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Design Guidelines to Develop Circular Products: Action Research on Nordic Industry

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Supplementary

This section presents the description of each circular strategy as well as each general design guidelines:

Circular Strategies:

Rethink and reconfigure: changing business model innovation for circularity by rethinking the way of delivering the function and/or value proposition, e.g., sharing economy, product service system, and access-based sharing.

Reinvent: reinventing current business through new meaning, complete dematerialization, and radically different products and/or technology. Reinvent usually focuses on the use of digital technologies, particularly advances in information and communications technologies to provide a wide variety of services.

Raw materials and sourcing: changes in material sourcing to use more secondary, renewable, and environmentally friendly materials.

Manufacturing: changes in manufacturing technologies and equipment, as well as production systems, to increase efficiency and effectiveness and have cleaner production.

Product use and operation: changes in products to last longer and consume less consumables during the operation/use phase.

Logistics and packaging: improving circularity, efficiency, and effectiveness in logistics and also use more recyclable, renewable, and environmentally friendly materials for packaging.

Upgrade: adding new changes and features to a functional product in order to extend the lifecycle and value beyond its original design condition.

Repair and maintenance: correcting, replacing, or fixing faulty components of a defective product to return it to its original functionality to the same user to extend the lifespan of a product.

Reuse: reuse of a (discarded) product that is still in good condition and fulfilling its original function to keep the product functional and attractive to as many different users as possible, and for as long as possible, to extend and intensify the use of a product by preventing it from becoming obsolete.

Refurbishment: repairing a returned product after a certain period of use to satisfactory and acceptable mechanical specification and operating condition by rebuilding or repairing major components that are close to failure, even when there are no reported or apparent faults in those components.

Remanufacture: disassembling, repairing, reassembling, testing, and even upgrading a used product to look and perform with equivalent or higher performance and functionality.

Repurpose: extending product lifecycle to new use cycles by using a product (discarded/not in use) or its parts for different functions.

Recycle: any recovery operation by which wasted material is reprocessed into products, materials, or substances whether for original or other purposes.

Cascade: reusing materials with usually lower quality for a new application to extend resources timeline.

Recover: energy recovery from incinerating materials with characteristics that no longer satisfy any application whatsoever.

General Design Guidelines

Focus mainly on functionality and quality performance:
Focus mainly on functionality and quality performance as age, make, and model are less important as long as the quality-performance is delivered.

Think about activity supports in the operational stage:
Think about activity support during the operational stage of the product/service to make the system runs as efficiently as possible, e.g., supplying replacement materials, maintenance services, repair, and control in post-use.

Focus on fulfilling the customer's requirements and value creation:
Develop close relationships with customers to understand their requirements and hence develop capabilities accordingly and adjust personalized services with individual access. The service design cycle is continuously repeated and improved to be able to adopt various human factors and requirements

Try to use digitalization, ICT, and IoT solutions:
IoT and digitalization enable collecting data about the usage behavior and product performance through its lifecycle which help discover latent design errors and understand what components and when are going to fail, so repair and maintenance can be planned with minimum effect on products' performance.

Make it easy to inspect the product and components:
Easy and safe to inspect the product and components, particularly exchanging components. Use indications and manuals for testing and inspections.

Make it easy to clean the product and components:
Avoid areas where dirt might collect like small holes, nooks, grooves, and sharp edges; remember that all components should be wear resistance and withstand the same chemicals and mechanical cleaning processes, liquid and chemicals, as well as temperatures, detergents, and cleaning tools

Make exchanging of faulty components easily accessible:
Make disassembly points and components subject to breakage or failure easily accessible and preferably from one side.

Make it easy to dismantle the product nondestructively:
Easy to open and dismount in a nondestructive way; using less glue and adhesives; robustness and wear resistance of joints; disassembly from one side; providing manuals

Think about boundary management:
Build and exploit cooperative networks, relationships, and inter-organizational collaboration, focusing on the core business and strategy, and possibly merge and acquisitions

Think about incumbent configuration:
High level of autonomy and mobility, internal interpreter involvement, decentralization, and inter-functional collaboration combined with informal and organic organizational structures, as well as having a look for long-term efficiency.

Think about complementary capabilities:
Evaluating the chance of changing value proposition and becoming customer-oriented, along with access to distribution channels and leverage on specialized technologies.

Design using renewable materials:
Reduce the use of materials which are limited in quantities such as tin and precious metals, and use more renewable and bio-based materials if possible.

Design using recyclable and secondary (recycled) materials:
Choose materials that have high recycling rate, and available recycling technology and market; increase material compatibility so that only one recycling method needed; increase the proportion of recycled material in the product and use less virgin raw materials.

Consider toxicity and other environmental aspects of materials:

Use materials that do not threatens biodiversity and do not contain hazardous chemicals; select materials that do not degenerate during the multiple lifecycles; select material with verified reliability; avoid materials that lose strength or get brittle or discolored.

Favor cleaner production, processes, machines. and equipment:
Favor manufacturing processes, machines, and equipment that use less energy and materials, generate less waste, and discharge less into air and water; select machines and equipment that require less frequent maintenance and cleaning, with a good working and ergonomic environment.

Treat production (pre-consumer) wastes appropriately:
Think about the type and amount of waste generated in manufacturing. What segment and fraction of the waste can be separated to be able to facilitate pre-consumer recycling?

Design for reduced energy consumption and usage of renewable energy:
Design the product with reduced energy consumption, usage of renewable and clean energy; select production processes with high energy efficiency to reduced energy consumption; consider energy recovery of biological nutrients.

Design standardized components across different products and models:
Compatibility and exchangeability of components required across other models and products, e.g., the same type and size of screws.

Design standardized tools required across different products and models:
Compatibility and adaptability of tools required across other models and products, e.g., the same type and size of screwdrivers.

Use durable and robust components and materials:
Choose durable and robust component and material with a long lifespan; the lifespan of the different parts should be recognizable with indicators for wear; avoid materials that might lose strength, get brittle or get discolored.

Design in modular construction:
Divide product into different modules and put all the components that need to be exchanged or upgraded into one single module, thus lowering the effort.

Provide manuals and documentation:
Provide user-friendly manuals and documentation on how to repair and upgrade, with signs on how to open the product and exchange components.

Make spare parts and exchanging components easily available:
Exchanging components of products must be easy to find on the market and preferably be inexpensive.

Consider timeless design, emotional attachment, and compatibility:
Think about the effects that time and fashion will have on the product; simplicity, timeless design, and compatibility can be some ways to give product longevity, for example, USB devices.

Investigate current and upcoming laws and regulations:
Comply with applicable laws and regulations on hazardous material or chemicals that, now or later, are harmful and might be banned.

Use joints and connectors that can easily be opened and closed multiple times:
Generally, minimize the number of connectors and joints; use fastening devices which can be easily opened and closed multiple times; prioritize latch, snaps, clips and bolts, and screws over welding, rivets, folding, staples, and gluing, which make a joint more difficult to demount.

Minimize the number of different incompatible or dissimilar materials:
Minimize the number of different incompatible or dissimilar materials to facilitate shredding, regeneration, and recycling; avoid molding and fusing incompatible materials; avoid multi-materials and composites.

Make it easy to identify the materials and relevant information:
Create a system for identification of the individual components by, for example, RFID, barcode, tag, or QR-code. Provide additional information about the product regarding material content, the material's age, the number of times recycled, additives used, guides to component separation and process for recycling.