Three Archetypes of Circular Manufacturing Practices

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Working Group 5.7
Advances in
Production Management Systems

Special Interest Group (SIG)
"Eco-Efficient and Circular Industrial Systems"

Three Archetypes of Circular Manufacturing Practices

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Full paper

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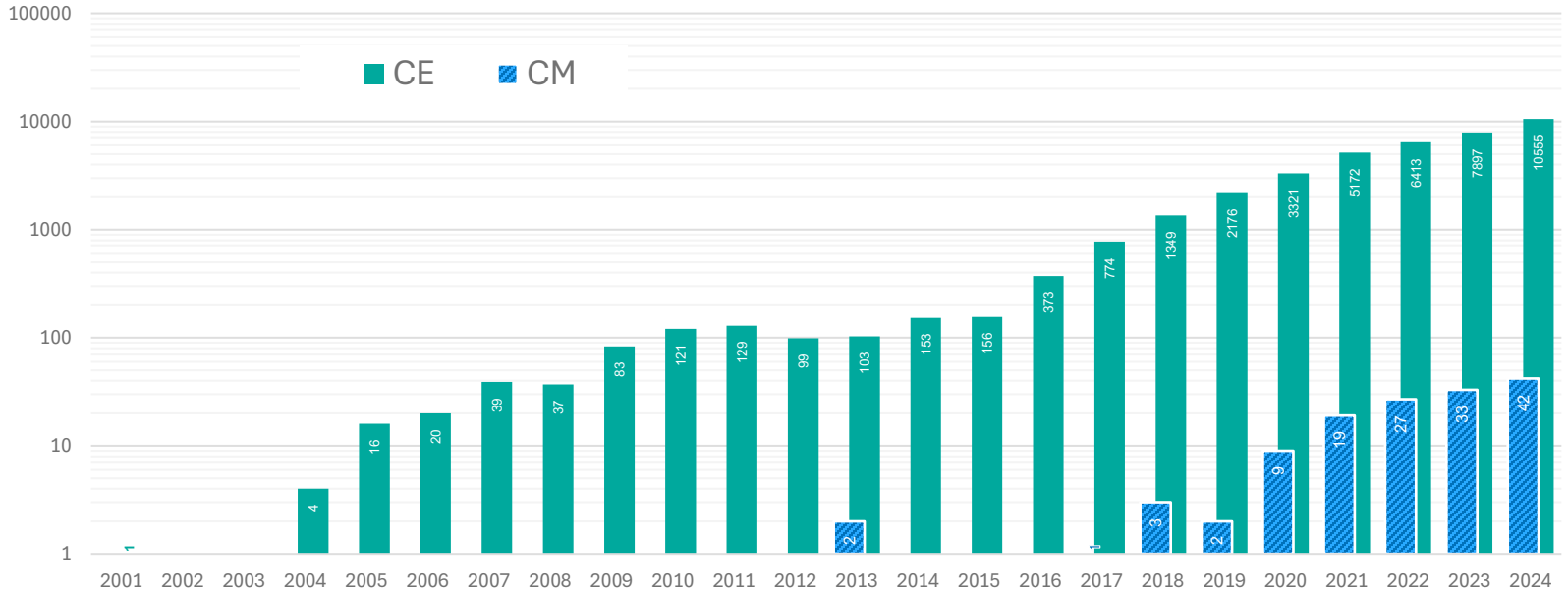
Circular manufacturing

Circular Manufacturing (CM) is defined as the implementation **circular strategies** in manufacturers' internal and external activities enabling **resource efficiency, resource life cycle extension, and closed resource loops** while meeting stakeholders' needs.

Definition adapted from Acerbi & Taisch 2020. A literature review on circular economy adoption in the manufacturing sector. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2020.123086

Evolution of the literature



Searching "circular economy" (CE) and "circular manufacturing" (CM) in title, abstract and keywords in Scopus

➡ Search results: N_{CE} = 41,427 documents; N_{CM} = 151 documents

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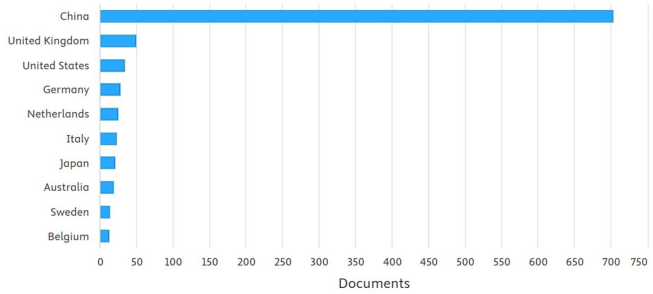
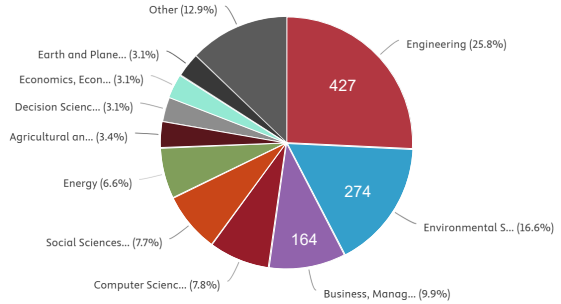
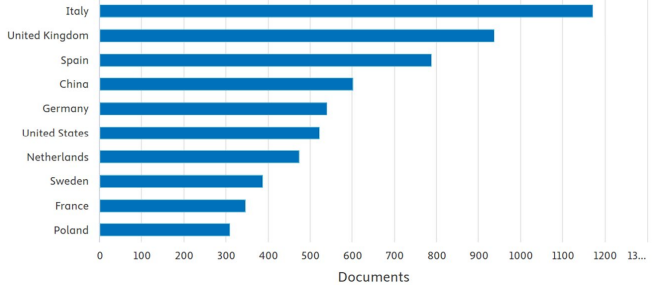
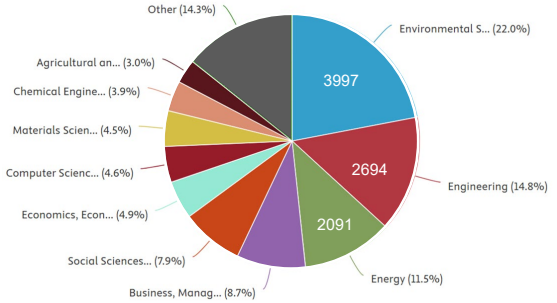
2001-2015 (N=961)



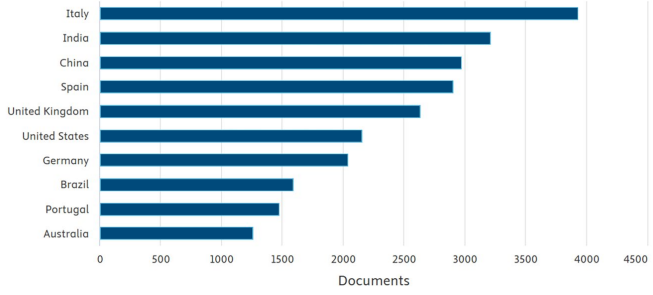


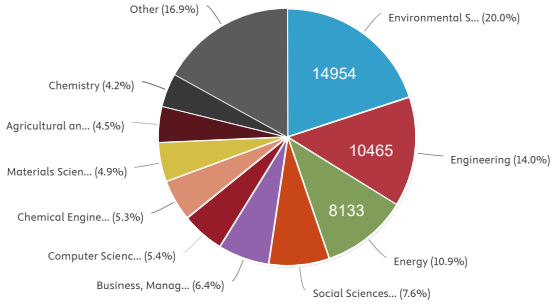
2016-2020 (N=7,993)





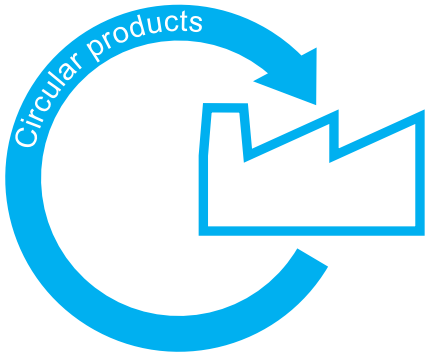
2021-today (N=32,573)

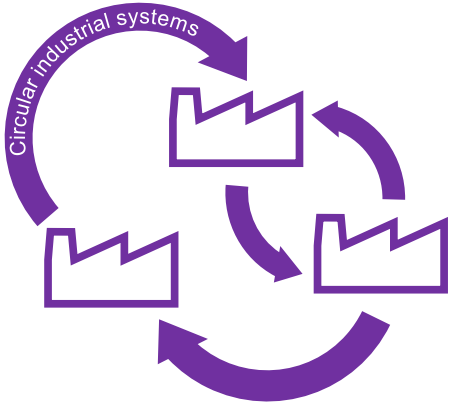




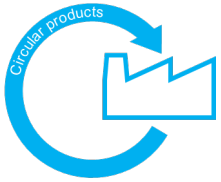
Three archetypes

Circular products	Circular processes	Circular industrial systems
Case A1: Eco-innovative product structure and dematerialisation (MyKirei)	Case B1: Durable and remanufactured high-performance equipment (DMG Mori)	Case C1: Modular circular products and service-based business model (Interface)
Case A2: Affordable circular products (IKEA)	Case B2: Resource-efficient and fault-free processes (Kaeser)	Case C2: Responsible material consumption (Nespresso)
Case A3: Reuse, remanufacture and recycle by design (Ricoh)	Case B3: Recirculation of materials within processes (DyeCoo)	Case C3: Industrial symbiosis (Kalundborg Symbiosis)



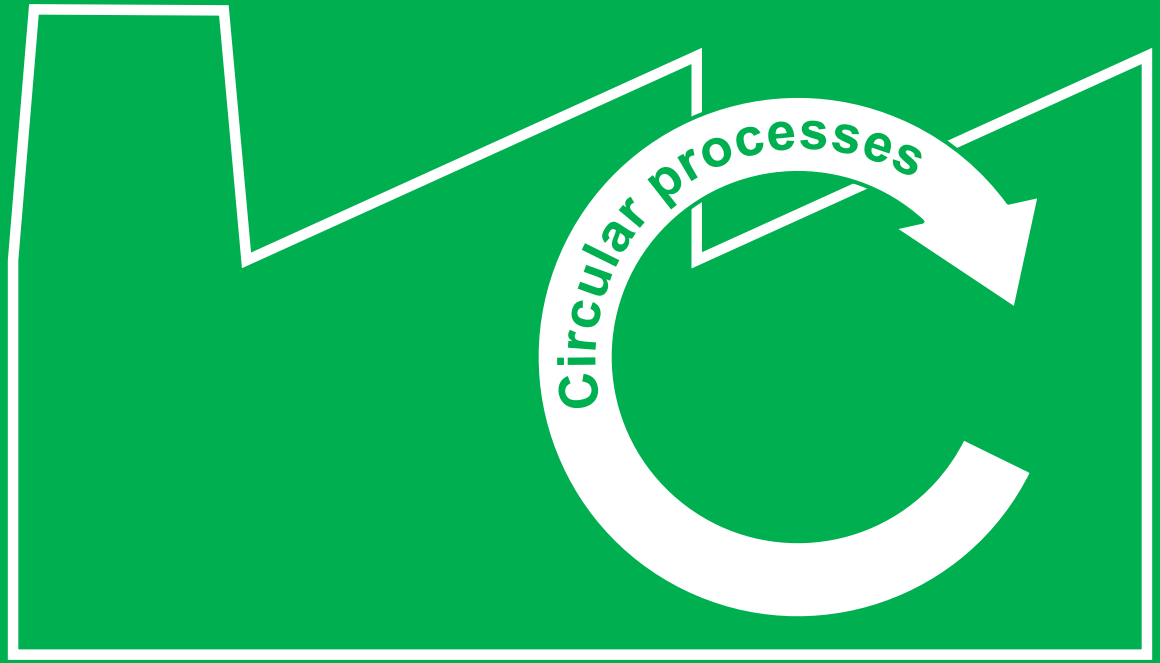



Circular products



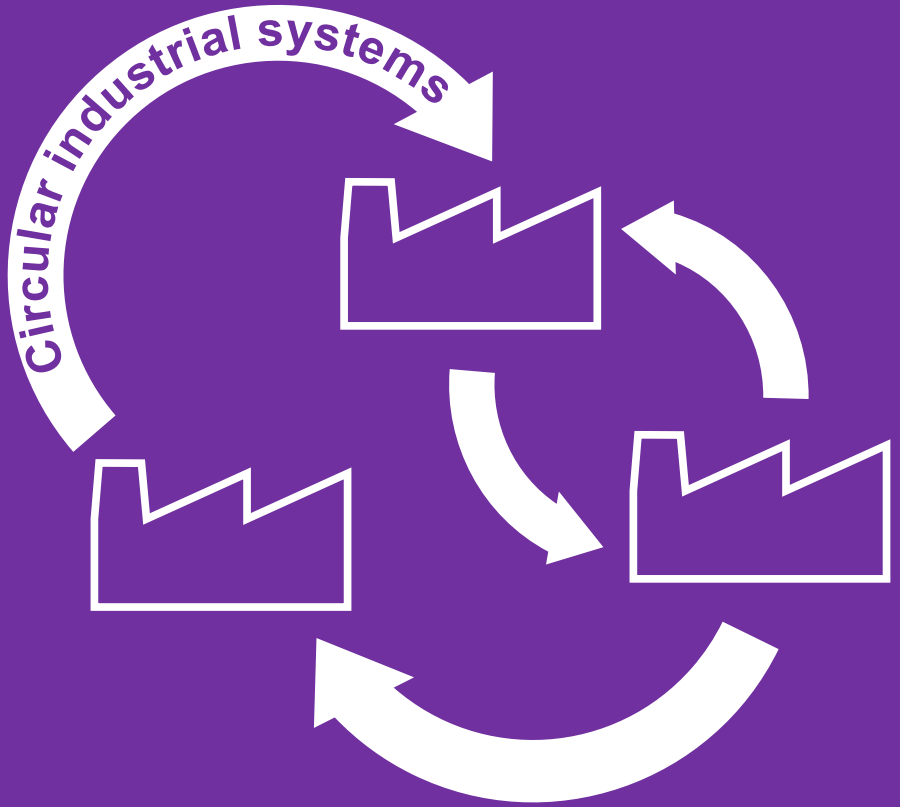
Manufacturing circular products

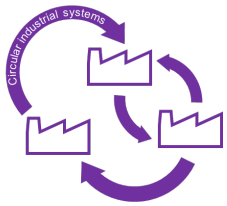
Case	A1: MyKirei by Kao	A2: IKEA	A3: Ricoh printers
Material and energy intensity	Dematerialization: lightweight air-fill bottle to reduce plastic by 50% Reduce water and energy use with concentrated formula	Flat-pack designs reduce material waste More compact products to reduce emissions in logistics	Reduce virgin material consumption by reusing parts from old devices Waste toner reuse system ensures unused toner is recovered and put back into machines Reuse 80-90% of machine parts in remanufacturing, lowering both material and energy demand
Toxicity and renewable sources	Plant-based formulas reduce environmental impact	Non-toxic and bio-based materials, waste treatment with minimal environmental impacts Sourcing from FSC-certified wood and recycled materials Investment in renewable energy (wind & solar)	
Recovery and recycling	Recyclable material	Designs for disassembly and recyclability Wood scraps and offcuts reused for new products	Fewer material types to ease separation and recycling Reduce landfill waste by up to 95% through multi-stage reuse and recycling
Durability		Modular furniture concept to extend product life	Offer remanufacturing and refurbishing programs for office equipment
Service intensity	Efficiency in use: bottle designed to reduce leftover product waste	Buy-back and refurbishment programs (Circular Hubs) Encourage customers to return used furniture, repair, resale, and second-life furniture usage	Provide take-back programs for used devices Engage corporate clients to adopt sustainable office solutions


Circular processes

Circular processes

Case	B1: DMG Mori	B2: Kaeser	B3: DyeCoo
Material and energy intensity (+toxicity)	Provide service to support shop floor digitalization for stable machine operation and high productivity	Provide energy-efficient air compressors Suggest an optimal system configuration to reduce the electricity cost	Energy-efficient, water- and chemical free process, hence requiring no wastewater treatment
Recovery and recycling			Recirculation and reuse of supercritical fluid and dyes
Product longevity and durability	Preventive maintenance to prevent machine breakdowns Reconditioning machine and components through retrofit and overhaul	Preventive maintenance including condition-based maintenance based on real-time monitoring of compressors, preventing machine breakdowns	Colour fastness for long-lasting aesthetic properties
Service intensity	Product sales with a 3-year machine insurance to cover repair costs (product-oriented PSS), 2-year warranty + 1-year machine insurance In-person diagnostic service provided by skilled engineers once a year for 3 years Note that some of the service provided for newly purchased machines installed in Japan only	Pay per cubic meter of compressed air (result-oriented PSS) The company's international logistics and service network supply spare parts to reduce downtime	


Circular industrial systems



Industrial systems

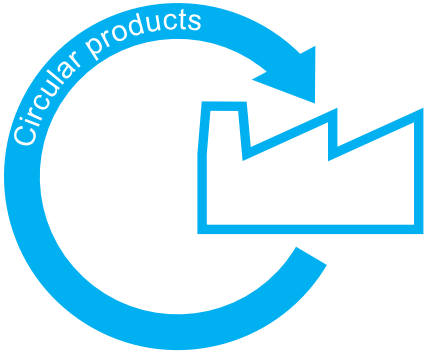
Case	C1: Interface	C2: Nespresso	C3: Kalundborg Symbiosis
Material and energy intensity at a system level (supply chains and value networks)	Collaborate with raw material producers to reduce their product's carbon footprint Continuous improvement for reduced material, energy and water consumption in production	Nespresso funded Programme AAA Sustainability Quality Program™ together with Rainforest Alliance to ensure responsible use of resources	Share surpluses of energy, water and materials (usually industrial waste) with other network actors to reduce total consumption of resources
Toxicity and renewable sources	Products made from over 50% recycled and bio-based materials 100% renewable electricity, 61% renewable thermal energy in production Incorporate ocean plastics as valuable material in fibre production	Shift to bio-based, compostable capsules (to replace aluminium) Promote regenerative agricultural practices in coffee farms	Encourage and mobilize investments in decentralized renewable energy production Heat pumps powered by renewable energy sources Careful treatment of all effluents to extract value and ensure safe disposal
Recovery and recycling	Collect post-consumer carpet for reuse, recycling and recovery	Stimulate customers to bring back used capsules to recycle aluminium and reuse used coffee as fertilizer	Collocated industrial companies from different sectors collaborate to share resources so that what would normally be waste for one company becomes value to another
Service intensity	Close operations with vendors and customers to increase accessibility to circular offerings through their business models based on longevity, renewability, reuse, repair, upgrade, refurbish, capacity sharing and dematerialization	Leasing of coffee machines for the period of usage Defective machine brought back to be refurbished and remanufactured (as needed), then resold at the same level of quality as new ones	

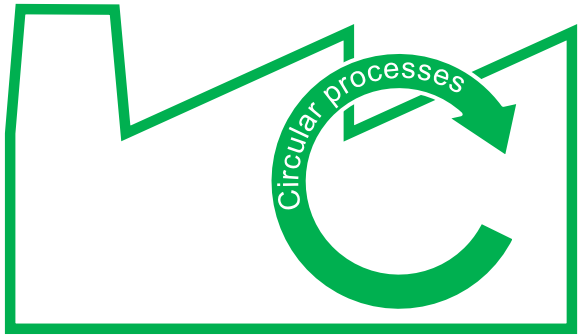
Mapping the examples

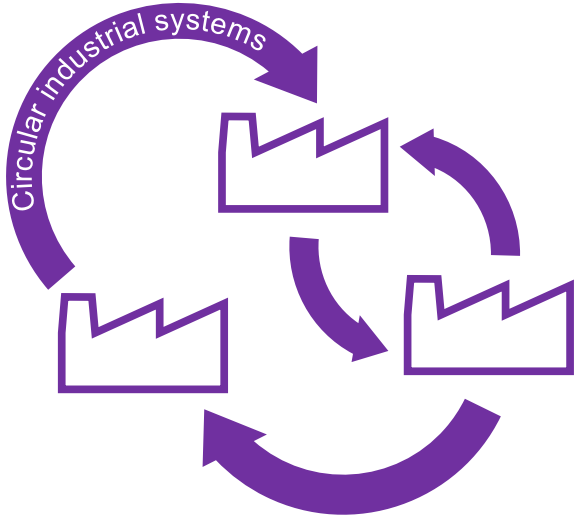
	Design strategies	Design for reduce	Design for durability	Design for sharing and reuse	Design for reman, refub, repair	Design for recycling and recovery	Design for disposal (safe emissions)
	Approaches/principles						
Material	Dematerialisation	A1, B1-2-3, C1					A1, B3
	Durable material		A3, B1-2-3, C1	A2-3, B1-2, C3			
	Recyclable material					A1-2-3, B3, C1-2-3	A1, B3, C1-2-3
	Recycled material	A3				A2-3, B3, C1-2-3	
	Material unification		A3		A2-3, B1-2, C1-2		A1, C3
	Non-hazardeous material						A1, B3, C1
	Bio-based and renewable material						A1, B3, C1-3
	Waste reduction	A1-2-3, B3, C2-3					
	Waste valorisation			A2-3, B1-2, C3	A2-3, B1-2, C1-2	A2, B3, C1-2-3	A2, B3, C3
Energy	Energy efficiency and optimization	A3, B1-2-3, C1-3					
	Waste energy recovery	B3, C3				B3, C3	
	Renewable energy source						A2, C1-3
	Low-carbon / carbon-neutral energy source						C1-3
	Carbon offsetting						B3, C2-3
Structure	Durable component		A3, B1-2-3, C1	A3, B1-2	A3, B1-2, C1-2		
	Remanufactured component		A3, B1-2, C1	A2-3, B1-2, C1	A2-3, B1-2, C1-2		
	Enhanced disassemblability			A1-2-3	A2-3	A1-2-3	
	Enhanced accessibility			A2-3, B1-2, C1	A2-3, B1-2, C1	A2-3, C1	
	Modularity and upgradability		A3, B1-2, C1	A2-3, B1-2, C1	A2-3, B1-2, C1-2		
ICT	Process or product monitoring	A3, B1-2-3, C3	A3, B1-2	A3, B1-2, C3	A3, B1-2	A3, C3	A3, B3, C3
	Diagnosis, repair and maintenance		A3, B1-2	B1-2	A3, B1-2		

Closing remarks

- CM is a multifaceted concept
- Proposed three archetypes of the role of manufacturing in a CE
- Towards a unified conceptualization to accelerate CM adoption







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