or wants to further develop, it is time to identify all the circular product attributes that are relevant to the circular strategies chosen. This enables to identify the relative relevance of the various circular product attributes from Table 1, giving a score (high, medium, or low) to each of them - see also Figure 5 in the next clause for the overview.

Once the assessment of each individual circular product attribute in respect to all other attributes is completed, the overall importance list can be calculated. The relative importance of the circular product attributes may be different for different product types and sectors, and the process needs to be repeated for each category individually.

6.5 Building a circular product design matrix

Figure 5 shows the circular strategies and the circular product attributes in a matrix form, where in the various rows the circular product attributes are shown, and at the top columns, the circular strategies. The interlinkage between circular product attributes and circular strategies shown in Figure 5 expresses the relative importance of the different circular product attributes in respect to each circular strategies:

a) the dark grey coloured cells indicates the critical attributes for the specific circular strategy, that the organisation has decided are the most relevant to be addressed during product design;

b) the light grey coloured cells express recommendations. They should be addressed by the organisation during product design; and

c) white fields indicate minor or no relevance and that will be addressed at the organisation's discretion.

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	Circular strategies													
	Use less principles				Facilitate reuse principles							Use again principles		
Circular products attributes	Physical to Virtual	Multiple functions	Lease & Share	Use less materials	SW update	HW or SW upgrade	HW maintenance	Longer life	Repair	Refurbishment	Reuse	Remanufacture	Parts recovery	Recycling & recycled content
1. Ability to clean, sterilise and restore aesthetic state														
2. Ability to guarantee digital security														
3. Ability to operate safely when given longer lifetimes														
4. Ability to assess and track performance														
5. Ability to disassemble and reassemble														
6. Ability of users to accept used products														
7. Forward and backward compatibility and use standardised parts														
8. Modular design														
9. Product durability and reliability (including parts, components, and materials)														
10. Potential for adaptability and flexibility														
11. Potential for product attachment and emotional durability by users														
12. Use of sustainable materials														
13. Ability for materials to be separated and recycled														
14. Potential for material minimisation														
15. Potential for digitalisation														
	HIGH RELEVANCE				SOME RELEVANCE				MINOR RELEVANCE					

Figure 5. Example of a circular product design matrix

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This matrix is an important tool for organisations moving towards circular as it offers an overview of all actions and activities by the organisation to achieve circular designed products. It can be used also to link to the KPIs dashboard and distributed per business or product (type).

The circular product design matrix addresses how design and architectural changes in the product can support the (new/future) generation circular categories. So, in practice by including product circularity already at the design stage of the product, the cost for operation or costs when products are returned can be lowered, improving the overall business case for repurposing.

EXAMPLES:

1. A refurbishing business model (category refurbish) will benefit most when during the design stage the ability to clean, secure and private data exchange, and repair and disassembly have been considered and improved. The ability to assess and track performance, modular design and a more durable component selection positively contribute to the circular design, although they are not critical to this specific category.

2. Today the costs incurred to take products back from the markets and reprocessing them so that they can be brought back to the market for a next life are often limitative (too high). Therefore, this process is often only observed for premium brands. By including product circularity already at the design phase, overall operation costs or costs when products are returned can be lowered, improving the overall business case for repurposing or refurbishment. For instance, a product that is designed to be easily disassembled will ultimately reduce the cost for refurbishment, and positively impact the business case for bringing that product back to the market as a refurbished product.

6.6 Circular design evaluation

The attributes being evaluated will be mapped against the circular product design matrix prepared per business or product (type).

The products shall be evaluated and scored on a rating of 1 to 5 (1 as low and 5 as excellent) against each element/sub-element of the fifteen circular design attributes as listed in Clause 6.3.

The circular design evaluation score sheet (see Annex B), or a similar format, may be used for the purpose of recording the result of the scoring by each evaluator. It is intended that the scoring by each evaluator will be used to support the final consensus-based decision by the team of evaluators.

7. Communication

7.1 Communication of the circular goals by the organisation

In order to make the circular economy and material efficiency ambition of an organisation known and well understood, intensive communication within the organisation as well as with interested parties outside the organisation is needed.

In its communication, the organisation should identify what information has to be exchanged, with whom, and in what form for it to be effective. The organisation should communicate with both internal and external stakeholders involved in the product's value chain.

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a) Communication with external stakeholders

The organisation should inform suppliers about circular design related needs (e.g. in relation to its circular economy and material efficiency ambition and chosen categories).

The organisation should inform customers about circular related aspects of the product during product use, maintenance, repair and disposal.

The organisation should inform users about the way a product has to be handled in the different life-phases to achieve the best performance (e.g. maintenance and repair possibilities and expected actions at end-of-life phase).

The designers should secure input from recycling companies about e.g. constraints for recycling of certain materials, the combination of materials which will positively or negatively influence the result of recycling, or availability technologies to recycling certain materials.

The organisations should inform end-of-life operators about the composition of products to optimise dismantling and recycling and to minimise loss of material.

b) Communication with internal stakeholders

An interdisciplinary approach is normally needed to accomplish circular designs by an organisation, helping to create a shared vision of product circularity throughout the organisation and to mobilise all of the concerned actors.

The organisation should create a communication strategy around its ambition toward circular product design and so create awareness and involvement of its personnel in realising the circular economy and material efficiency ambition.

7.2 User information and guidance on circular aspects of the product

The organisation should prepare information about product design. User interfaces should support or even stipulate the user to implement the circular ambitions for the product which may require changed use patterns or behaviour.

The organisation should provide product information such as printed user manuals, product integrated electronic manuals or online manuals and so guide users:

a) on how to install, use, and maintain the product to ensure optimum durability;

b) on how to resolve potential errors/ failures or on how to have the product repaired;

c) on offers and possibilities for upgrade, refurbishing or product exchange and remanufacturing programs; and

d) on how to return or dispose of the product at end-of-life.

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Annex A
(informative)

Series of questions supporting the circular product design requirements

Table A.1. Supporting questions to determine circular product design requirements

Circular product attributes	Design questions	Description/Guidance/Example
1. Ability to clean, sterilise and restore aesthetic state	1.1 Will the end user be confident that the product has a high quality of hygiene?	A product expressing a high quality of hygiene is essential to a sharing model. It is also important to ensure the end-user or the product's cleanliness. Example: The packaging states 'This product has been controlled to have the same hygiene standard of a new product''.
	1.2 Will the product withstand many cycles of cleaning and sterilisation?	Product looks and functions expressing a high quality is essential to achieve end user acceptance. 'Age with grace' is necessary.
	1.3 Will the dismantler be protected from contagious or hazardous content?	It is important that the dismantling process happens in a safe and quick way, avoiding e.g. infectious liquid or leaking battery. Example: A leaking water tank with infectious water could be designed with an anti-drip function.
	1.4 Will the dismantler be able to disinfect the product with standard tools and methods?	Using standard tools reduces throughput time for service. Example: Disinfection liquid + cloth, autoclave.
	1.5 Is the product designed so it maximises cleaning efficiency?	Smooth surfaces with no/few gaps or ridges accumulate less dirt. Example: Design all buttons as foil buttons.
	1.6 Is a long life ensured by 'age with grace' materials? Also, after some physical damage?	It is necessary to include in the design aesthetics that product looks good after use, also considering potential damages. Example: Scratches on a leather backpack.
2. Ability to guarantee digital security	2.1 Are past, current and future users protected against data threats?	A high level or trust is essential to convert end users into circular products. Example: Guaranteeing privacy and digital security.

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Table A.1. Supporting questions to determine circular product design requirements *(continued)*

Circular product attributes	Design questions	Description/Guidance/Example
	2.2 Can data of previous users be completely removed?	Where data are stored on storage internal to the product, secure data deletion tools should be pre-installed or built in or made available which permanently delete all user data without compromising the functionality or the device for further use.
	2.3 Can spyware or malware be removed?	A previous user may have(inadvertently) introduced spyware or malware to the product in question. A high level of trust is essential to convert end users into circular products.
	2.4 How will the products express a high level of security and privacy?	It is necessary that users are confident of a high-quality security and privacy
3. Ability to operate safely when given longer lifetimes	3.1 How will the prolongation of the lifetime of the product influence safety?	Example: Deterioration of the materials over lifetime could result in unsafe situations
	3.2 Can safety be guaranteed during the dismantling of the product at the end of life?	Ensuring safety during the dismantling of the product at its end of life involves using non-toxic materials designed for easy disassembly, providing clear instructions and training, implementing risk management protocols or partnering with certified recycling and disposal facilities to handle and dispose of all materials properly.
	3.3 Can substances added to improve the lifetime of the product/material be safely handled during manufacturing?	Safe handling of substances added for product durability during manufacturing includes using non-toxic additives, providing safety data sheets, requiring Personal Protective Equipment, ensuring proper storage and ventilation, offering training, and establishing emergency protocols where required.
4. Ability to assess and track performance	4.1 Can the product's location be determined?	Knowing where product is and how it is doing, in full agreement with the user, will optimise the service and lower the costs. Example: Each product has a tag that can be monitored remotely (digital product passport).
	4.2 Can the product's performance be sufficiently' monitored?	Sufficient enough to enable effective servicing, refurbishment, and parts harvesting. Example: Product/software monitors information on usage history and is connected to larger supply/demand database.
	4.3 Is artificial intelligence (AI) monitoring optimised to automatically maximise usage?	AI systems are designed and fine-tuned to oversee and manage resources or processes in such a way that they ensure the most efficient and effective use without human intervention. The goal is to achieve the highest possible utilisation and productivity by automatically adjusting operations based on real-time data and analytics.
	4.4 Is remote monitoring enabled across the full installed base?	Example: Allowed shift of location for shared hardware.
	4.5 Is the product monitored on a granular level?	Example: Elements/parts are monitored separately.

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Table A.1. Supporting questions to determine circular product design requirements *(continued)*

Circular product attributes	Design questions	Description/Guidance/Example
5. Ability to disassemble and reassemble	5.1 Are replaceable and reusable parts easily accessible?	Example: Making parts, in particular fragile ones, easily accessible will make it more efficient for the disassembly and reassembly process
	5.2 What type of tools and conditions are needed to dis- and reassemble the product?	For example, can the product be dis- and reassembled with bare hands/standard tools or are more sophisticated process and tools necessary? No or standard tools are easier/cheaper. Examples: 1. Screwdriver, hexagon socket key (e.g. IKEA), combination wrench, etc. 2. Shape memory alloy material could make disassembly efficient.
	5.3 Has complexity been reduced during disassembly and re-assembly?	Example: Reducing the number and type of operations required for the dismantling of the product makes the process easier.
	5.4 Can a non-expert dismantle the product?	Designing the product to be intuitive for service- an experience flow will also support this process.
	5.5 Has convenience been improved?	Where possible, avoid using fasteners that are neither removable nor reusable.
	5.6 Is there an automatic or digital way to diagnose the repair problems?	A robot can be efficient in analysing problems when disassembling and re-assembling products.
	5.7 Repair and upgrade made easier by manufacture	Organise process to make easy for user to know what to do in case of issues, etc.
6. Ability of users to accept used products	6.1 What is it that hinders the user from buying a used device?	Having scratch resistance surfaces reducing the visual proof of the product having been used.
	6.2 If the outside parts are exchanged, will that result in increased chance for buying the used product?	Making parts that hinder the consumers the most to buy second hand products, replaceable parts such as the ear pads of headphones, can allow for reusing most of the product.
	6.3 Next to the actual possibility to clean the product, is the product also perceived to be easily cleaned?	Seamless product design with smooth surface finishing giving the look that it has been cleaned. Making parts that require cleaning capable of being cleaned by appropriate method and also making sure that the product looks- like-new after the cleaning process.

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Table A.1. Supporting questions to determine circular product design requirements *(continued)*

Circular product attributes	Design questions	Description/Guidance/Example
7. Forward and backward compatibility and use standardised parts	7.1 Is the product part of a platform?	A platform is bigger than one product. A platform results in several products that are designed based on the same elements and parts.
	7.2 Is the product compatible with backward and forward generations?	A product, its elements and parts should be replaceable with older and future designs.
	7.3 Are spare parts available?	Spare-parts are needed to avoid early product obsolescence.
	7.4 Are spare parts (industry) standard?	When spare parts are standard, they are easily available. This will speed up repair, refurbishment and remanufacturing.
8. Modular design	8.1 Has the product been optimised by including modules?	Modules can be a group of elements and or parts. A module can be grouped around similarities.
	8.2 Are the modules grouped based on similarities"?	Similarities can be: - Same lifespan or reverse cycle strategy. - Combine all hazardous/non-recyclable materials into one module. Grouping parts with same lifespan in a module makes it more efficient when replacement is needed"
9. Product durability and reliability (including parts, components, and materials)	9.1 Does the quality and lifetime enable reliability and durability?	Safe, reliable, and durable during use, maintenance and disposal.
	9.2 Can already used parts and materials be reused into new products without compromising safety and performance?	Reusing already used parts and materials in new products involves rigorously evaluating their condition and compatibility to ensure they meet safety and performance standards, (eg. Reclaiming and refurbishing functional automotive components like engines and transmissions from end-of-life vehicles for reuse in new vehicle manufacturing).
10. Potential for adaptability and flexibility	10.1 Will the product have different users?	If the product has different users think about what on a design level needs to be adaptable to still meet the user requirements. Example: Office chairs; adaptable to different body shapes of different users.
	10.2 What aspect of the device needs to change to adapt to the different user?	
	10.3 Will the product be used in different environmental conditions?	If the product will be used in a different environment think about what needs to be done on a design level to make it adaptable to fit the new environment. Example: After moving the long side of the corner sofa is on the wrong side. Having an adaptable product that allows for changing that prevents buying a new sofa.

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Table A.1. Supporting questions to determine circular product design requirements *(continued)*

Circular product attributes	Design questions	Description/Guidance/Example
11. Potential for product attachment and emotional durability by users	11.1 Can the user bond with the product?	Prevent the use of 'clean and practical' designs. Example: A user is more likely to separate from a mug without a pattern and s simplistic standard design than a mug shaped like a camera lens reminding them of their favorite hobby and the moments they took the mug with them when they went on a trip. Give the product a design that can be used to express someone's personality allowing the user to get more attached to it. Example: A very specific flower print design on a backpack.
	11.2 Is the product part of the user's personality?	
	11.3 Will the user easily connect memories to this product?	
12. Use of sustainable materials	12.1 Is the product made of non- toxic materials?	When designing a product, hazardous chemicals and materials should be minimised and, where possible, proactively avoided.
	12.2 Are employees dealing with products (at manufacturing, installation, maintenance, decommissioning, and recycling phases) protected from the leaching or emission of hazardous substances from the product?	Examples: 1. Hazardous substances as described in legislations such as RoHS and REACH or eco-label product criteria or green furniture criteria document or MyHIJAU Mark Recognition provide overview of substances that are considered hazardous. 2. Safety data sheets allow for understanding of degree of hazardousness and potential risk of exposure of employees and users to hazardous chemicals in the product
	12.3 Is the product made of durable/ recycled / recyclable/ renewable materials?	The use of renewable or recycled materials supports the circularity of the product because they can be easily regenerated or by using recycled content, one prevents use of primary raw materials. Example: Recycle content requirements can be referred to the eco-label product criteria or green furniture criteria document or MyHIJAU Mark Recognition. Example: Bio-degradable materials can replace conventional materials for short lifetime cycles usage like consumables. Where possible: - Select recyclable materials - Select renewable materials - Select low environment impact materials - Maximise use of recycled content - Avoid scarce/critical (raw) materials
	12.4 Are circular materials (e.g. renewable or recycled) used for the parts and consumables?	
	12.5 Are materials that are critical or scarce in nature replaced by other, more abundant and easier to access materials?	
	12.6 Are products, part and accessories made of materials with low environmental impact	NOTE. It is important to notice that use of renewable materials (e.g. bamboo) together with oil-based materials (e.g. plastics) may not always have a positive effect, in particular to the recyclability of the material. 4.3 addresses aspects such as trade-offs that can be considered.

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Table A.1. Supporting questions to determine circular product design requirements *(continued)*

Circular product attributes	Design questions	Description, guidance, examples
	12.7 Are circular materials used for the packaging?	Packaging should be recyclable and be made from recycled or sustainable bio-degradable materials. Example: Malaysia Plastic Sustainability Roadmap target 15 % average recycle content by 2030.
13. Potential for materials to be separated and recycled	13.1 Are the materials, surfaces, and construction compatible with the needs of the recycling industry?	Overall objective is to minimise number of different materials in the product. Examples: 1. Avoiding or reducing mixing materials, using lacquers, using coatings. 2. Designing a product with single materials for easy recycling through straightforward physical dismantling, reducing the complexity of separating different materials and enhancing the efficiency and effectiveness of recycling processes. 3. Categorising the recycle material by type. 4. Stay up-to-date with advancements in high-tech dismantling technology to design products that can be efficiently disassembled for material extraction and recycling.
	13.2 Are materials easily" identified also after wear and tear?	Automated or manually coating causes the problem of changing the material density, so that the underlying material cannot be correctly detected".
	13.3 Are the fasteners that are neither reusable nor removable avoided?	Use of reusable or removable fasteners (e.g. screws, click fingers, removable glue) will support clean disassembly or dismantling.
	13.4 Is the number of materials reduced?	Reducing materials can make it more efficient to dismantle and more easily recycled. .
	13.5 Have light colors been used for inner components?	Light colors are more easily re-colored, and therefore more easily reused.
	13.6 Can the substances used in the product be identified at the end of life (to allow for reuse)	Availability of knowledge of the materials and substances content of products when at the end-of-life to facilitate recycling (e.g. plastic logo, digital product passport, sorting and testing technologies).

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Table A.1. Supporting questions to determine circular product design requirements *(concluded)*

Circular product attributes	Design questions	Description, guidance, examples
14. Potential for material minimisation	14.1 Can the product/parts be designed 'smarter' minimising the material needs, while still delivering the same function to the user?	I-beam structures allow for the use of less materials while maintaining the same mechanical properties.
	14.2 Can the currently used materials be replaced by new materials that allow for overall material reduction?	Assessing whether currently used materials can be replaced by new materials that allow for overall material reduction involves evaluating alternatives that provide the same or improved functionality with less material usage, (e.g replacing traditional plastic packaging with innovative, lightweight bioplastics that achieve the same protective qualities with a reduced environmental footprint).
	14.3 Can the product/parts be designed 'smarter' replacing part of the hardware by digital solutions while still delivering the same function to the user?	Cloud storage of data instead of local data storage on devices is a good example. It avoids the provision of many small storage solutions in the devices which might not be used in full or would need to be expanded if full.
15. Potential for digitalisation	15.1 Can part of your hardware be replaced by software?	Example: Having a calculator app on a smartphone reduces the need for a calculator.
	15.2 Can the dedicated hardware be replaced by generic hardware?	Use of generic hardware has the advantage reducing the number of spare units on inventory (e.g. in large data-centres if all computing units are of the same type, when one fails it is convenient to take a replacement from stock and make immediately operational. Having many types would require having at least one spare unit of each type). Of course, trade offs have to be considered.
	15.3 Can you divide the product in separate modules of one module that can run on generic hardware and one that requires specific hardware?	Examples: 1. An oscilloscope can be made of a measuring module connect by USB to a computer performing data analysis and display. 2. As smart TV can be upgraded with a wi-fi dongle.

NOTE. The assessment of the ability of products to be disassembled, repaired, etc. is not part of this standard.

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Annex B
(informative)

Circular design evaluation score sheet

Scoring Guide	
Scale	**Status**
1	Poor
2	Fair
3	Good
4	Very good
5	Excellent

No.	Circular product attributes	Weightage (Based on matrix)	Scoring				
			1	2	3	4	5
1	**Ability to clean, sterilise and restore aesthetic state**						
1.1	End user will be confident that the product has a high quality of hygiene.						
1.2	The product will withstand many cycles of cleaning and sterilisation.						
1.3	The dismantler will be protected from contagious or hazardous content.						
1.4	The dismantler will be able to disinfect the product with standard tools and methods.						
1.5	The product is designed so it maximises cleaning efficiency.						
1.6	A long life is ensured by 'age with grace' materials. Also, after some physical damage.						
2	**Ability to guarantee digital security**						
2.1	Past, current and future users are protected against data threats.						
2.2	Data of previous users be can completely removed.						
2.3	Spyware or malware can be removed.						
2.4	The products will express a high level of security and privacy.						
3	**Ability to operate safely when given longer lifetimes**						
3.1	The prolongation of the lifetime of the product will influence safety.						
3.2	Safety can be guaranteed during the dismantling of the product at the end of life						
3.3	Substances added can improve the lifetime of the product/ material can be safely handled during manufacturing.						
4	**Ability to assess and track performance**						
4.1	The product's location can be determined.						
4.2	The product's performance can be sufficiently monitored.						

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No.	Circular product attributes	Weightage (Based on matrix)	Scoring				
			1	2	3	4	5
4.3	Artificial Intelligence (AI) monitoring is optimised to automatically maximise usage.						
4.4	Remote monitoring is enabled across the full installed base.						
4.5	The product is monitored on a granular level.						
5	**Ability to disassemble and reassemble**						
5.1	Replaceable and reusable parts are easily accessible.						
5.2	Specific type of tools and conditions are clearly defined to enable dis- and reassemble of the product.						
5.3	Complexity has been reduced during disassembly and re- assembly.						
5.4	A non-expert can dismantle the product.						
5.5	Convenience has been improved.						
5.6	There is an automatic or digital way to diagnose the repair problems.						
5.7	Repair and upgrade are made easier by manufacture.						
6	**Ability of users to accept used products**						
6.1	Reason that hinders the user from buying a used device has been identified.						
6.2	The exchange of outside parts are exchanged will result in increased chance for buying the used product.						
6.3	Next to the actual possibility to clean the product, the product is also perceived to be easily cleaned.						
7	**Forward and backward compatibility and use standardised parts**						
7.1	The product is part of a platform.						
7.2	The product is compatible with backward and forward generations.						
7.3	Spare parts are available.						
7.4	Spare parts are (industry) standard.						
8	**Modular design**						
8.1	The product has been optimised by including modules.						
8.2	The modules are grouped based on similarities.						
9	**Product durability and reliability (including parts, components, and materials)**						
9.1	The quality and lifetime enable reliability and durability.						
9.2	Already used parts and materials can be reused into new products without compromising safety and performance.						
10	**Potential for adaptability and flexibility**						
10.1	The product will have different users.						

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No.	Circular product attributes	Weightage (Based on matrix)	Scoring				
			1	2	3	4	5
10.2	Identified aspect of the device needs to change to adapt to the different user						
10.3	The product will be used in different environmental conditions						
11	**Potential for product attachment and emotional durability by users**						
11.1	The user can bond with the product.						
11.2	The product is part of the user's personality.						
11.3	The user will easily connect memories to this product.						
12	**Use of sustainable materials**						
12.1	The product is made of non- toxic materials.						
12.2	Employees dealing with products (at manufacturing, installation, maintenance, decommissioning, and recycling phases) are protected from the leaching or emission of hazardous substances from the product.						
12.3	The product is made of durable/ recycled / recyclable/ renewable materials						
12.4	Circular materials (e.g. renewable or recycled) are used for the parts and consumables.						
12.5	Materials that are critical or scarce in nature are replaced by other, more abundant and easier to access materials.						
12.6	Products, part and accessories are made of materials with low environmental impact						
12.7	Circular materials are used for the packaging.						
13	**Potential for materials to be separated and recycled**						
13.1	The materials, surfaces, and construction are compatible with the needs of the recycling industry.						
13.2	Materials are easily identified even after wear and tear.						
13.3	Fasteners that are neither reusable nor removable are avoided.						
13.4	The number of materials is reduced.						
13.5	Light colours have been used for inner components.						
13.6	The substances used in the product can be identified at the end of life (to allow for reuse)						
14	**Potential for material minimisation**						
14.1	The product/parts can be designed 'smarter' minimising the material needs, while still delivering the same function to the user.						

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No.	Circular product attributes	Weightage (Based on matrix)	Scoring				
			1	2	3	4	5
14.2	Currently used materials can be replaced by new materials that allow for overall material reduction.						
14.3	The product/ parts can be designed 'smarter' replacing part of the hardware by digital solutions while still delivering the same function to the user.						
15	**Potential for digitalisation**						
15.1	Part of the hardware can be replaced by software.						
15.2	The dedicated hardware can be replaced by generic hardware.						
15.3	The product can be divided into separate modules of (1) one module that can run on generic hardware and (2) one that requires specific hardware.						

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Annex C
(informative)

Background information

C.1 Considerations of sustainable development goals

The 17 Sustainable Development Goals (SDGs) are the world's best plan to build a better world for people and the planet by 2030. Adopted by all United Nations member states in 2015, the SDGs are a call for action by all countries - poor, rich and middle-income - to promote prosperity while protecting the environment.

The circular economy is concerned with the effective scaling of sustainable economic models within planetary boundaries. The principle of extending the life cycle of materials - to keep the value of products and materials in the loop as high as possible for as long as possible and the ability to recover materials from products at end of life - is central to this vision, as is the transition to renewable energy, respect for biodiversity, societal balance and social inclusion.

Working on the circular economy means working on several of the SDGs, not as a cost item but as a business model. In some areas of the world, action takes place under the framework of the SDGs; in other countries, climate issues are the dominant driver for action. Some focus on measures that are creating sustainable and economically viable cities, while there are also regions, such as Europe, setting out on the transition towards a circular economy.

Among all SDGs, SDG 12 - responsible consumption and production, at the core of circular economy, is amongst the most important goals to mitigate trade-offs and to create synergies to resolve development and environmental challenges when the product is designed. In order to achieve economic growth and sustainable development at the same time, a balance between how products are produced and so are designed, and the way natural resources are consumed needs to be found.

Circular economy can help achieve sustainable economic growth while retaining value of resources in the economy. This requires that the product is not only environmentally conscious designed (ECO) to limit its environmental impact, but also designed to minimise the utilisation of resources and also to prolong the useful life of products. The circular design of a product has different dimensions of which the technical specification part. Therefore, circular design should take into account all the functionalities that the product will have to fulfil, whether they are technical, environmental, social or economic. Circular design may require the management of trade-offs between functionalities according to their level of importance for the users.

Product development approaches covering the full range of functionalities to be fulfilled by a product in its life cycle and aiming at economic, social, technical, and environmental objectives may be considered through the value management methods covered by EN 12973 [2] and the functional expression of the need covered by EN 16271 [4].

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Theme 3 in Malaysia Twelfth Plan (RMK-12) focuses on advancing green growth as well as enhancing energy sustainability and transforming the water sector. The next five years will see a nationwide shift to more sustainable economic practices and lifestyles that value natural endowments and environmental health. This shift will address the issues of climate change, unsustainable consumption and production practices, loss of biodiversity, lack of coherence in the implementation of policies and inefficient water resources management. In the RMK-12, green growth will be augmented to achieve sustainability and resilience. In this regard, the need to share responsibility in moving towards a low-carbon nation will be emphasised, while more equal benefit sharing from the utilisation of natural resources will be promoted.

C.2 Circular product design extends environmentally conscious design

Environmentally conscious design (ECD) is a strategic design management process that considers the full life cycle environmental impacts of products (including parts and materials) (EN/IEC 62430, EN 50693 [6], IEC 63366 (24), IEC Guide 109 [21], systems, processes, services, and organisations, to quantify the impacts to most effectively reduce them. ECD includes material efficiency strategies as well as strategies for material circulation (like design for disassembly or design for refurbishment/remanufacturing) but does not lay the focus on design for multiple life cycles and therefore misses possibilities for resource conservation.

Circular design has emerged as a practice of design alongside ECD, based on the principles of the circular economy and systems thinking and taking nature as model for true sustainability. It is a broader concept as it focuses on practices contributing to a circular economy, from choosing the right circular business model, ending waste and pollution with adequate design, up to the paradigm shift from a linear to circular economic model.

In recent years, the circular design concept has been merged with ECD, so that currently, for example, the proposal for an ecodesign sustainable products regulation (ESPR) [4] and circular economy action plan [3) refer to a broader concept including ECD and several circular design aspects.

Circular design, in conjunction with circular business models, has emerged as design direction within ECD, focusing on practices contributing to a circular economy and changes in paradigms (from linear to circular) ECD aspects, however, still are carefully considered in order to find truly sustainable solutions.

Circular design applies systems thinking, which means to identify interrelationships and indirect effects, feedback loops, dynamic relationships and rebound effects, for making system improvements. New developments include design for system change, which means e.g. rethink and reconfigure systems for supporting circular resource flow. Guidance for system thinking can be found in ISO/IEC/IEEEE 15288 [19].

As with any design, functional requirements from stakeholders over the life cycle be identified. However, for circular design, additional requirements should be identified to minimise resource use or maximise resource life over multiple part or product life cycles. Better consideration is needed of requirements related to material efficiency such as the percentage of material recycled content and any other functional requirements related to the EoL for future lives. ECD aspects are still carefully considered in order to find truly sustainable solutions.

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Additionally, it is important to consider designs for closing the loops and for multiple use-cycles, and designs utilising recovered resources (use of recycled material or reused parts in new products) and thus increasing opportunities for resource conservation. When a product reaches the end of its useful life, it can be reused by another user, or if one part has failed, the other parts can remain suitable for reuse. Both products and parts can be designed for multiple cycles. Systems for testing and qualification of reused parts are specified in IEC 62309 [8].

Therefore, a key focus is on a product design that supports easy separation to ensure the quality and value (EN12973 [2]) of the material when recycled, so that the recycled content can be used for the same purpose without being downgraded. These strategies support value retention and high-quality resource recovery, though care needs to be taken for trade-offs, e.g. optimising energy efficiency might reduce recyclability of material, or using a different material may result in poorer material efficiency. Innovations in recycling technologies and processes are also needed to accelerate the closing of loops (design of systems supporting circular resource flow).

Careful selection of materials and adequate product design for the technical and especially biological cycle are newly introduced. In order to stop the wasteful use of biological resources as an important contribution for climate and species protection and allow safe return of nutrients to the soil, design strategies have been developed that enable the recovery of biological material at the end-of-use and to ensure that only sustainably grown or harvested biological material is used.

Hence, circular design helps implement the principles of the circular economy which are to optimise resource utilisation by circulating products, parts and materials at the highest utility for as long as possible in both technical and biological cycles, by designing out negative externalities such as emissions and non-recoverable resources in the form of waste and by preserving and enhancing natural systems so they can continue to provide natural capital and to ensure that only sustainably grown or harvested biological material is used For practical reasons and as the mandate of this standard is to focus on material efficiency, this standard mainly deals with aspects of slowing, narrowing and closing the material flows. Therefore, the following aspects of the circular design concept are not addressed:

a) system of product-systems (analysing the big picture and interactions of social, environmental and technical systems the product will be part of (see Annex A of ISO Guide 84 [20]) and BS 8001 [1]);

b) guidance for design for the biological cycle; and

c) help natural systems to regenerate.

The user of this standard is encouraged to especially consider environmental aspects in depth and to apply environmental management systems and additional methods to ensure sustainable product development (e.g. ISO 14040 [16]), ISO 14044 [15]).

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Ms Zulaikah Zulkifely (Technical Secretary)	SIRIM Academy Sdn Bhd
Mr Eric Tiau	Big Hand Creation Sdn Bhd
Dr Suffian Misran	Forest Research Institute Malaysia
Mr Husaini Ismail	Independent expert
Mr Ismail Rosdi/ Mr Quzailan Abd Rahman/ Ms Siti Sabarina Jusoh	Majlis Rekabentuk Malaysia
Ms Wan Nadia Kamarudin/ Ms Kiranjeet Kaur Ambra Singh	Malaysian Green Technology and Climate Change Corporation
Mr Muhammad Azidan Zakaria,CIDe	Persatuan Pereka Perindustrian Malaysia
Ms Zanariyah Ali/ Ms Hasimah Hassan/ Ms Nassya Mohd Said	SIRIM Berhad
Ts. Ahmad Lutfee Mohd Lasa, CIDe	Universiti of Teknology Sarawak

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