ICoR

international conference on **remanufacturing**

8-10 April 2025

International Conference on Remanufacturing

ICoR 2025

Amsterdam, Netherlands
April 8-10 2025

Conference Chair:

Prof Winifred Ijomah, University of Strathclyde, Scotland

Conference Organisers:

Prof Erik Sundin, Linköping University, Sweden

Dr Yan Wang, University of Brighton, UK

Prof James Windmill, University of Strathclyde, Scotland

The organisers would also like to thank all the members of the Sustainability & Remanufacturing Group at Strathclyde for their help and support.

Conference Sponsors

ReMaTec

Conference Information

Special features:

- Access to the ReMaTec remanufacturing show bringing together everyone working in the automotive and aftermarket for a series of formal and informal networking activities
- Prize giving: Best presentation and Best paper

Networking:

- Reman Industry Reception at Rematec on the evening of the 8th April
- Buffet event on the evening of the 9th April
- Lunch and coffee breaks each day
- ReMaTec trade show floor access

Notes:

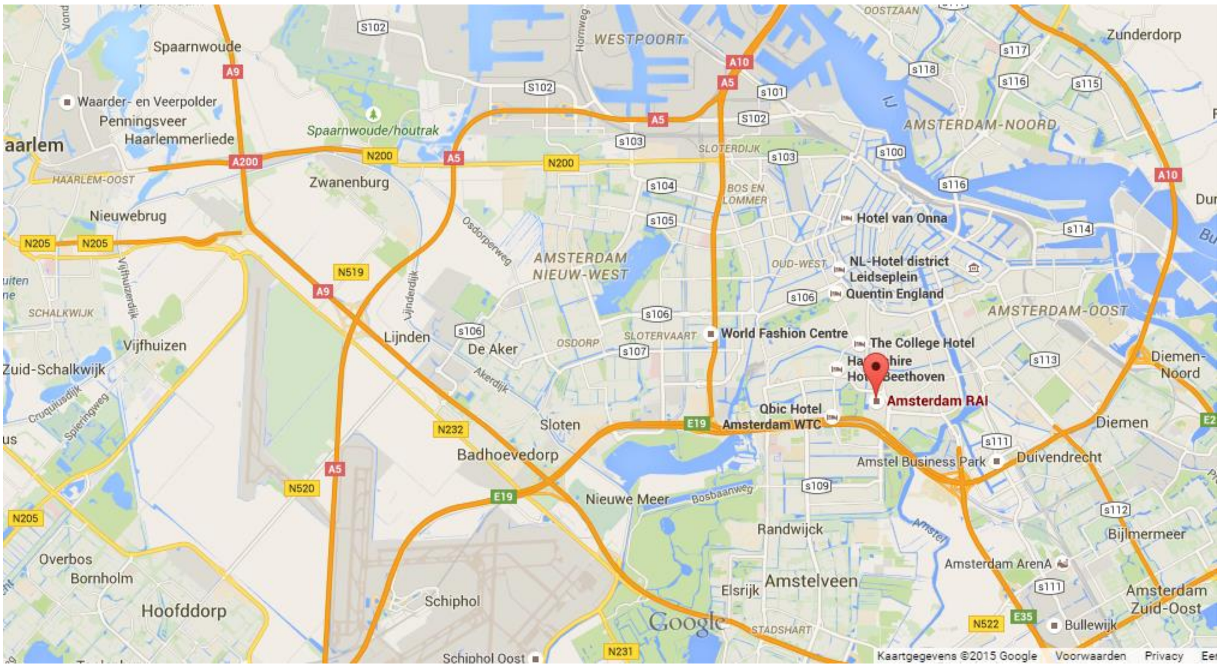
Accommodation can be booked via the conference website.

For further information:

Email: icor2025-conf@strath.ac.uk
Web: www.remanufacturing-conference.com

Conference Site

Amsterdam RAI
Europaplein
NL 1078 GZ
Amsterdam



RAI Entrance 'F'
ICoR 2025: E102, Ruby Lounge and surrounds

Invited Talks

Professor Surendra M. Gupta
Northeastern University, USA

Professor John W. Sutherland
Purdue University, USA

Michael Hague-Morgan
Autocraft Solutions Group, UK

Stefan Caba
EDAG Engineering GmbH, Germany

Dr Hagen Thielecke
Vanguard AG, Germany

Dominic Schultze
Herrenknecht AG, Germany

Siva Balakrishnan
GE HealthCare, USA

And a special welcoming statement from **Prof Dr -Ing Rolf Steinhilper**!

ICoR 2025 Conference Programme

Tuesday 8th April

09:30	**ICoR Registration**		
10:00	**ReMaTec SHOW OPENING CEREMONY**		
11:30	*Welcome*	**Prof Winifred Ijomah** University of Strathclyde	
11:40	*Opening*	**Prof Rolf Steinhilper**	
11.50	*Keynote*	**Siva Balakrishnan, General Manager (Lifecycle Solutions), GE HealthCare, USA** Circularity in GE HealthCare	
		Talk Session 1 – Developing Remanufacturing Markets I *Chair:* ***Yan Wang***	
12:20	*Talk*	**Remanufacturing in Ireland – building capacity for now and the future** Damian Coughlan	University of Limerick, Ireland
12:40	*Talk*	**An Investigation on Optimizing Sustainable Remanufacturing in Developing Countries: A Novel Application of Lean Six Sigma** Abdullahi Goni	University of Strathclyde, UK
13.00	**LUNCH**		
14:00	*Keynote*	**Dominic Schultze, Manager Components Rebuild & Warehouse, Herrenknecht AG, Germany** High quality rebuilds for ensuring resources and ecological efficiency in tunneling	
		Talk Session 2 – Consumer Perception *Chair:* ***Yan Wang***	
14:30	*Talk*	**The changing perception of aftermarket goods and sustainable terminology in UK students** Ross Amberger-Harris	University of Dundee, UK
14:50	*Talk*	**Statistical Analysis for Evaluating Consumer Decision-Making in the Context of New vs. Remanufactured Electronic Products** Murtadha Aldoukhi	Al Yamamah University, Kingdom of Saudi Arabia
15:10	**COFFEE**		
		Talk Session 3 – Remanufacturing Technologies I *Chair:* ***Andreas Reimer***	
15:30	*Talk*	**Robotic eyes-in-hand unscrewing using deep learning for binocular screw detection and geometric mapping** Anthonie Coopman	KU Leuven, Belgium
15:50	*Talk*	**Applying additive manufacturing technology to remanufacture a wind turbine pinion shaft** Ashfaq Mohammad	National Manufacturing Institute of Scotland, UK
16:10	*Talk*	**An Experimental Robotic Cell for the Disassembly of Electric Vehicle Battery Modules** Anselmo Parnada	University of Birmingham, UK
16:30	*Talk*	**Referencing of Moving Assembly Components** Florian Schmutzler	Fraunhofer Institute for Machine Tools and Forming Technology IWU, Germany
16:50	*Talk*	**Pathways to Circular Energy Storage: A Comparative Analysis of End of Life Recovery Approaches in Flow Batteries Technologies** John Agbonrofo	University of Strathclyde, UK
18:00	**REMAN INDUSTRY RECEPTION – ReMaTec**		

Wednesday 9th April

08:40	**COFFEE & DANISH**		
09:00	*Keynote*	**Prof Surendra M. Gupta, Professor Emeritus, Northeastern University, USA** Reverse Supply Chains, Disassembly and Remanufacturing Research and Future Trends	

Talk Session 4 – Digital Product Passports
Chair: ***Paulina Golinska***

09:30	*Talk*	**Enabling Remanufacturing with Digital Product Passports: The ReMake Remanufacturing Data Model and Open-Source Toolkit** Syed Awais Hassan Munawar	National Manufacturing Institute of Scotland, UK
09:50	*Talk*	**Approach for Data-Driven Battery Disassembly: Leveraging Digital Product Passports and Sensor Technologies for Re-X Strategies** Lars Schaupeter	Trier University of Applied Sciences, Germany
10:10		**COFFEE**	
10:30	***Keynote***	**Dr Hagen Thielecke, Vanguard AG, Germany** Medical Remanufacturing: Opportunities, Regulatory Requirements and Challenges in Research and Development	

Talk Session 5 – Circular Systems
Chair: ***Okechukwu Okorie***

11:00	*Talk*	**Revaluing Re-manufacturing. A systems thinking approach to enhancing the value of remanufacturing for the circular economy** Carl Waring	University of Derby, UK
11:20	*Talk*	**Framework for a Worker Assistance System to Enable Circular Economy Processes** Junjie Liang	RWTH Aachen University, Germany
11:40	*Talk*	**Choosing remanufactured products in a Business-to-Customer (B2C) Market** Jelena Kurilova-Palisaitiene	Linköping University, Sweden
12:00	*Talk*	**Model for practitioners' capacity building for remanufacturing in product-as-a-service (PaaS)** Paulina Golinska-Dawson	Poznan University of Technology, Poland
12:20		**LUNCH**	
13:20	*Keynote*	**Michael Hague-Morgan, Executive Director, Autocraft Solutions Group, UK** Why We Need to Remanufacture EV Batteries, and Not Prematurely Recycle Them!	

Talk Session 6 – Remanufacturing Optimisation I
Chair: ***Jelena Kurilova-Palisaitiene***

13:50	*Talk*	**Defining Key Characteristics of Manufacturing Strategies for Remanufacturing: A Systematic Literature Review in the Circular Economy Context** Chamirangika Hetti-Arachchige	Chalmers University of Technology, Sweden
14:10	*Talk*	**How best to assess the environmental impacts of product design, does Life Cycle Assessment (LCA) really provide the answer?** Fiona Gutteridge	University of Strathclyde, UK
14:30	*Talk*	**Lighting Remanufacturing, overview of the process and specific case studies** Benedetta Zarpellon	Società Italiana Remanufacturing, Italy
14:50	*Talk*	**Pathway to Circularity through Remanufacturing: A Study on Waste Reduction by Construction Machinery Remanufacturing Business** Elvis Kumar	Hitachi Construction Machinery Co Ltd, Japan
15:10		**COFFEE**	

Talk Session 7 – Decision Making
Chair: ***Erik Sundin***

15:30	*Talk*	**Triage for Circular Economy: Techniques for Optimising End-of-Life Decision-Making** Gustav Jonsson	University of Birmingham, UK
15:50	*Talk*	**Information management for remanufacturing industrialization – An outline of a conceptual model** Paraskeva Wlazlak	Jönköping University, Sweden
16:10	*Talk*	**Optimization of end-of-life decision-making** Moritz Hoffmann	Robert Bosch Automotive Steering GmbH, Germany
16:30	*Talk*	**A Methodology for Evaluating the Viability of Circular Strategies: Integrating Environmental Impact and Cost-Effectiveness Analysis** Myriam Soto-Gordoa	Mondragon Unibertsitatea, Spain

16:50	*Talk*	**Evaluating the relationship between sourcing policies and remanufacturing operations adoption rate: A simulation modelling approach** Okechukwua Okorie	University of Manchester, UK
17:10	*Talk*	**Exploring the Factors Affecting Purchase of Remanufactured Products using a Multi-Criteria Decision Making Model** Aditi Joshi	FLAME University, Pune, India
17:45		**ICoR BUFFET DINNER**	

Thursday 10th April

08:50		**COFFEE & DANISH**	
	Talk Session 8 – Remanufacturing Technologies II *Chair:* ***Myriam Soto-Gordoa***		
09:10	*Talk*	**Semantic 3D Product Modeling for Automated Inspection in Remanufacturing Processes** Jan-Philipp Kaiser	Karlsruher Institut für Technologie, Germany
09:30	*Talk*	**Data Management System for Robotic Demanufacturing: a case study for Hard Disk Drives (HDDs)** Hao Qin	KU Leuven, Belgium
09:50	*Talk*	**Enabling circular economy R-strategies through human-centric smart and flexible automation** Kristina Eriksson	University West, Sweden
10:10	*Talk*	**How to design production systems for circular economy – applying the modular Aachen factory planning approach to a white goods manufacturer** Niklas Schäfer	RWTH Aachen University, Germany
10:30		**COFFEE**	
10:50	*Keynote*	**Stefan Caba, EDAG Engineering GmbH, Germany** Circular Vehicle Design – A prerequisite for Remanufacturing	
	Talk Session 9 – Developing Remanufacturing Markets II *Chair:* ***Kristina Eriksson***		
11:20	*Talk*	**Navigating the Remanufacturing Trilemma: Balancing Customer, Manufacturer, and Lawmaker Interests** Lisa Reintanz	University of Kassel, Germany
11:40	*Talk*	**Understanding consumer acceptance and preferences through environmental knowledge to optimize remanufacturing end-of-life strategy: Theory development and case study** Okechukwua Okorie	University of Manchester, UK
12:00	*Talk*	**Challenges and Opportunities to adopt Remanufacturing by Original Equipment Manufacturers** Jelena Kurilova-Palisaitiene	Linköping University, Sweden
12:20		**LUNCH**	
13:20	***Keynote***	**Prof John W. Sutherland, Purdue University, USA** Environmental Sustainability and Circularity via Value Retention Strategies: Past, Present, and Future	
	Talk Session 10 – Reverse Logistics *Chair:* ***Okechukwu Okorie***		
13:50	*Talk*	**The importance of reverse logistics strategy to the remanufacturing in (independent) small and medium businesses: A Review** Etimbuk Bassey	University of Strathclyde, UK
14:10	*Talk*	**Circular Strategies for IT Devices in Southeast Asia: Addressing Barriers to Used Mobile Phone Collection in Cambodia** Erik Sundin	Linköping University, Sweden
14:50	*Talk*	**Optimization of a Sustainable Transportation System for A Bottled Water Firm in the Kingdom of Saudi Arabia** Murtadha Aldoukhi	Al Yamamah University, Kingdom of Saudi Arabia
15:10		**COFFEE**	
15:30	*Journal*	**Prof Erik Sundin** Editor-in-Chief, Journal of Remanufacturing	
16:00		**ICoR CLOSING CEREMONY**	

Invited Talk Abstracts & Speaker Biographies

Circularity in GE HealthCare

Siva Balakrishnan
General Manager (Lifecycle Solutions), GE HealthCare, USA

The talk will discuss global population dynamics, the need for health equity around the world, and for expanded healthcare solutions. It will provide an overview of what GE HealthCare does and what remanufacturing they do in GE HealthCare.

Siva Balakrishnan has approximately 30 years of experience spanning multiple industries including construction and industrial equipment. During his career, he has led remanufacturing and lifecycle operations for a wide variety of products including industrial cranes, mobile cranes, Utility trucks, aerial work platforms, industrial compressors, industrial blowers and trailers over and above his current area of expertise in healthcare equipment. In addition to extensive operational experience in product and part circularity, Siva's career also spans multiple functional areas including internal audit, Lean, and Six Sigma. Siva is extremely passionate about driving inclusiveness in organizations and has been involved in inclusiveness efforts over the last ~20 years. He continues to champion these efforts within GE HealthCare.

GE HealthCare Technologies, Inc is an American multinational medical technology company spun-off from General Electric. The company is committed to people and planet and aims to enable earlier, better, and faster diagnosis and treatment for more people in need, while reducing or eliminating their impact on the environment. This group drives product and parts circularity initiatives, supporting sustainability within GE HealthCare including solutions for parts repair and harvesting and equipment remanufacturing and refurbishment. The group also drives one stop shopping options for its customers worldwide with availability of accessories and locally sourced items for usage with GE HealthCare products. The GE HealthCare industry keynote will be presented by Siva Balakrishnan the General Manager for Lifecycle Solutions in Global Services which includes the GE GoldSeal Programs (Remanufacturing and Refurbishment) as well as Repair and Harvesting of parts and subassemblies.

Circular Vehicle Design – A prerequisite for Remanufacturing

Stefan Caba
Head of Innovation Field Sustainable Vehicle Development, EDAG Engineering GmbH, Germany

The new End-of-Life Vehicle Directive by the European Union is still under elaboration, but already today it becomes clear that circular economy in all possible ways will become a mandatory part of vehicle manufacturing business. This generates novel business models, but in particular the way vehicles are designed and manufactured will be influenced towards more sustainable options. Remanufacturing is established in particular for parts concerning the drivetrain. The changes in regulation on the one hand and the stronger identification with sustainability on the other hand will lead to increased demand for circular solutions also for other parts of the vehicle. This creates chances for novel approaches of vehicle design that is dedicated to remanufacturing and adherent business models. In different projects approaches for vehicle concepts including circular economy thinking were elaborated. General findings showed that long-term use of components in combination with detachable joints deliver solutions that show lower carbon footprints and suitable business cases for remanufacturing. The combination with other circular businesses like car sharing creates a friendly environment to achieve marketability. Materials that enable long-term use are mandatory. Here, lightweight design using carbon fiber reinforced plastics is a viable option, since it shows excellent durability. The keynote will present the basic requirements for improved vehicle design for circular economy and remanufacturing. It will highlight benefits and discuss shortcomings based on vehicle concepts. Economic and ecologic aspects will be covered and possible pathways for future circular vehicles demonstrated.

Stefan Caba has worked in composites for more than 15 years. In 2017 he completed his PhD working on void reduction in Resin Transfer Molding. Since then he has been part of the EDAG Innovation Department. His main area of work is the circular economy and sustainable solutions in the automotive industry with a focus on composite concepts for circular design.

The EDAG Group is a globally leading, independent engineering service provider that providing excellent engineering with the latest technology. With a global network of some 60 branches, the EDAG Group realizes projects in the Vehicle Engineering, Electrics/Electronics and Production Solutions segments. EDAGs proprietary 360-degreee development approaches has become a hallmark of quality in the holistic development of vehicles and smart factories.

Reverse Supply Chains, Disassembly and Remanufacturing Research and Future Trends

Professor Surendra M. Gupta
Northeastern University, USA

Human beings would like to maintain the existing and future economic prosperity, environmental protection and lifestyle. This requires the need to embrace sustainability which is the ability to continue the modern activities forever. Consequently, a push for reduction and elimination of waste as well as preservation of resources, which are the goals of lean manufacturing and product recovery through reverse supply chain, is warranted. Reverse supply chain consists of a series of activities required to collect used products from consumers and process them to either recover their leftover market values or dispose of them. Remanufacturing is an important constituent of reverse supply chains. The increase in popularity and implementation of remanufacturing have created many challenges including uncertainties in the quality and quantities of returned products, difficulties in estimating the remaining lives of the components, unspecified timings of the availability of end-of-life (EOL) products, balancing the remanufacturing line, pricing decisions, warranty cost estimation and potential for committing fraud by third party and customers, just to mention a few. This presentation will offer an overview of the various modeling techniques used by researchers to address the above-mentioned challenges as well as opportunities for future research.

Surendra M. Gupta, Ph.D., P.E., is Professor Emeritus of Mechanical and Industrial Engineering at Northeastern University in Boston, Massachusetts, USA. He received his BE (Honors) in Electronics Engineering from Birla Institute of Technology and Science, MBA (Honors) from Bryant University, and MSIE and Ph.D. in Industrial Engineering from Purdue University. He is a registered professional engineer in the State of Massachusetts, USA. Dr. Gupta's research interests span the areas of Production/Manufacturing Systems and Operations Research. He is mostly interested in Environmentally Conscious Manufacturing, Reverse and Closed-Loop Supply Chains, Disassembly Modeling and Remanufacturing. He has authored or coauthored thirteen books and well over 700 technical papers published in edited books, journals and international conference proceedings. His publications have received over 20,000 citations (with an h-index of 73) from researchers all over the world in journals, proceedings, books, and dissertations. He has traveled to all seven continents viz., Africa, Antarctica, Asia, Australia, Europe, North America and South America and presented his work at international conferences on six continents. In addition, he has delivered over 35 plenary/keynote speeches in international conferences in several countries including Spain, The Netherlands, Denmark, France, Japan, Korea, Thailand, India, Taiwan, China, Saudi Arabia and Turkey. He has supervised 35 PhD's dissertations and over 70 Master's Thesis and Projects. Dr. Gupta has served as editor, associate editor and editorial board member of dozens of international journals. Among the many accolades received, he is Listed in the Stanford's List of World's Top 2% Scientists; Distinguished Professor Award from the Industrial Engineering and Operations Management Society International; Best Dissertation Advisor Award from the American Society for Engineering Management; Outstanding Research Award, Outstanding Industrial Engineering Professor Award and Multiple Major Works Awards from Northeastern University; and Outstanding Author Contribution Award from Emerald Publishing.

Why We Need to Remanufacture EV Batteries, and Not Prematurely Recycle Them!

Michael Hague-Morgan
Executive Director, Autocraft Solutions Group, UK

When asked about the major reservations consumers have in switching to EV ownership, most state range anxiety and charging infrastructure as the main factors, closely followed by the cost of battery replacement and the risk of the battery pack failing out of warranty. In the mature ICE market, replacement engines are easy to come by for many years after vehicle manufacture, and vehicle owners can make a cost vs risk based decision whether to replace with new, fully remanufactured, refurbished or used.

With EV battery failure rates during ownership of up to 2.5% the reality of battery pack failures out-of-warranty is leading to consumers avoiding the move to EV ownership, particularly in the used market which has seen a move to very low residuals for used EVs and very high cost of ownership after the first 3 years of its life. This is primarily driven by the lack of availability of replacement battery packs for used vehicles, and unknown State-of-Health of the battery pack which often forms more than 50% of the value of the vehicle. When battery packs fail within the first few years of the vehicle's life, some VMs are rushing to recycle packs to meet recycling targets rather than repair or remanufacture, to keep the battery pack in vehicular use.

Premature recycling of failed or accident damaged packs not only creates and environmental and economic headache, but once the cells and modules are gone, they're gone.

Mike Hague-Morgan will explain how Autocraft Solutions Group is helping to close the confidence gap surrounding EV ownership with its OptEVizer® world-leading state-of-health testing, giving real and accurate diagnostics and future performance prediction down to cell level. This unlocks the value and potential of failed packs, and in its REVIVE® Battery Workshop facilities, Autocraft are remanufacturing thousands of battery packs for use back in EVs, meaning no pack ever need be prematurely recycled. And with each remanufactured battery pack from Autocraft saving between 5 and 12 tonnes of CO2 compared with fitting with new, the industry cannot afford not to!

Michael Hague-Morgan is co-owner and majority shareholder of Autocraft Solutions Group. With his strong track record in turning companies around, Mike was appointed Commercial and Engineering Director of US-owned Autocraft Industries in 2008, with a brief to turn the loss-making company into profit. Seeing the potential of this very unique company, Mike led the MBO of the company in 2010 and the company was re-born as Autocraft Drivetrain Solutions. Under Mike's and his senior leadership team's direction, Autocraft Solutions Group was formed following the purchases of Vertex Engineering Solutions in 2015 and Autocraft Machining Solutions in 2018. Since the MBO, the company has grown from £6m to £60m+ turnover, and from 98 to over 430 employees. It has diversified into EV battery repair and remanufacture, and provides a fully outsourced IC engine assembly solution for OEMs moving to EV.

Mike has a BEng in Mechanical Engineering and prior to entry into the remanufacturing arena had a successful career in the conventional manufacturing automotive sector. Mike is a passionate believer in B2B partnerships with a win-win philosophy and champions the use of new technology in manufacturing businesses. Mike is a Vice President of the SMMT, Chair of their Automotive

Components Section (ACS), former Vice Chair of the East Midlands Regional Advisory Board for Make UK, and a former Manufacturing Board Member of the Greater Lincolnshire LEP. He regularly supports Innovate UK and KTN Workshops to promote engineering and manufacturing in the UK.

High quality rebuilds for ensuring resources and ecological efficiency in tunnelling

Dominic Schultze
Manager Components Rebuild and Warehouse, Herrenknecht AG, Germany

The talk will provide a short introduction on the topic “What is a TBM” and how Herrenknecht creates the circular economy for TBM-Components. It will discuss what does Herrenknecht understand behind the heading REBUILD and why we have a separate plant for these activities. Carbon footprint is becoming more and more important, and Herrenknecht has a unique selling point here.

Dominic Schultze graduated from the University Offenburg - University of Applied Sciences with a Bachelor of Engineering, then joined Herrenknecht AG, Schwanau, Germany as a Project Engineer / Manager for Tunnel Boring Machines. In 2013 he moved to become Technical Support Engineer at Herrenknecht Rebuild Services in Kehl, Germany, then in 2022 started his current position as Manager Components Rebuild and Warehouse at Herrenknecht Rebuild Services.

Herrenknecht AG is a German company that manufactures tunnel boring machines, headquartered in Allmannsweier, Schwanau, Baden-Württemberg. It is the worldwide market leader for heavy tunnel boring machines. Roughly two-thirds of its 5,000 employees work at the company's headquarters in the installation of hydraulic and electronic components and final inspection. Approximately 300 work at three locations across China. The company has 82 subsidiaries around the world and has worked on 2,600 projects. As the leading premium supplier of comprehensive technical solutions in mechanized tunnelling, Herrenknecht is the first port of call for underground infrastructure projects around the world. Dominic Schultze, Technical Support Engineer will provide an overview of Herrenknecht AG remanufacturing activity.

Professor Dr -Ing Rolf Steinhilper

Prof Rolf Steinhilper graduated as a mechanical engineer specializing in Factory Management and Automotive Technology at the University of Stuttgart, Germany in 1978. He then worked as a Fraunhofer R&D Manager on innovation projects dealing with Manufacturing, Remanufacturing, Recycling and EcoDesign for major industrial clients in Europe, USA and Canada, Japan, China and Taiwan in the past 40 years. In 1990, Rolf belonged also to the founding members of the APRA European Division. In 2001 he was appointed full professor for Manufacturing and Remanufacturing Technology at the University of Bayreuth, Germany. Since 2006 he was also responsible for the Fraunhofer Project Group "Process innovation" there, where he started and orchestrated the European Remanufacturing Technology Center from 2001 until 2018, when he retired from his academic positions at the age of 66 years. His team consisted of more than 45 specialized scientists and engineers who gave significant innovation support to the remanufacturing industry worldwide. He has written 15 books among them a Bestseller entitled "Remanufacturing", which has been published in seven World languages, also Japanese, Chinese, Korean. In 2016, Rolf Steinhilper won the "Remanufacturer of the year" award as the first academician among the so far industry management award winners.

Environmental Sustainability and Circularity via Value Retention Strategies: Past, Present, and Future

John W. Sutherland, Ph.D.
Professor and Fehsenfeld Family Head
Environmental and Ecological Engineering
Purdue University, USA

Over the last decade there has been growing interest in the circular economy (CE) paradigm, with many believing it is a key to achieving environmental sustainability. The CE paradigm calls for abandoning the “take-make-use-dispose” approach in favor of closing product/material loops, e.g., reusing, remanufacturing, and recycling. While the concept of circularizing material loops is not new to those familiar with remanufacturing, its espousal by corporate executives and policymakers is a more recent development. This presentation will review the origins of environmental engineering and industrial ecology, and how that has led to advances in the environmental analysis of industrial systems. The life cycle benefits of remanufacturing and recycling will be discussed as will the economic and environmental challenges of circularization. Specific examples will be discussed including i) projections of critical material demands for clean energy technologies and potentially recoverable resources from end-of-life products, ii) life cycle and techno-economic assessment applications, iii) life cycle symbiosis, and iv) recent efforts to develop circularity indicators. Promising research directions for the future will be discussed.

Prof John W. Sutherland is a Professor and the Fehsenfeld Family Head of Environmental and Ecological Engineering (EEE) at Purdue University, USA. He has made pioneering research and education contributions to establish and advance the field of environmentally responsible design and manufacturing. He has served as an investigator on numerous externally funded projects, mentored over 100 students to the completion of their graduate degrees (including 34 Ph.D. students), and published nearly 450 papers in various journals and conference proceedings. His honors and recognitions include the SME Outstanding Young Manufacturing Engineer Award (1992), Presidential Early Career Award for Scientists and Engineers (1996), SAE Ralph R. Teetor Educational Award (1999), SME Education Award (2009), SAE International John Connor Environmental Award (2010), ASME William T. Ennor Manufacturing Technology Award (2013), SME Gold Medal (2018), AEESP Frederick George Pohland Medal (2022), and National Academy of Engineering member (2023), and AEESP Dist. Service Award (2024). He is a Fellow of SME, ASME, CIRP, and AAAS. He received his B.S., M.S., and Ph.D. degrees from the University of Illinois at Urbana-Champaign. Environmental and Ecological Engineering (EEE) at Purdue University has undergraduate and graduate degree programs and is one of the largest environmental engineering programs in the USA. EEE is unique in that it embraces industrial sustainability in addition to classic environmental engineering. For more info see the EEE homepage.

Medical Remanufacturing: Opportunities, Regulatory Requirements and Challenges in Research and Development

Dr Hagen Thielecke
Director R&D, Vanguard AG, Germany

The healthcare sector has an enormous impact on global warming and resource consumption. Medical remanufacturing as part of the circular economy enables hospitals to optimise their supply chains ecologically and economically, but also poses high challenges for process development and is highly regulated.

Medical remanufacturing is a practice that has been established for decades and enables the reuse of complex and expensive disposable medical devices. Reprocessing is strictly regulated in the Medical Device Regulation (EU) 2017/745 (MDR). Remanufacturing companies must generally comply with the same general safety and performance requirements as original manufacturers. For remanufactured products, this usually means that the products leave the remanufacturing process with a CE mark and are proven to be as safe and efficient as newly manufactured products. To make this possible, extensive preparatory work is required, which is carried out by the Research and Development department. Interdisciplinary teams ranging from engineers, biologists and chemists to specialists in clinical use are needed. The engineers specialise in particular in the fields of mechanics, electrical engineering, embedded systems, materials science and process engineering.

In contrast to most other industries, manufacturers of medical devices not only have to prove the safety and performance of their products, but also fulfil extensive regulatory requirements. Of course, this also applies to the remanufacturing of medical devices. Particular challenges in remanufacturing are material and product-friendly processes, especially for cleaning and sterilisation as well as for disassembly for cleaning. For example, many complex medical devices are made of thermolabile plastics. Only low-temperature processes and chemicals that are compatible with the plastics and do not have a negative impact on biocompatibility may be used for these plastics. When complex medical devices are placed on the market by manufacturers as so-called single-use devices, the manufacturers often do not co-operate with the re-manufacturers. In these cases, it is necessary to analyse the design, the material and the relevant product properties. Additionally, suitable procedures for recognising product changes must be developed. After an introduction to the topic, the presentation will first provide a regulatory categorisation of medical remanufacturing and then look at the development of remanufacturing processes. Finally, the presentation will look at life cycle assessment studies to analyse the environmental impact of medical remanufacturing.

Dr Hagen Thielecke is currently the Director of R&D at Vanguard AG since December 2010. Dr. Thielecke previously held significant positions, including Head of the Biohybrid Systems Department and Founder and Manager of the Interdisciplinary Cell-based Sensors & Biomonitoring Group at Fraunhofer IBMT from February 2002 to November 2010. Dr. Thielecke began as a Project Manager at Fraunhofer Gesellschaft from September 2000 to January 2002 and previously worked as an R&D Project Manager at QUEG Thermometerbau GmbH from October 1994 to August 1997. Academic qualifications include a Diplom-Ingenieur in Electrical Engineering and Electronics from Humboldt-Universität zu Berlin, a Doctorate in Engineering from Universität des Saarlandes, and a Master's in Engineering and Production Technology from Middlesex University.

Contributed Talk Abstracts

Pathways to Circular Energy Storage: A Comparative Analysis of End of Life Recovery Approaches in Flow Batteries Technologies

John Agbonrofo[1]*, Winifred Ijomah[1], Edward Brightman[2]

[1]Design, Manufacturing and Engineering Management, University of Strathclyde, Glasgow, United Kingdom
[2]Chemical and Process Engineering, University of Strathclyde, Glasgow, United Kingdom

The global energy trilemma; balancing energy security, environmental sustainability, and affordability necessitates scalable, efficient, and sustainable energy storage solutions. Flow batteries, characterized by decoupled power and energy ratings, long operational lifespans, and high scalability, are emerging as critical enablers for large-scale renewable energy integration. However, the environmental and economic sustainability of these systems hinges on effective End of Life (EoL) recovery strategies that minimize environmental impact and optimize resource utilization. Despite the significance of this issue, comparative analyses of EoL recovery pathways encompassing remanufacture, repair, repurposing, and recycling for flow batteries and their components remain limited.

This study addresses this gap by examining EoL recovery approaches for three key subsystems of flow batteries: cell stacks, electrolyte storage, and balance of plant systems. Focusing on major flow battery technologies, including Vanadium Redox Flow Batteries (VRFB), Zinc-Bromine Flow Batteries (ZBFB), and All-Iron Flow Batteries (IFB), the research evaluates recovery strategies against criteria such as material type, durability, upgradeability, and valuability. The findings offer a systematic categorization of components and their optimal EoL recovery pathways, providing actionable insights to enhance the lifecycle sustainability of flow battery technologies. This work aims to inform industry practices and policy frameworks, advancing the deployment of sustainable energy storage systems globally and contributing to potentially addressing the global energy trilemma.

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Optimization of a Sustainable Transportation System for A Bottled Water Firm in the Kingdom of Saudi Arabia

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Environmental considerations are a crucial component of sustainability. Consequently, numerous efforts have been made to embrace this responsibility, particularly through the concept of remanufacturing, which can significantly reduce carbon emissions associated with production. Optimizing the transportation system is also another critical area where can significantly reduce the carbon emission. This paper is framed to focus on optimizing logistical efficiency while minimizing environmental impact of carbon emission.

In recognition of competitive demands within a bottled water company and driven by ecological concerns, this study assesses the company's current transportation setup in terms of transportation cost and routing as well as emission efficiency. By employing a mathematical model based on the vehicle routing method, the model identifies the optimal alternative that can lower both total costs and carbon emissions by selecting the best path and trucks that will deliver the shipment to the demand's points.

Keywords: Sustainability, Carbon Emission, Transportation, Mathematical Model

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Statistical Analysis for Evaluating Consumer Decision-Making in the Context of New vs. Remanufactured Electronic Products

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Remanufactured products bring a very promising solution toward sustainability by significantly reducing the consumption of raw resource as well as promoting and supporting the principles of a circular economy. However, what drives the consumer toward buying and using these products is still questionable compared with new products. This paper employs statistical analysis to explore how variables such as price, quality, availability, and warranty influence consumer decisions when selecting between new and remanufactured products. Data were collected from consumers in the Kingdom of Saudi Arabia, a rapidly emerging market, with a particular focus on electronic products due to the anticipated differences in consumer preferences across product categories. The results will include, but not limited to, descriptive analysis, comparative analysis correlation analysis and any other relevant analysis.

Keywords: Statistical Analysis, Remanufactured Products, Electronic Products, Price

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The changing perception of aftermarket goods and sustainable terminology in UK students

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Remanufacturing as an industry sector has suffered from misconceptions and poor public perception for many years, with the often mistaken belief that all remanufactured and aftermarket products are inferior to newly manufactured OEM equivalents a prevalent factor. As UK culture and society has become increasingly aware of the value and need for sustainable thinking, this shift towards a more sustainable mindset has prompted more widespread exposure to the terminology and operations of the aftermarket sector. While the internal industry reputation and perception of aftermarket goods and processes has significantly improved in recent years, the general public's viewpoint remains an uncertain factor. To assess this an investigation was conducted within UK university campuses, involving surveys and discussions with the student body across multiple disciplines, before being followed up by interviews and questionnaires, with design students in particular, across multiple year groups. The results of this investigation presented varying perspectives and stances towards the student beliefs regarding the aftermarket and the inherent quality of the products produced by it. The importance of understanding the student perspective on these aspects of the manufacturing and sustainability sectors lies in using this information to more effectively address any concerns regarding aftermarket goods through bespoke or adaptive marketing and promotional strategies towards this audience.

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Lighting Remanufacturing: Overview of the process and specific case studies

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This project has the aim of developing a protocol regarding remanufacturing in the lighting industry.

The analysis started with bibliography research of the state of the art of remanufacturing, deepening the meaning and the general procedure in different sectors of application and considering the European Remanufacturing guidelines and examples of other projects. Then, a study of the manufacturing process of WayPoint srl, an Italian SME, a lighting equipment manufacturer, was carried out, analyzing both mechanical and chemical processes. The last phase of this project was the implementation of a possible remanufacturing process, and eventually the improvement of the production process. In WayPoint, two case studies were analyzed, understanding and facing all the different aspects for the feasibility of the project which include the reverse logistics, the technical aspects and the regulatory issues. To conclude, alternative solutions were proposed for the extension of the life of WayPoint products and the entire lighting sector compliant with the European Remanufacturing guidelines. During the study and the implementation, significant tools were considered. These are eco design of the products, the efficiency of the disassembly and the reassembly, and Digital Product Passport.

By optimizing the process with a traceable system which is easily handled and interchangeable, a final protocol for remanufacturing in the lighting industry was developed.

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The importance of reverse logistics strategy to the remanufacturing in (independent) small and medium businesses: A Review

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The recovery of used products (cores) in its right quantity, quality and at the right time, constitute the main factors that enable the profitability of remanufacturing business for independent remanufacturing. Adaptability and sustainability of the remanufacturing business are embedded in the strategies that are forged into the planning and implementation of reverse logistics for the business. However, profitability is influenced and enhanced, by the ability to effect certain changes into the reverse logistics process. This paper presents a review of the concept (plan of intention) of reverse logistics process for effective remanufacturing and highlights the importance of certain characteristics in the design of the strategy reverse logistics, for the benefit of remanufacturing profitability and sustainability. The method adopted for this review is the systematic review approach. Findings presented in this paper highlights, the critical components in the reverse logistics process, which can influence effective collection of cores for best productivity from remanufacturing process. Further, the study validates the significance of product recovery strategy, to the business of remanufacture. This is important for the identification of factors/gaps that present as inhibitors to the effective planning and implementation of reverse logistics process for the improvement of remanufacturing for independent businesses. Finally a discussion on, how reverse logistics can be effectively engaged, to enable it, address the issues of remanufacturing, is presented.

Keywords: Reverse Logistics, Product recovery, Strategy Management, Remanufacturing, Sustainability

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Production Planning and Control of Remanufacturing Operations

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The Circular Economy with its various approaches is becoming increasingly important for enterprises due to global challenges like the rising scarcity of resources or the necessity to decrease greenhouse gas emissions. Remanufacturing as one major approach of the circular economy which aims to enable multiple product life cycles by restoring the quality of used products.

Despite its high capability to overcome different global challenges, the realization of effective remanufacturing operations in enterprises is highly challenging since remanufacturing operations differ from manufacturing operations in multiple dimensions. Methods for production planning and control, which have been proven their benefits in many manufacturing operations, cannot be copied in remanufacturing operations without adaptions.

However, there is a lack of knowledge about planning and control of remanufacturing operations. Therefore, this paper presents the results of an empirical study which investigates production planning and control of European remanufacturing enterprises. Based on these results, recommendations that aim to support the realization of effective remanufacturing operations are elaborated and described. These recommendations address enterprises to improve their existing remanufacturing operations as well as to set up new remanufacturing operations.

Keywords: Circular Economy, Remanufacturing, Production Planning and Control, Remanufacturing Operations, Efficiency

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Circular Strategies for IT Devices in Southeast Asia: Addressing Barriers to Used Mobile Phone Collection in Cambodia

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Purpose and Background

Mobile phones play an important role in the lives of Cambodian people: Even though the country is classified as a low-income, developing country, statistically every Cambodian citizen owns at least one mobile phone. At the same time, previous research in Cambodia has revealed that most users are keeping their used phones when purchasing new ones. The used phones remain unutilized in the drawers of the previous owners. The high number of mobile phones in use, the short period of usage before replacing them with a new phone, and the fact that used phones are not returned to the market, lead to huge amounts of electronic waste ('e-waste') resulting in a negative impact on the environment.

By returning used mobile phones, the key value (e.g., precious materials) could be recovered by refurbishing them and returning them to the market. This would lead to positive effects on the environment by reducing the amount of e-waste and recovering valuable materials and energy. Additionally, it would benefit the sustainable economic growth in Cambodia by creating jobs and business opportunities in this sector as well as providing less expensive alternatives to new mobile phones, which is of specific interest in a cost-sensitive, developing country like Cambodia.

This research aims to identify the barriers of Cambodian people to refrain from returning their used mobile phones as well as targets to define potential incentives to cross those barriers. Specifically, this research targets to (RQ1) analyze the factors influencing decisions to retain rather than return devices, (RQ2) explore cultural values and habits differing from markets with established returning behaviours, and (RQ3) define actionable incentives to reduce barriers resulting from data privacy concerns or lack of awareness of return programs.

Design/methodology/approach

This exploration is using a qualitative research approach. It aims to collect data from 30 to 40 semi-structured interviews with Cambodian mobile phone users. The sample will include interviews with users who are returning their used mobile phones as well as with users who refrain from returning them, to understand the factors influencing the decisions within both groups.

After transcribing the interviews, data analysis software is used to perform open coding. Each of these codes, which are generated during the data analysis process, represents a certain perspective of the analyzed phenomena, such as (RQ1) factors influencing decisions, (RQ2) cultural values and habits, as well as (RQ3) potential incentives to increase return rates.

Originality/value

Various research has been conducted exploring circular strategies, such as for example the refurbishment of mobile phones. One recently published research paper analyzes this strategy in the Cambodian market. Nevertheless, there remains a gap in understanding the barriers for mobile phone users in Cambodia to contribute to such strategies by returning their used mobile phones. Understanding their perception and knowledge as well as their perceived risks, will provide the opportunity to define actions and incentives to increase the return rates of used mobile phones and to raise the values hidden in the drawers of Cambodian people.

Findings (preliminary)
Initial analysis of the first received interview data shows certain patterns: A large number of participants state that they keep the used phone for a potential 'emergency' which is often described as the breakdown or loss of the new phone. In such a situation, the used phone is seen as a potential backup solution. Nevertheless, many participants add that in reality such backups are hardly needed. Additionally, reasons for keeping the used phones include using the used phone as a data storage, perceived risks of data security when giving the used phone away, and missing information on how and where to return the phone. Participants added that better knowledge of trade-in programs from sellers, receiving (small) financial incentives, and a better understanding of the data deletion process would lead to a more likely return of their used phones. More data will be collected, analyzed, and compared with other studies.

Keywords: IT Devices, Mobile Phones, Circular Economy, End-of-Life (EoL), Closed-Loop-Supply-Chain (CLSC), Sustainability, Refurbish, Recycle, Cambodia

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Robotic eyes-in-hand unscrewing using deep learning for binocular screw detection and geometric mapping

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Robotic unscrewing is one of the core operations in a demanufacturing process, which is known to be highly challenging to automate when jointly treating a high variety of product models and conditions. Previous research has demonstrated promising results in this field using deep learning computer vision approaches. However, further improvements in fastener detection, classification and image-to-world mapping are crucial to enhance the robustness of robotic unscrewing for Waste Electrical and Electronic Equipment (WEEE).

Therefore, the presented research compares a one-stage perceive-plan-act approach with a two-stage approach in which a second imaging step is added to increase the detection (position) and classification accuracy. Both approaches are compared in a real-world unscrewing experiment with Torx 8 (T8) fasteners in hard disk drives (HDDs). This screw type is selected for these experiments, as it is especially difficult to unscrew, because of its small size and the non-self-centering nature of Torx unscrewing bits.

For the second stage detection an eye(s)-in-hand binocular vision system is developed to provide the robot with a more accurate screw location to correct the initial unscrewing coordinates. The improvement of localization is achieved by leveraging the additional positional information detected in the higher resolution images to triangulate the centre point of the detected fastener.

Initial results demonstrate that the presented two-stage approach and binocular stereo imaging system allows to significantly improve the unscrewing success rates to >98% for T8 fasteners with less than 0.5s additional time needed per screw with the presented deep learning vision system.

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Remanufacturing in Ireland – building capacity for now and the future

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Remanufacturing has been identified as a key product recovery strategy and an important value retention process (VRP) for manufacturing companies and third parties (Nasr et al., 2018) and is an important strategy for the circular economy in economic and environmental terms (Arnold et al., 2021).

Ireland has attracted a large amount of amount of foreign direct investment which has led to a high-tech, high-end, global manufacturing sector (Ibec, 2023) from BioPharma, MedTech, Engineering to Technology. Manufacturing accounted for 37.2% of Ireland's GDP (CSO, 2021) and has been identified as a hotspot for remanufacturing (Conseil Européen de Remanufacture, 2017). Ireland's geographic location on the edge of the Atlantic Ocean, puts it in a strong position to exploit significant renewable offshore energy (Government of Ireland, 2023) and this has been identified as an opportunity to develop a new manufacturing base for Ireland (Government of Ireland, 2021) by sectors seeking to decarbonise their production. Coupling this with emerging material supply chain challenges, can create an opportunity for incorporating remanufacturing as a national strategy.

The current Irish Government has adopted the Circular Economy Act to achieve Net Zero by 2030 in line with EU policy (European Commission, 2015). However, while the Whole of Government Circular Economy Strategy (DCCAE, 2022) has identified remanufacturing as a circular economy strategy and there is a need for a remanufacturing roadmap to be developed.

The recent adoption of a green public procurement framework with a specific sectoral target for the supply of remanufactured ICT end user products (EPA and Government of Ireland, 2024) has shown how a top-down approach can incentivise, publicise and stimulate remanufacturing procurement and could have the potential to lead to the onshoring of remanufacturing facilities on the island of Ireland.

This paper will investigate the needs of industry, academia and government and how best to initiate and support remanufacturing to promote the circular economy and create resilient jobs.

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Enabling circular economy R-strategies through human-centric smart and flexible automation

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Smart flexible automation enhances the efficiency, sustainability, and adaptability of manufacturing processes. Such intelligent and adaptable systems are thus suitable for diverse productions tasks and conditions and as such can be advantageous from aspects of remanufacturing. Industry 5.0, evolving from Industry 4.0, emphasizes human-centric, sustainable, and resilient approaches to manufacturing, complementing circular economy principles by integrating advanced technologies with an emphasis on the well-being of workers and the environment. Hence, the implementation of smart flexible automation is not merely driven by technological development, but also needs to be carefully tailored to existing organisational structure and company culture by considering the human-technology nexus.

This study reviews state-of-the-art of smart and flexible automation from the circular economy R-strategies of repair and remanufacture. In synergy with this, perspectives of human-centricity are brought forward in relation to smart and flexible automation and further focusing on the R-strategy of rethinking.

Initial results for smart and flexible automation in relation to repair highlights; the applications of collaborative robotics, i.e., cobots to assist workers in repair tasks, combining human dexterity with machine precision, and the use of augmented reality for training and real-time repair assistance, enabling workers to fix complex machinery more efficiently. In relation to remanufacturing the integration of robotic disassembly systems are brought forwards, as well as AI and agent-based approaches for optimisation to determine the most cost-effective and resource-efficient remanufacturing paths and processes for components. The human-centric perspectives or rethinking focuses on innovation, human creativity, and ethical decision-making when redesign of industrial systems towards smart and flexible automation. Further, rethinking relates to the need for new knowledge, new ways of collaborating, and new ways of managing and organizing work, all which brings forth the importance of management for the perspective of human-centricity.

Human-centric smart and flexible automation envisions the creation of sustainable systems that prioritize human perspectives when reusing existing automated equipment in combination with adaptable technologies for remanufacturing purposes. Combining smart flexible automation with intelligent management strategies equips the manufacturing industry with adaptive capabilities to be able to respond to changing conditions and component variations. Thus, enabling circular economy R-strategies of rethinking, repairing, and remanufacturing through human-centric smart and flexible automation.

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Model for practitioners' capacity building for remanufacturing in product-as-a-service (PaaS)

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Remanufacturing restores used products to like-new condition supporting product value retention in circular business models. Product as a Service (PaaS) is an example of a servitised business model that allows companies to create value by proactively managing the lifecycle of their products. Currently, remanufacturing in PaaS is a niche practice for electrical and electronic equipment in consumer markets.

The aim of this paper is to present a novel capacity building model that helps companies establish and scale up remanufacturing in PaaS settings for EEE in consumer markets (B2C). The model combines the individual and organisational level. The individual level allows identification of the critical skills of employees needed for remanufacturing. The organisational level combines the requirements for establishing a PaaS business model, the design of process, and the provision of the necessary resources for an economically viable and environmentally beneficial remanufacturing process, referred to as "lean and green". The framework takes into account the conservation of critical raw materials.

We apply the following research methods: literature review, longitudinal case study with semi-structured interviews, gap analysis, process mapping, and observation to establish the remanufacturing process and identify the necessary capabilities. We search the answers for the research questions: 1) What are the hotspots for establishing remanufacturing of EEE in PaaS? 2) What capacities are needed? 3) How to develop the necessary capacities in a company? The results focus on providing practical guidelines for the companies on how to establish and scale up remanufacturing in PaaS settings.

Keywords: Circular economy, Remanufacturing, Value-retaining process, Capacity building, Servitization

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An Investigation on Optimizing Sustainable Remanufacturing in Developing Countries: A Novel Application of Lean Six Sigma

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Remanufacturing, a process that restores used products to like-new condition with a warranty to match, offers significant environmental, economic, and social benefits. However, traditional remanufacturing faces persistent challenges, including variability in returned cores, high reverse logistics costs, lack of standardization, and low consumer trust. These issues are particularly severe in developing countries, where a lack of infrastructure and policy further hinder remanufacturing's potential. The aim of this research is to investigate the optimization of remanufacturing through the integration and application of Lean Six Sigma tools and techniques, and to provide knowledge on the combined construct with a focus on addressing the challenges and enhancing sustainability in developing countries particularly Nigeria. A systematic literature review of 289 papers was conducted. Web of Science and Scopus databases were utilized and searched using the keywords; Remanufacturing, Lean Six Sigma, Sustainability, Challenges, Developing countries and Nigeria. Based on the systematic literature review, this research uncovers that there is a dearth of knowledge on remanufacturing and Lean Six Sigma (LSS), leaving a critical gap in the literature. To address the gap, this study seeks to investigate the application of Lean Six Sigma techniques to remanufacturing. The combination of Lean's focus on waste elimination with Six Sigma's emphasis on reducing process variability, the two offer a systematic approach to tackle inefficiencies, reduce defects, and foster customer trust. The findings from the literature suggest that integrating Lean Six Sigma tools such as DMAIC, Kaizen, and Value Stream Mapping into remanufacturing can significantly mitigate core variability, streamline reverse logistics, enhance process standardization and customer perception. The novel contribution of this paper is demonstrating the potentials of Lean Six Sigma as a transformative tool for a sustainable remanufacturing.

Keywords: Remanufacturing, Lean Six Sigma, Sustainability, Challenges, Developing countries, Nigeria

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How best to assess the environmental impacts of product design, does Life Cycle Assessment (LCA) really provide the answer?

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This literature review has assessed the use of environmental assessment techniques in early product design. Life cycle assessment (LCA) is a popular method for assessing the environmental impact of products and comparing products, however the use in early-stage design is problematic due to complex data needs and the requirement for the assessment of outputs by practitioners. Eco design tools can also be useful to support product planning but do not provide quantitative information on impacts nor do they adequately support design decisions. The needs of designers are not necessarily compatible with the systematic process of environmental assessment and tools are required that offer simplification whilst also providing support to designers regarding the extent of environmental impacts and solutions available. Attempts at fixing the incompatibility of fitting product life cycle considerations into the design process have only partly solved the issues of technical complexity, data intensity as well challenges with including a whole life cycle approach in particular from cradle to cradle rather than just cradle to gate or cradle to grave.

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Defining Key Characteristics of Manufacturing Strategies for Remanufacturing: A Systematic Literature Review in the Circular Economy Context

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Over the past years, numerous literature reviews have been conducted to address manufacturing strategies (MS). These structured reviews cover aspects such as theoretical developments, contextual and process-related issues of manufacturing strategy, and benchmarking. However, the intersection between circular economy (CE) and MS has received limited attention. Remanufacturing is a key circular strategy for manufacturers to retain value from end-of-use (EOU) products, supporting sustainability and driving the transition to CE. Despite its potential, remanufacturing is inherently more complex than traditional manufacturing due to uncertainties related to the quality, quantity, and timing of EOU product and component returns. Therefore, there is a need to develop manufacturing strategies that support remanufacturing in order to facilitate the transition from linear to circular manufacturing.

This study aims to define the key characteristics of a remanufacturing strategy (ReMS) by synthesizing existing literature on CE and MS. To achieve this aim, a systematic literature review was conducted following PRISMA principles and the methodology proposed by Moher *et al*. A total of 80 peer-reviewed articles from the Scopus and Web of Science databases were selected for full-text screening. To ensure internal validity, blind reviews were carried out by four researchers. The keywords covering aspects of manufacturing strategy, remanufacturing, and CE are used in the review.

The findings indicate seven different thematic areas in the intersection between CE and MS for remanufacturing: 1) manufacturing planning for hybrid manufacturing system, 2) integration of hybrid manufacturing systems by optimizing capacities and gaining profits, 3) best practices including, lean, JIT, and six sigma, 4) process-related innovation and modelling for remanufacturing, 5) Industrial 4.0 technologies including blockchain, IoT, and AI applications in predictions, 6) the configuration of the circular supply chain (CSC) supporting hybrid manufacturing and reverse logistics, and 7) product designs with multiple life cycles and material selection.

The review identified key characteristics of a ReMS, including integrating hybrid manufacturing and remanufacturing systems, production planning, best practices, process-related aspects, product design, CSC design, and technology utilization. The research is limited to a selection of articles and databases; however, the identified trends provide clarity to the field of remanufacturing research. This study offers practical implications by identifying new research directions to further advance knowledge in the domain. The paper's novelty comes from a broader and deeper review of manufacturing strategy facilitation for remanufacturing within the context of the CE.

Keywords: Manufacturing Strategy, Remanufacturing, Circular Economy, Circular Manufacturing Strategy
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Optimization of end-of-life decision-making

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As the global demand for raw material continues to escalate while their availability decreases, the imperative for sustainable production and consumption practices becomes ever more pronounced. The circular economy offers viable strategic initiatives to either rethink product utility, extent the product's lifespan, or reintroduce materials into circularity. Particularly, remanufacturing and recycling depict two industrial strategies that create environmental and economical benefits after the product's end-of-life (EOL). However, the selection of a suitable circular economy strategy (i.e., remanufacturing or recycling) prevails a challenge for industrial decision-makers. This is due to fluctuating raw material prices, disassembly or dismantling schedules, or supply and demand uncertainties. In response, this paper developed a mathematical model to optimize EOL decision-making. The quantitative model considers economical and environmental factors for remanufacturing and recycling to assess the most suitable circular strategy. The feasibility of the developed model was tested by an industrial case study of an original equipment remanufacturer. The findings of this paper provide valuable insights for industrial decision-makers from the remanufacturing and recycling domain to keep more products and components in circularity and enhance their profitability.

Keywords: Remanufacturing, Recycling, Decision-making, Optimization

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Triage for Circular Economy: Techniques for Optimising End-of-Life Decision-Making

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This paper investigates the application of hospital triage principles to optimise decision-making processes for end-of-life (EOL) electronic components. Both domains (hospital triage and EOL decision-making) involve the prioritisation of complex systems through evaluation of individual aspects. Similar to how triage prioritises patients based on severity of illness and medical history, EOL looks at components based on status, maintenance, and structure. This study looks to create a general system by investigating common triage prioritisation systems, looking at impact of resource allocation, and cost-benefit analyses for the decision-making in emergency departments. Moreover, the study conducts an investigation into what factors in EOL decision-making, along with various case studies to determine common decision-making sequences. Subsequently, the two domains are compared for similarities and parallels that could benefit either system. As suggested by research, hospital triage principles could be adapted to optimise EOL decision-making. By prioritising components and utilising shared decision-making tools, resource allocation can be streamlined, which minimise waste and maximises resource recovery.

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Exploring the Factors Affecting Purchase of Remanufactured Products using A Multi-Criteria Decision Making Model

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Incorporating sustainability in manufacturing is gaining paramount importance and End of Life (EOL) product management offers a solution to achieve it. Technology advancements have led to efficient and cost effective manufacturing, resulting in increased product availability with constant functionality upgrades. As a side effect of this, consumers are constantly buying and upgrading their products and scrapping existing products even if they are in good working conditions. All these prematurely disposed off products end up in the landfills or are incinerated, which causes environmental degradation through release of harmful emissions and pollutants.

To control this damage to the environment, Original Equipment Manufacturers (OEMs) are responsible for taking their EOL products back and disposing them responsibly. To enable this, they are implementing various circular economy approaches, such as product recovery, disassembly, redesign, remanufacturing, recycling, and reuse. These approaches help in delaying the disposal of these products by extending their useful life.

However, purchase of remanufactured products is not accepted by consumers in all fields and research on understanding of factors influencing purchase of remanufactured products is sparse. Towards bridging this gap, this paper identifies various factors affecting the purchase of remanufactured products, such as, cost, quality, warranty and transparency in the reverse supply chain and evaluates how these can be used in the design of the remanufacturing process itself. A framework is developed using a multi-criteria decision making technique to evaluate the factors involved in designing the remanufacturing process.

Keywords: Remanufacturing, Circular Economy, Reverse Logistics, Multi Criteria Decision Making

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Semantic 3D Product Modeling for Automated Inspection in Remanufacturing Processes

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Remanufacturing is a key process for enabling a circular economy by restoring used products, often referred to as cores, to a like-new condition. Despite its benefits, remanufacturing still relies heavily on manual work, particularly for tasks like the visual inspection of cores before reprocessing. This manual effort arises from uncertainties such as varying product conditions, a large variety of product variants, and the lack of product information, such as CAD models, to support automation. To address these challenges and enable the automation of tasks like visual inspection, flexible and adaptive inspection systems are required. These systems must be capable of automatically detecting defects and performing product-specific inspections across a wide range of product variants.

This paper introduces a semantic three-dimensional product modeling method that integrates two-dimensional (images) and three-dimensional (point cloud) data. Using semantic segmentation approaches at runtime, the method assigns each surface point of the 3D model to a specific component, thereby creating a semantic 3D product model during the inspection process. This model encodes both geometric and semantic information, enabling automated defect detection, product-specific inspection, and sensor positioning for the evaluation of surfaces and components. Additionally, the semantic 3D model supports subsequent remanufacturing steps by providing detailed product geometry and identifying missing components.

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Pathway to Circularity through Remanufacturing: A Study on Waste Reduction by Construction Machinery Remanufacturing Business

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While the manufacturing sector plays an important role in wealth generation for the economy, the energy consumption and waste discarded through the production processes cannot be ignored. Construction machinery equipment manufacturing is no different, considering the rapid evolution of machinery sizes and functions. With increasing awareness of the need to realize circular economy, it has led the rapid growing construction machinery businesses to pay attention to their contribution to environment pertaining to products and the manufacturing processes involved. As so, some of the world's leading construction machinery companies are advancing on their transitions into a circular business model through their well-established remanufacturing businesses. However, this transition comes with a plethora of challenges as well, especially with waste reduction. Wastes materials including carbon dioxide emissions are one of the major concerns for the production processes and this study aims to provide an analysis of the reduction of waste materials (parts reuse rate) leading to reduction of carbon dioxide emissions by Hitachi Construction Machinery's Remanufacturing Business. This study will provide an insight into the case of remanufacturing hydraulic excavator cab glasses. It will discuss the processes involved in retaining almost all the front cab glass component, that is, a very small amount of scrap, contributing to reduced energy consumption. It will further highlight the technical challenges the business faces in implementing the circularity-conscious measures relevant to waste reduction. Finally, this study will attempt to determine the projection of future reductions of waste by the business.

Keywords: Circular economy, Remanufacturing, Waste reduction, Carbon dioxide, Heavy machinery

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Challenges and Opportunities to adopt Remanufacturing by Original Equipment Manufacturers

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The global trend towards responsible production and consumption is driving the growth of the remanufacturing industry. However, despite the increase in independent remanufacturers, original equipment manufacturers (OEMs) have been slow to adopt remanufacturing practices. This reluctance is due to a knowledge gap and a scarcity of successful OEM remanufacturing case studies. Current research predominantly addresses the reasons for adopting remanufacturing rather than the practical implementation. Consequently, OEMs interested in remanufacturing face numerous challenges.

This paper aims to identify the challenges OEMs encounter when adopting remanufacturing and to discuss opportunities to address these challenges. To achieve this, we employed literature review and case study methodologies. Our literature review identified 12 clusters of challenges at the micro and meso companies' levels, which we validated through case studies at eight European OEMs. Based on these findings, we developed 14 recommendations, implying both, managerial and technological solutions, for OEMs to overcome the challenges and enable greater OEMs adoption of remanufacturing.

Keywords: Circular economy, Circular transition, Value-retaining process, Initiate / establish / integrate / scale up remanufacturing

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Choosing remanufactured products in a Business-to-Customer (B2C) Market

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Resource criticality, growing production, and consumption rates call for the urgent implementation of circular economy (CE) solutions within the business-to-customer (B2C) market. Circular solutions at the product end-of-use phase, such as providing direct reuse or reuse after product repair, refurbishing, or remanufacturing, are central to circular businesses. B2C remanufacturing enables sustainable production and consumption in the CE by bringing used products to their as-good-as-new condition and reintroducing them back to the consumer market. This study investigates the factors influencing consumer perceptions of the quality and value of remanufactured products compared to their new counterparts, building upon a systematic literature review. Through a survey of 1206 Swedish consumers, this study defines the rationales behind consumer intention to choose remanufactured products. Managerial recommendations include guidelines for circular businesses and policymakers to define better critical factors influencing consumers' choices of remanufactured products.

The findings of our study provide valuable insights into both the drivers for and barriers to choosing remanufactured consumer products. Consumers are largely motivated by price and environmental benefits, reflecting both economic and ethical concerns, while quality assurance and trendiness further enhance their intention to choose remanufactured products. However, significant barriers remain, particularly in terms of low awareness, disgust toward reused products, and distrust.

Keywords: Circular economy (CE), Remanufacturing, Sustainable consumption, Consumer behavior, Survey

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An Experimental Robotic Cell for the Disassembly of Electric Vehicle Battery Modules

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The increasing shift towards electrification in the automotive industry has highlighted the critical need for a large-scale and efficient processing of end-of-life (EoL) lithium-ion batteries (LiBs) from electric vehicles (EVs). Linear EoL strategies, such as landfilling, pose significant environmental hazards, while recycling, repurposing, and remanufacturing offer more sustainable alternatives but require scalable and efficient disassembly processes. This paper presents a novel robotic cell designed for the automated disassembly of EV battery modules, addressing the challenges of safety, cost-effectiveness, and flexibility. The robotic cell integrates an industrial robot, a supporting structure, a tool opening system, an electrical and electronic system, and a pneumatic system. This paper also proposes a methodology for assessing the economic impact of the robotic cell. Initial assessments conducted on a mock-up Samsung model 12S1P battery module demonstrated that the robotic cell could match the productivity of 5.50 workers within a workweek, save over £15k per month in operational expenses, and have a payback period of 1.33 years. This research marks a step towards realising scalable and financially feasible robotic disassembly systems for EoL EV-LiBs, promoting a circular economy in the automotive sector.

Keywords: Robotic Disassembly, Battery Module, Prototype Design, Remanufacturing

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Framework for a Worker Assistance System to Enable Circular Economy Processes

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Climate change, one of the most significant threats to humanity, underscores the urgent need for advancing the circular economy, particularly in promoting sustainability. Within the home appliances industry, implementing R-strategies such as refurbishment and remanufacturing is central to establishing sustainable and environmentally friendly business models. Key processes, such as workpiece disassembly, reassembly, and component status evaluation, are critical for implementing R-strategies. These processes are inherently more complex and variable than conventional production workflows. Due to the skilled worker shortage and impact of demographic shifts, the development of precise and comprehensive work instructions is increasingly vital for maintaining process quality. To meet this need, a work assistance system is essential, providing robust decision support to ensure efficiency and accuracy. This paper proposes a framework for a worker assistance system tailored to the application of R-strategies in washing machine production. The framework is validated by data from an industrial scenario and identifies critical information that should be incorporated into the system, enhancing its effectiveness and usability in real-world contexts.

Keywords: Circular economy, R-strategy, Remanufacturing, Refurbishment, Worker assistance

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Information management for remanufacturing industrialization – An outline of a conceptual model

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Background/purpose
Remanufacturing is a well-known value retention process for retaining the inherited value of a product, one among other strategies that facilitate the transition to a circular value chain. As remanufacturing is gaining increased interest from manufacturing companies, the industrialization of remanufacturing is still highly industry-dependent and usually more complex than traditional manufacturing due to uncertainties about adequate information. Here, information management plays a crucial role as it is essential that accurate, and accessible information can be gathered in secure ways. However, recent publications highlight that there seems to be a lack of accurate and accessible information as well as a lack of information systems to ease the remanufacturing industrialization process. By this study knowledge relevant for the remanufacturing industrialization process is captured by exploring required information as well as information flows for remanufacturing at manufacturing companies.

The purpose of the paper is to explore the required information and flows in remanufacturing for manufacturing companies. The following research questions will be addressed: RQ1: What is the required information for remanufacturing? RQ2: What are the information flows for remanufacturing in manufacturing companies?

The analysis will position the required information and flows in relation to the industrialization process for remanufacturing at manufacturing companies. The aim is to propose a conceptual model for information flow for remanufacturing that eases the industrialization process.

Research methodology
This study is based on empirical data from two research project and a systematic literature review. The systematic literature review aimed at identifying required information and flows for remanufacturing. 40 publications were identified as relevant from the literature review. The empirical data from the two research projects consist of two multiple case studies at in total eight OEMS and one remanufacturing company. Empirical data was collected by interviews, observations and workshops. The empirical data was analysed by inductive thematic analysis and a cross-case analysis. After the analysis, the findings were compared against the findings from the literature review.

Findings
The results from both the literature review and empirical data indicates that there is a lack of information in general for used products that are going to be remanufactured. Another finding from both literature review and empirical data is that there is a lack of repair history of the used products. A finding from the empirical data is that the there is a lack of information about materials, joints, manufacturing year and process, user information, as well as contamination

Conclusion
The paper will outline a conceptual model for the information flows related to remanufacturing process. The model consists of required information and information flows for remanufacturing and can be used to ease the industrialisation process.

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Applying additive manufacturing technology to remanufacture a wind turbine pinion shaft

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The functionality of a wind turbine is significantly impacted by the failure of its components, with certain components being more critical than others due to factors like supply chain constraints and frequent design changes that render older versions obsolete. Yaw motors, which adjust the nacelle to optimize wind capture or protect blades during extreme weather, are particularly vital. Damage to the pinion shaft within a yaw motor can lead to increased stress on other motors, necessitating prompt replacement. This study explores remanufacturing as a solution to restore damaged pinion shafts, promoting sustainability by reusing the bulk of the shaft. Due to limited information on existing pinion shafts, benchmarks were established based on material properties and geometry. A methodology was then developed to identify damage patterns and determine the extent of material removal required. Given the substantial material addition needed, Directed Energy Deposition by Arc (DED-Arc), an additive manufacturing technique, was chosen for material addition on the remaining shaft section. The remanufactured samples representing an actual shaft then underwent rigorous testing, with results constantly being compared to existing benchmarks. Finally, suggestions about the future steps such as dynamic testing, machining, and surface property evaluation are provided to further improve the confidence in the remanufactured part. This approach demonstrates that by incorporating additive manufacturing into the remanufacturing sector, we can simultaneously achieve the objectives of sustainability and digital transformation.

Keywords: Directed Energy Deposition, Additive Manufacturing, Remanufacturing, Wind turbine, Microstructure analysis, Mechanical testing, Metallic alloys, Steel, Shaft, Sustainability

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Enabling Remanufacturing with Digital Product Passports: The ReMake Remanufacturing Data Model and Open-Source Toolkit

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Digital Product Passports (DPPs) have been recommended as key technology for product traceability and enabling circularity to achieve the EU's net zero objectives. However, the Ecodesign for Sustainable Products Regulation (ESPR) regulation does not specify data models for remanufactured products; rather, it will establish interoperability standard for DPP system which is expected to be announced in December 2025. This presents a challenge for remanufacturers looking to share product information via DPPs. Another barrier for remanufacturers is the absence of open-source tools to aid in the creation of DPPs to enable prototyping for market validation. To address to these problems, the National Manufacturing Institute Scotland (NMIS), through the ReMake Glasgow project, has created a open source DPP toolkit that allows companies to efficiently align their data with the ReMake Remanufacture data model, hence ensuring compatibility with other DPP data models. This solution optimises the creation and integration of remanufacturing data into industrial DPPs and, owing to its open-source nature, promotes cooperation and discussion to support DPP adoption.

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Evaluating the relationship between sourcing policies and remanufacturing operations adoption rate: A simulation modelling approach

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The remanufacturing industrial process demands that remanufactured products meet the "same as new" warranty standards, after strict quality assurance testing and inspection has been completed (Niu et al., 2024a). The stages for remanufacturing, include: collection of used or discard cores, sorting, disassembly, cleaning, refurbishment, inspection, reassembly and quality testing(Gong & Liu, 2024). Thus, the availability of cores remains a key determination of "remanufacturability" and while this has been investigated in the literature, several gaps remain (Bulmus et al., 2014; Lindkvist Haziri & Sundin, 2020). For this study, we define "remanufacturing sourcing policies" as the policies or structured guidelines that the remanufacturer would encounter while acquiring used products, also known as the cores. In addition, we define "remanufacturing operations adoption rates" as the speed at which the OEM adopts the decision to involve in remanufacturing operations.

Studies by Sundin (2004) identifies three main kinds of remanufacturers to be OERs, or original equipment remanufacturers, contracted remanufacturers and independent or third-party remanufacturers (Li et al., 2024; Sundin, 2004; Zhou et al., 2021). This study shall focus on third-party remanufacturers for the following reasons; first more research has been done on third-party remanufacturers, as observed from documents on SCOPUS database. Indeed, studies by Orsdemir et. Al., (2014) identified third-party remanufacturers as the most dominant kind of remanufacturer in the remanufacturing space (Örsdemir et al., 2014). Finally, relevant literature on competition in remanufacturing show that third-party remanufacturers are more profitable than OERs and contracted remanufacturers, leading to cannibalisation practices on these third-party remanufacturers (Okorie et al., 2021; Yeoman, 2012; Zhou et al., 2021).

While there have been few studies on remanufacturing sourcing policies, none of these extant literatures have investigated its impact, if any, on the decision for new actors to undertake remanufacturing operations. For instance, (Agrawal & Lee, 2019) the effect of sourcing policies on suppliers' sustainable practices. Andrew-Munot & Tanjong (2022) conducted a study which investigated the effects of inspection, grading and sourcing policies on the cycle time performance of a remanufacturing system under varying quality here have been several studies on sourcing policies in remanufacturing (Andrew-Munot & Tanjong, 2022). Finally, (Niu et al., 2024b) develops a game-theoretic supply chain model to address the production location concern of the core component supplier under the pressure of global tax-planning.

The extant literature on sourcing policy immediately suggests that investigation of remanufacturing sourcing policies in the context of environmental, economic, geographical and social perspectives are both important for researchers and industry stakeholders. Thus, we ask the following research questions: (1) What are the sourcing policies for these cores and (2) how do they affect the decision to switch to remanufacturing operations by [eventual] third party remanufacturers? Using the Chinese remanufacturing marking, we shall answer this question through a case study approach to identify third-party remanufacturers sourcing policies for across the types of remanufacturers and employ system dynamics simulation modelling to identify how these policies affect the adoption rate of remanufacturing.

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Understanding consumer acceptance and preferences through environmental knowledge to optimize remanufacturing end-of-life strategy: Theory development and case study

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Modelling the consumer as the major stakeholder has been pervasive in early across economics, marketing, social sciences and behavioral sciences studies, as observed in databases such as SCOPUS and Web of Science (Mitchell, 1992; Ölander & Thøgersen, 1995; Pérez et al., 2013; Sammer & Wüstenhagen, 2006). Within sustainability studies, however, modelling the consumer as the major stakeholder has only begun to see an uptake in research. For example, Alt & Stamminger (2024) studied consumer behaviors in adapting to sustainable product design using an automatic dishwasher as the device. They found a relationship between eco-design and reduced energy consumption, leading to savings on electrical energy and 2.2 million m3 of drinking water for Australia per year (Alt & Stamminger, 2024). Review studies of consumer behavior towards carbon footprint labels on food, show that there is need for a commonly recognizable carbon footprint system (Rondoni & Grasso, 2021). Without this common system, consumers are unable to interpret the current available labels and are limited in making more sustainable choices. Other important studies exist in the nexus of consumer behavior and aspects of sustainability, such as battery recycling (Tang et al., 2023; Wang et al., 2024), willingness to pay for remanufactured products (Llerena, 2011), suggesting that this is a critical area for researchers, policymakers and industry practitioners.

This study follows a PRISMA literature review conducted in this area, where we find that, while consumer knowledge of environmental issues exists, there are no studies that assess the environmental knowledge of consumers with respect to end-of-life strategy, such as remanufacturing (Okorie et al., 2024). We focus on remanufacturing as the choice end-of-life approach, as it remains a topical issue amongst researchers, policymakers and industry practitioners due to its social, economic, environmental benefits (Okorie et al., 2021; Shu et al., 2016). In addition, global challenges such as climate change and the subsequent need to reduce greenhouse gas emissions have contributed in driving the interest in remanufacturing. This study focuses on the electric vehicle (EV) battery, as they typically account for 30% to 40% of the value of an electric vehicle (IER, 2022; Li & Wang, 2023). While studies have shown that consumers are becoming increasingly knowledgeable of the environmental implications of products, few studies have (a) addressed the economic cost of remanufacturing from a systems level and (b) and have consequently modelled the consumer as a major sustainability stakeholder where the end-of-life choice is understood. From the review of literature earlier conducted, we argue that remanufacturing uptake can be increased if consumers are aware of the environmental benefit of remanufacturing. Furthermore, we argue that there is a clear economic benefit for the remanufacturer and consumer in purchasing remanufactured EV batteries.

Thus, we ask these two research questions: (1) Does consumer environmental knowledge influence their decision to purchase remanufactured electric vehicle batteries? (2) Does government policies increase consumer appetite to adopt remanufactured electric vehicle batteries? Drawing on a unique dataset of over 3,000 respondents of UK vehicle users, we examine the economic costs of electric vehicle battery remanufacturing from a systems perspective and advance the theoretical framework underpinning our case study. Our modeling and analysis focuses on the customer perspective, a key stakeholder in sustainability initiatives—incorporating variables such as customer perceptions influenced by environmental awareness, technological advancements, and pollution taxation.

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Data Management System for Robotic Demanufacturing: a case study for Hard Disk Drives (HDDs)

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To reduce Europe's dependencies for critical raw materials, the development of efficient demanufacturing approaches for Waste of Electric and Electronic Equipment (WEEE) is crucial, as targeted by the European Commission in the Raw Materials Act. To increase the robustness of such robotic demanufacturing processes for different models of end-of-(first-)life products that return in different conditions, the authors developed a novel method to (re)identify product these product models, so that information gathered during the previous demanufacturing of the same models can be used to enhance the process efficiency. In the presented research, this approach is adopted to improve the robotic demanufacturing efficiency for hard disk drives (HDDs) disassembly to recover the magnets containing the critical raw material Neodymium.

This novel method makes use of innovative data management schema to facilitate systematic data collection and querying. For this the design utilises two database management systems (DBMS), SQL and NoSQL. In addition, a data modelling scheme is developed to save the Digital Passports (DPPs). To evaluate the performances of the proposed methods and data management system, failure cases for the HDD screw location detection are first identified when solely relying on information from the vision system without the use of a DPP database. The main reasons identified for unsuccessful disassembly is the presence of screws under the plastic label and the limited screw position detection accuracy of the vision system. Thereafter, a demanufacturing image retrieval method, You Only Demanufacture Once (YODO), is tested on a dataset of >1000 HDD images to calculate the image-based retrieval rate to demonstrate how the disassembly success rate can be increased with the use of DPPs.

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Navigating the Remanufacturing Trilemma: Balancing Customer, Manufacturer, and Lawmaker Interests

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Transitioning towards a circular economy presents a significant challenge for companies and the society, particularly in balancing the economic, environmental, and social dimensions of sustainable production and consumption. Circular principles and the so called R-Strategies (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover) form the basis for a holistic approach. To meet the continuously growing resource demand recycling is not enough the added value of a production process needs to be retained. Therefore, remanufacturing is the next logical step for achieving sustainability and transitioning towards a circular economy.

However, balancing the different interests of the key stakeholders (customers, manufacturers, and lawmakers) poses a significant challenge. Recognizing the cost benefits of remanufacturing processes, increasing the acceptance among customers, and abiding regulators is crucial for the advance of the circular economy. The resulting remanufacturing trilemma is the topic of this paper. Customers, on the one hand, demand high quality, affordable remanufactured products that meet their performance expectations and offer value for money. Manufacturers, on the other hand, deal with the economic and technical complexities of integrating remanufacturing into their operations while remaining profitable and competitive. Lawmakers, seek to promote remanufacturing through regulations and policies aimed at environmental protection, consumer safety, and fair competition.

The paper explores this remanufacturing trilemma in the automotive sector by first analyzing the requirements of the different stakeholders Checking the requirements for conflicts and synergies allows to demonstrate the interactions and dynamics between the stakeholders. For solving conflicts and using synergies a methodology is developed and evaluated. The resulting methodology is then evaluated through expert interviews and proposes a way to tackle the remanufacturing trilemma. This research aims to contribute to the development of effective strategies that facilitate the transition towards a more sustainable and circular economy.

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How to design production systems for circular economy – applying the modular Aachen factory planning approach to a white goods manufacturer

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Linear production systems fail to sustainably increase production targets while reducing resource demands, a conflict that circular value creation networks can resolve. For this purpose, it is essential to integrate ReX-strategies, such as refurbishment and remanufacturing, into industrial production systems. Current planning approaches, however, predominantly focus on linear production system design. In contrast, we propose applying the modular Aachen factory planning approach to design production systems that enable industrial-scale and combined remanufacturing and refurbishment within circular value creation networks. This paper outlines the planning approach from production structure planning through capacity and layout planning to workplace design, emphasizing the unique challenges and differences inherent in planning for circular value creation systems. We validate our approach through a case study involving a white goods manufacturer, supported by digital factory tools. Our findings demonstrate that existing planning methodologies can be adapted to meet the requirements of transitioning to a circular economy. In addition, the case study provides a practical reference for companies looking to implement circular value creation strategies. By addressing the specific requirements and challenges of circular value creation, we contribute to the development of sustainable industrial production systems.

Keywords: Factory planning, Production design, Refurbishment, Remanufacturing, Circular economy, Digital factory

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Approach for data-driven battery disassembly: Leveraging digital product passports and sensor technologies for Re-X strategies

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The concept of the circular economy has gained increasing political attention in recent years. Transforming the current predominant linear economic system into a circular economy is considered a key measure to achieve climate neutrality. According to the European Union, an important tool to facilitate this transformation is the concept of the digital product passport (DPP) [1]. The goal of the DPP is ensuring transparency throughout the entire lifecycle of a product and enabling the exchange of product-related data between various stakeholders. Batteries are the first product group for which a product passport will be mandatory. [2]. The Global EV Outlook 2023 of the International Energy Agency (IEA) shows a sales surge of electric vehicle with 26 million units sold globally in 2022, representing a 60% increase compared to 2021 [3]. However, significant challenges remain regarding the reintegration of used electric vehicle batteries into the circular economy due to the lack of standardized battery designs, hindering disassembly, reuse, and raw material recovery. One of the main reasons for this lies in the necessity of professional battery disassembly at the module level, which is a fundamental prerequisite for a variety of the Re-X Strategies. Additionally, obtaining information about the lifecycle of batteries or disassembly information is challenging [4]. The DPP has the potential to address these challenges by providing lifecycle and disassembly data, thereby enabling efficient and scalable battery disassembly systems.

Our proposed approach directly addresses this need by leveraging the DPP to provide disassembly-relevant information essential for automated disassembly processes. Specifically, we focus on collecting data during manual disassembly using sensors and converting it into a machine-readable format. This data is then structured to meet the technical requirements for seamless integration into the DPP, ensuring its compatibility with automated and semi-automated disassembly workflows in the future. In this paper, we focus on the development of a data structure and its provision to enable future automated disassembly planning for battery modules. Using a simplified example, we demonstrate how relevant data is systematically generated, structured, and formatted to meet the technical requirements for potential integration into the Digital Product Passport (DPP). Our approach involves capturing key information about the battery's design, condition, and components through sensor and measurement systems during manual disassembly. This data is then processed and organized into an ontological framework, ensuring semantic clarity and machine-readability. The focus of this work is on the technical aspects of data generation, structuring, and preparation, providing the foundational elements necessary for seamless integration into the DPP. By illustrating these steps with a simplified example, we aim to provide a clear understanding of how relevant data can be systematically captured, analyzed, and formatted to support future applications in the circular economy.

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Referencing of Moving Assembly Components

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This paper presents the development of a procedure for controlling automated assembly and disassembly processes with position uncertainties of involved moving end-effectors, moving components to be assembled and moving assembly groups. This scenario can be found, for example, in the assembly of passenger cars. The following explanations are based on the practical fact that there are differences between target and actual positions in automation processes. The causes can be found in insufficient actuator stiffness, deflection of flexible components, inaccuracies in the path algorithms (see PTP and NC), dynamic motion influences, cumulative errors from tolerance chains, sensor limitations (incremental encoder accuracy in the actuator axes) or machining forces.

To compensate for these influences and increase precision, a cyclical data processing chain is implemented on a manageable test setup and the effects of software adaptation are investigated. The focus is therefore not on the development or optimization of hardware, but on the use of data from the actuators and process sensors within an efficient processing logic to continuously send correction commands to the actuators.

Specifically, the test setup consists of a turntable on which a test object is rotated in a circle. The aim is to automatically synchronize a three-axis actuator system (gantry) to the moving position of the test object. A mounted gripper should pick up the test object safely and jerk-free. The setup should be able to react to spontaneous changes in acceleration, compensate for inaccurate positions and autonomously perform the process flow of test object detection, path planning and movement synchronization, beyond a pre-trained pick-and-place application. The process and the test setup described until this point is shown in Figure 1.

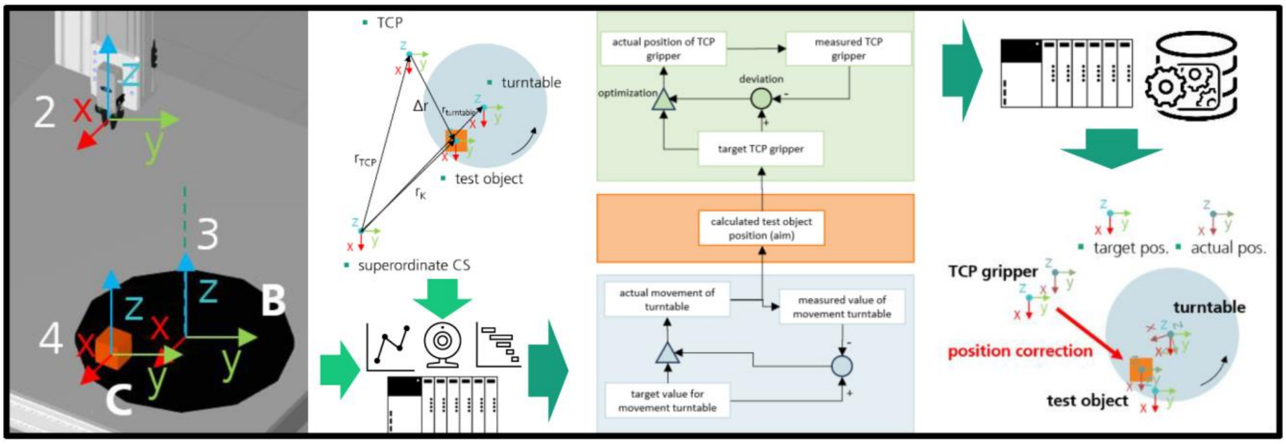

Figure 1. Depiction of the Cyclical Data Processing Chain for improved Position Accuracy[1,2]

Keywords: Process Automation, Dynamic Process Guiding, Real-Time Position Correction

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A Methodology for Evaluating the Viability of Circular Strategies: Integrating Environmental Impact and Cost-Effectiveness Analysis

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The growing imperative to transition towards sustainable production systems has prompted industries to explore circular economy strategies such as remanufacturing. These approaches promise environmental benefits while posing new challenges in economic viability and market acceptance. This work proposes a novel methodology to evaluate the feasibility of incorporating circular schemes by systematically addressing three core dimensions: (1) the environmental impact, quantified as changes in CO_2 emissions; (2) the cost implications of adopting the strategy; and (3) customer willingness to pay (WTP), as a decisive criterion for strategy adoption.

The methodology employs an analysis framework that maps costs and environmental outcomes onto a cost-effectiveness plane. The plane (Figure 1) consists of four quadrants that provide actionable insights into decision-making. Strategies in the Quadrant IV are unequivocally preferred as the new strategy brings lower costs and emissions. In the Quadrant I the decision depends on the customer's WTP for environmental improvements. The strategies in Quadrants II and III should be avoided, since they provoke higher emissions. The analysis enables industries to visualize and quantify the trade-offs between economic and environmental objectives. Furthermore, it incorporates customer WTP as a dynamic threshold, reflecting societal preferences for sustainable practices. This approach aligns with the principles of the circular economy and promotes data-driven, stakeholder-informed decision-making. Moreover, to address the uncertainty inherent to remanufacturing processes and market dynamics, especially at this level of maturity, we extend the analysis by employing acceptability curves. These curves visualize the probability that a given strategy is cost-effective across a range of WTP thresholds. By incorporating variability in input parameters, the acceptability curve enhances decision-makers' confidence in selecting robust and sustainable options, even under uncertain conditions.

The proposed methodology will be demonstrated through a case study assessing the potential of remanufacturing for an Original Equipment Manufacturer (OEM) under two scenarios, centralized and decentralized. We will use a Discrete Event Simulation in order to obtain results for costs and CO2 emission. We will develop a probabilistic sensitivity analysis running 100 simulations. Figure 1 shows hypothetic results for the cost-effectiveness results of both scenarios. The centralized scenario is dominant, meaning that both costs and emissions are lower in the circular strategy. However, in the decentralized scenarios, despite emissions being lower in the circular strategy, costs are higher with an incremental cost-effectiveness ratio of 33,619.03€/kg of CO2, with a IC 95% of 31,682.70 and 35,555.36. Moreover, Figure 2 shows the probability of the strategy being cost effective for different WTP thresholds. For instance, the probability of decentralized scenario being cost effective is of the 30% if the customer's WTP is of 30,000€/kg of C02. This value will increase to an 80% if the customer's WTP is of 40,000€/kg.

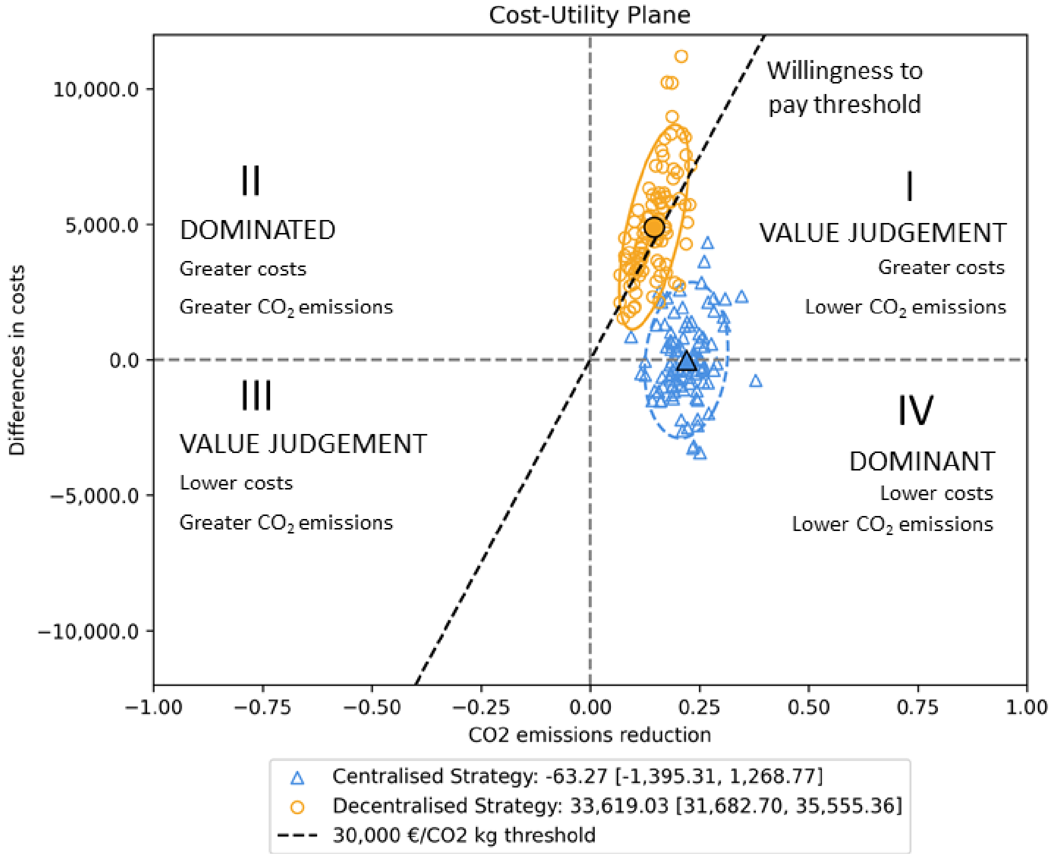

Figure 1. Cost-effectiveness plane for two circular economy strategies vs manufacturing

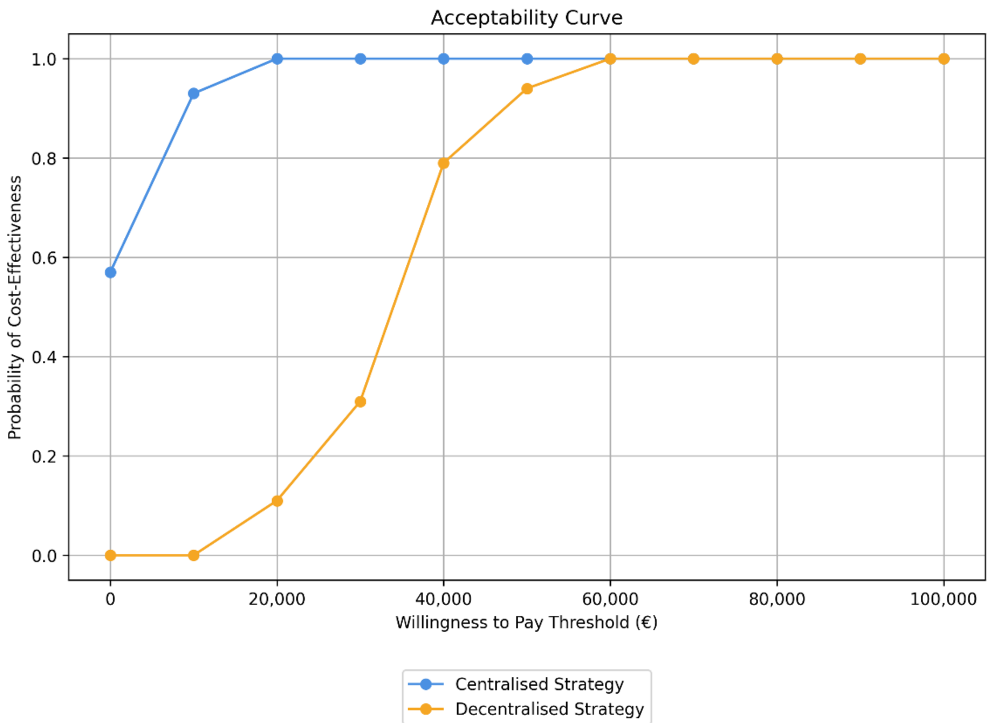

Figure 2. Acceptability curve for two circular economy strategies vs manufacturing

Keywords: Decision-making, Circular strategies, Cost effectiveness, Acceptability curve

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Revaluing Re-manufacturing. A systems thinking approach to enhancing the value of remanufacturing for the circular economy

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Remanufacturing, a practice rooted in the industrial revolution, has historically delayed capital expenditures by extending the life of products. Its value lies in its ability to repair, upgrade, and preserve resources—a philosophy once embodied by a "make-do-and-mend" mentality.

However, since the 1970s, this mindset has given way to a "take-make-waste" paradigm, driving climate change, diminishing skills and capabilities, and eroding critical know-how. This societal shift has conflated cost with value, embedding short-term profit-driven models into business operations while neglecting the broader, long-term impacts—a perspective in urgent need of revaluation.

Remanufacturing is a key enabler for the circular economy which offers a transformative opportunity to redefine value creation through systems thinking. Despite its potential, latest research suggests that systems thinking is not being deployed effectively to change how we perceive value and optimising processes within remanufacturing. This gap presents a significant opportunity to explore how systems thinking can uncover alternative value streams, enabling businesses to innovate and thrive in a circular economic framework.

This paper, underpinned by research from the University of Derby and supported by the Institute of Asset Management, offers a high-level literature review exploring the intersection of remanufacturing, systems thinking, and the circular economy. It carries out a high level literature review of the relationship between asset management, remanufacturing, systems thinking and the circular economy and explains how additional value streams can be created to inform business strategies that embraces remanufacturing as an enabler for the circular economy.

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