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16

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Dear reader,

The manufacturing sector stands at a pivotal crossroads. For decades, manufacturing has driven progress, prosperity, and innovation, but often at the expense of our planet's finite resources. Today, a new philosophy is reshaping the way we make things: a circular approach. This movement is not just about efficiency or profit. It's about designing processes that sustain, repair, and regenerate the world we rely on.

Remanufacturing lies at the heart of this transformation and of the articles presented in this issue. By restoring used products to "like-new" condition, manufacturers can reduce material waste, energy consumption, and carbon emissions. It turns end-of-life into a new beginning, keeping valuable materials in circulation rather than letting them diminish. There is even the possibility of upgrading products (better-then-new) during this process. A circular approach also requires us to look more closely at the products we discard. In-depth analysis of discarded products can highlight the potential for reuse, repair and reconditioning.

In this issue of InnovatieNU, we can see the value of circularity in areas ranging from lead-acid battery reconditioning, through extending the life of components through additive manufacturing, up to the development of digital product passports. Advancing circularity demands efforts from an array of stakeholders in the manufacturing industry. It is not a single-party intervention. From policy change, to academic research, and different sectors of industry, from packaging to healthcare. The diversity of efforts are collected in the articles you are about to read to widen your understanding of possibilities and to inspire your next steps.

"Made with circular thinking" is more than an inspirational slogan; it's a call to action. It's proof that innovation and responsibility can go hand-in-hand and that the manufacturers of tomorrow can build not just products, but a sustainable future for all. Think of this issue as an invitation to rethink the way we create value and to build a future where manufacturing and sustainability advances hand-in-hand.

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CONTENT

Add-reAM

Building a Circular Future through ***Additive Remanufacturing***

The Dutch manufacturing industry stands at the forefront of Europe's transition toward a circular economy. Yet the sector still faces a critical challenge: how to move from a linear model of "make, use, discard" to one that keeps materials and products in use for as long as possible. A new national research and innovation initiative, Add-reAM, aims to provide the answer.

Add-reAM, which stands for ***Advancing the Dutch Circular Economy through Additive Manufacturing: Strategies for Repair and Remanufacturing using AM***, has been awarded €6.8 million under the Dutch Research Agenda (NWA-ORC 2024) programme. Led by Professor Ian Gibson of the University of Twente, in collaboration with the Materials Innovation Institute (M2i), the project brings together the country's leading universities and major industrial partners. These include SKF, Signify, RAMLAB, Capgemini Engineering, Repair Cafe and Allseas, working alongside municipalities and knowledge institutes.

Their shared mission is clear: to make repair the new standard and remanufacturing the driving force of a sustainable, circular manufacturing industry.

From Linear to Circular Production

Traditional manufacturing processes, even when supported by advanced recycling systems, are often wasteful. Valuable materials, embedded energy and technological know-how are lost when products reach the end of their first life. Recycling can recover part of this value, but often through downcycling, where materials and components lose quality and usefulness.

Add-reAM offers a different approach. By using Additive Manufacturing (AM), also known as 3D printing, components can be rebuilt, upgraded and reused instead of discarded. AM enables rapid, localised production of spare parts and opens new possibilities for repair and remanufacturing across sectors such as aerospace, rail, and heavy machinery.

The consortium's targets are ambitious but measurable. Add-reAM aims to reduce production waste by 30 percent, cut maintenance downtime by 20 percent, and lower CO_2 emissions and e-waste by 20 percent. These figures demonstrate not only the environmental benefits but also the operational and financial value of embracing circular production.

"Additive manufacturing allows us to rethink the way we create and maintain products," says Professor Gibson. "Instead of designing for obsolescence, we can design for longevity. By integrating repair and remanufacturing into production systems, we reduce waste and strengthen industrial resilience."

Technology Meets Intelligence

Additive Manufacturing is already well established in prototyping and specialised production. What Add-reAM seeks to do is scale it up and integrate it into mainstream industrial operations. To achieve this, the project combines advanced 3D printing techniques with artificial intelligence and digital quality monitoring.

AI-supported tools will help manufacturers make data-driven decisions about when and how to repair components. They will be able to predict wear and failure, recommend optimal repair strategies and ensure that remanufactured parts meet or exceed original performance standards.

At the same time, design guidelines for 3D-printable spare parts will help companies standardise digital inventories and simplify logistics. This will enable decentralised and on-demand production, reducing the need for large warehouses filled with rarely used components.

For companies operating in high-value sectors such as aerospace or maritime engineering, where downtime costs are high and part availability is critical, the combination of AM and AI offers a significant competitive edge.

A Business Case for Sustainability

Circular manufacturing is often perceived as a sustainability initiative, but Add-reAM positions it firmly as a business opportunity. The Netherlands' manufacturing sector employs more than 600,000 people and adds around €47 billion to the economy each year. Yet it remains highly resource intensive.

> **"Instead of designing for obsolescence, we can design for longevity. By integrating repair and remanufacturing into production systems, we reduce waste and strengthen industrial resilience."**

By rethinking production processes, companies can cut costs, improve efficiency and enhance their resilience to global supply chain disruptions.

Additive Manufacturing enables production to take place closer to where it is needed. Spare parts can be produced locally, often within hours rather than weeks, reducing logistics costs and dependency on international suppliers. For large industrial players, this opens the door to new service-based business models, where the focus shifts from selling new components to extending the lifetime of existing ones.

Small and medium-sized enterprises also stand to benefit. AM technologies are becoming more accessible and affordable, allowing SMEs to offer niche repair and remanufacturing services that were previously out of reach. By combining local production with digital design and data analytics, they can participate in new circular value chains that reward quality, flexibility and innovation.

Aligning People, Policy and Practice

Technology alone cannot deliver the circular transition. Add-reAM recognises that policy frameworks, education and social acceptance must evolve in parallel.

The consortium will work with industry associations, public agencies and academic institutions to help develop the knowledge and regulatory clarity required for large-scale adoption of AM-based repair and remanufacturing. Clear standards and certification procedures will be crucial to build confidence among both manufacturers and consumers.

Equally important is education. Universities and technical institutes will use insights from Add-reAM to develop training programmes that equip engineers, designers and technicians with the skills needed for Industry 5.0. This will ensure a workforce that understands not only how to produce efficiently, but also how to design for longevity and circularity from the outset.

A cultural shift is needed in how businesses and consumers perceive remanufactured products. Research within the project will examine how product design, communication and customer experience can increase trust in repaired and remanufactured goods. By demonstrating that such products can meet high performance standards, the project aims to remove one of the last psychological barriers to circular consumption.

Collaboration for Impact

The scale of the Add-reAM consortium reflects the magnitude of the task. It brings together expertise from materials science, production engineering, logistics, environmental assessment, behavioural science and law. Industrial partners contribute real-world challenges and test environments, ensuring that research results are directly applicable in practice.

The project will demonstrate the benefits of AM-based repair and remanufacturing through pilot cases

> **By combining local production with digital design and data analytics, [SMEs] can participate in new circular value chains that reward quality, flexibility and innovation.**

in sectors including aerospace, construction and rail infrastructure. By showing how these technologies work in real industrial contexts, Add-reAM will provide a foundation for broader adoption across the manufacturing landscape.

Beyond technical innovation, the initiative also strengthens collaboration between academia, industry and policymakers. This integrated approach is essential to achieving the long-term ambition of a circular, climate-neutral Dutch economy by 2050.

Remanufacturing for Growth and Good

The vision behind Add-reAM goes beyond environmental responsibility. It represents a new economic paradigm where waste is eliminated, resources are kept in circulation and value is created through longevity rather than volume.

For business leaders in the high-tech manufacturing sector, this project signals a future where circularity and competitiveness go hand in hand.

By combining digital technologies with sustainable design, Dutch industry can enhance its global position while meeting urgent climate goals.

As Professor Gibson summarises, “Add-reAM is not just about developing new tools or processes. It is about changing the mindset of manufacturing. When repair becomes part of the business model and remanufacturing becomes a strategic capability, sustainability becomes a strength rather than a cost.”

In the years ahead, the success of Add-reAM will be measured not only by the technologies it develops, but by the way it reshapes industrial practice. It offers a compelling vision for how additive manufacturing can support both prosperity and the planet — a truly modern example of remanufacturing for good. ▪

Add-reAM Academic Partners

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DESIGNING FOR REPAIR

*LESSONS FROM THE EU'S **RIGHT TO REPAIR** MOVEMENT*

Across Europe, the way we think about product design is changing. The traditional model of consumption, where products are made, sold, used, and then discarded, is giving way to a more circular vision. Durability, repairability, and remanufacturing are no longer niche ideas; they are increasingly at the centre of product policy and innovation.

At the forefront of this shift is the Right to Repair movement, which calls for products to be designed so that they can be fixed easily, affordably, and for many years after purchase. In the European Union, this movement has influenced a wave of legislative changes that aim to make repair more accessible. But while progress has been made, the road to a truly repairable product ecosystem is still long.

To understand the opportunities and challenges, we spoke with Cristina Ganapini, Coordinator of the Right to Repair Europe coalition, whose advocacy has shaped much of the current policy landscape.

She points to recent EU regulations, such as the Battery Regulation, the minimum eco-design requirements for smartphones and tablets, and the Right to Repair Directive, which have introduced important new measures. These include requirements for easier device disassembly, mandatory spare parts availability, repair scores, and obligations for manufacturers to provide repair services even after the guarantee period.

Cristina views these steps as significant but not transformative. "The direction is promising," she says, "but the scale and pace of change fall short of delivering a universal Right to Repair and unlocking viable circular business models." As of 2025, only a small number of product categories are covered by repairability rules, and often only specific parts are accessible. Many products still sit entirely outside any legal obligation to be repairable, and even where laws exist, enforcement remains a challenge, with spare part pricing rules vague and software practices that impede repair still allowed.

Barriers to Effective Repair

Even with these regulations in place, significant obstacles remain in achieving truly repairable products. Change must begin at the design stage, yet many products are still built in ways that make disassembly difficult or impossible without specialist tools. Adhesives, proprietary fasteners, and sealed casings create unnecessary obstacles, while one of the most problematic trends is software-controlled parts pairing. This practice locks replacement parts via the manufacturer's software, preventing them from functioning unless "authorised" or paired. While the Right to Repair Directive addresses this to some extent, Cristina warns that exceptions and vague definitions leave loopholes wide open.

Access to diagnostic tools, internal components, and repair information also remains patchy. “Without comprehensive access,” Cristina notes, “both consumers and independent repairers face severe limits on what repairs they can carry out effectively.” Even where repairs are technically possible, they often fail the affordability test. Price is consistently the number one barrier reported by both consumers and professional repairers. If a repair costs more than 20–30% of a new product’s price, most people will choose to replace rather than fix.

Spare parts make up a large share of this cost. Ideally, their prices should be no more than 15–20% of the product’s retail value. Yet in many cases, they are far higher, making repair uneconomical and undermining circular economy ambitions. This is why Cristina and the coalition are pushing for spare part pricing to be a core metric in repairability scoring and policy enforcement.

From Europe to the World

Alongside addressing these barriers, upcoming changes such as the EU’s repairability label requirement have strong potential to influence both design and consumer choice. From June 2025, smartphones sold in the EU will display a repair score at the point of sale, similar to the French repair index. This score will be based on factors such as ease of disassembly, availability of repair guides, and access to spare parts. Cristina expects this to create a competitive incentive for manufacturers to improve repair-related aspects of their products. However, she warns that without including spare part prices in the score, the label risks misleading consumers. “A product might score high for technical repairability but still be prohibitively expensive to fix in practice,” she says.

For marketers, these labels offer an opportunity to showcase a brand’s commitment to sustainability and product longevity, provided the scoring system reflects real-world repairability. The EU, often a global trend-setter in product regulation, may well see its Right to Repair framework, even in its current limited form, set a precedent internationally. Manufacturers could choose to apply EU standards globally, avoiding the need to create separate models for different markets, which in turn could encourage better design and after-sales practices worldwide.

Yet for this influence to be truly impactful, EU policies must become broader and more enforceable. Cristina points out that the piecemeal, category-by-category approach slows progress. Clearer, more comprehensive standards are needed, particularly on spare part pricing, long-term software support, and rights for self-repair, if the EU is to accelerate the global shift towards circular product lifecycles.

> **We are not just fighting for the Right to Repair, but for the right to choose products that respect our environment and our intelligence.**
>
> — *Cristina Ganapini*

Lessons for Industry and Policy

From our conversation with Cristina and the EU's evolving policy framework, several lessons stand out for manufacturers, marketers, and policymakers:

1

Design with repair in mind from day one, ensuring modularity, standardised fasteners and minimal adhesives.

2

Control the total cost of repair, recognising that affordable spare parts are as important as their availability.

3

Remove software barriers, since parts pairing and locked diagnostics undermine repairability.

4

Use repairability as a brand advantage by leveraging labels and scoring to communicate sustainability commitments.

5

Support broad, enforceable standards that close loopholes and apply across more product categories.

A Shared Responsibility

The Right to Repair is not just a policy issue; it is a design challenge, a market opportunity, and a consumer right. By aligning these dimensions, Europe can move closer to a product ecosystem where longevity is the norm and waste is the exception.

As Cristina reminds us, "We are not just fighting for the Right to Repair, but for the right to choose products that respect our environment and our intelligence." In the context of remanufacturing, this is not simply about extending product life, but about designing the circular economy into the product from the very start. ▪

ADAPTIVE LAW AND REMANUFACTURE IN THE CIRCULAR ECONOMY

To remanufacture is to restore used products or components to a performance standard which equals or exceeds that of newly produced ones. Remanufacture prolongs lifecycles, reduces demand for materials, lowers emissions, and creates jobs and skills, yet it is fairly uncommon in practice. Technical barriers are to blame in part, but here we focus on the role of governance structures such as laws, liability regimes, and product regulations. At present, the structures in question are intended for a linear make-use-discard economy, and their chief concern is with the first life of products – little provision is made for repair, refurbishment, remanufacture, or re-entry into the market. Two concepts from EU law and scholarship are meant to disrupt this make-use-discard paradigm: Safety and Sustainability by Design (SSbD) and the right to repair.

Safety and Sustainability by Design and the Right to Repair

SSbD actuates the legal principles of precaution and prevention by amalgamating two concepts: Safe by Design (SbD) and Sustainable by Design (SuBD) (Reins & Wijns, 2025). The first, SbD, is about anticipating hazards to human health and the environment and "designing them out" across the lifecycle of the product. First proposed in the mid-20th century and later formalised in initiatives such as the U.S. "Prevention through Design" (Schulte et al., 2008), SbD has been applied in sectors as varied as construction, consumer goods, aviation, and nanotechnology. The other component of SSbD, SuBD, imprints considerations of environmental, social, and economic sustainability into the early stages of design. SuBD aligns with various trends in contemporary EU policy, including eco-design and circularity by design, as reflected in the Circular Economy Action Plan (European Commission, 2020) and the Eco-design for Sustainable Products Regulation, which came into effect in 2024.

As far as remanufacture is concerned, SSbD gives full play to the objectives of the Union in the domains of safety and circularity. First, repair, refurbishment, and remanufacture are likely to be more viable when products are both safe and sustainable from the outset. Second, modularity and avoiding hazardous substances conduce to longer lifecycles. The right to repair complements SSbD by ensuring that products which are designed to last will last in fact. Owners and their representatives are accordingly equipped with the right to access tools, spare parts, software, and technical documentation in order to repair products. While it is commonly associated with consumer goods such as household appliances, electronics, and vehicles, this right is no less relevant to industrial equipment, high-value components, and complex machinery.

A robust right-to-repair framework rectifies information asymmetries by requiring manufacturers to make pertinent information available to legitimate providers of repairs (Terryn, 2019). Furthermore, spare parts must remain accessible for the intended life of the product, while contractual terms and technological measures that obstruct lawful repair, such as software locks, are inconsistent with the right and therefore ought to be banned. The right to repair also supports economic decentralisation by enabling independent repair networks and small and medium-sized enterprises to flourish.

The right to repair operates in tandem with SSbD: design choices make repairs safe and sustainable, while legal rights ensure that repairers may claim to the resources which they need. This synergy is particularly important for remanufacture because disassembly, part replacement, and testing require both a high degree of technical compatibility and unfettered access to technical resources.

The Need for an Adaptive Law

Whatever their merits, SSbD and the right to repair cannot bring about a circular economy on their own. Manufacturing technologies, material sciences, and sustainability priorities change quickly, and the applicable regulatory frameworks aimed at protecting the environment should develop in step (Quintavalla and Yalnazov, 2025). An adaptive legal approach to SSbD and remanufacture would focus on desired parameters, such as durability, reparability, and environmental performance, rather than staid technical prescriptions. Regular review and collaborative governance are thus of the essence. The various stakeholders which will people the circular economy, such as manufacturers, consumers, and waste-management entities, may have different needs, which a rigid right to repair whose form and substance are set in stone may well fail to meet. The Add-reAM Project, in which both of us are involved, is about this problem. We will first analyse SSbD principles and the right to repair in the context of remanufacture. We will then examine the legal, technical, and policy links between these principles, identify points of overlap and tension, and assess various proposals for reform. Our goal will be to develop a dynamic regulatory roadmap for remanufacture policy that is not a static compliance checklist but a forward-looking governance tool that is designed to evolve with technology, society, environmental protection and the market.

Conclusion

Traditional manufacturing in Europe, including in the Netherlands, is resource intensive, wasteful, and harmful, and it induces consumers to prefer replacing to repairing. Recycling helps a little, but its outputs are often degraded, and it requires a non-negligible outlay of energy. With national and EU policy now gearing for the ascent of a genuinely circular economy and with additive manufacturing having matured sufficiently to make a real difference (Inayathullah & Buddala, 2025), the time has come to close the knowledge gaps that remain.

The future of remanufacture will be shaped as much by law and policy as by technological innovation. Embedding SSbD and the right to repair into adaptive regulation will allow remanufacture to be scaled across industries. In the last analysis, the three concepts which we adumbrated here reinforce one another: SSbD ensures that products are physically and environmentally suited for multiple lifecycles, the right to repair guarantees that the tools, knowledge, and parts that are needed for those reincarnations are accessible, and adaptive lawmaking generates flexible regulation which develops in synchrony with technology and society. ▪

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CIRCULAR CARE IN PRACTICE

REUSE AND REMANUFACTURING AS A KEY TO SUSTAINABLE HEALTHCARE

The healthcare sector faces growing pressure. Not only are healthcare costs rising, but the environmental impact and use of scarce raw materials are a cause for concern. In the Netherlands, healthcare accounts for around 12% of national raw material consumption and 7% of CO_2 emissions. To make healthcare future-proof, it is important to extend product life cycles and reduce waste.

Reuse plays a key role in this, ranging from sterilisation at the Central Sterilisation Department (CSA) to remanufacturing (the technical reprocessing of instruments).

The *High-Quality Medical Instrument Reuse* (HHMI) project is investigating how these strategies can be applied in practice and which design principles need to be considered.

From sterilisation to reprocessing

For decades, hospitals have relied on the CSA to clean and sterilise medical instruments after use. However, over the past twenty years, more and more high-quality instruments, such as surgical staplers and ultrasonic scalpels (Figure 1), have been marketed as single-use products. Infection prevention, convenience, time savings, and a favourable business model have ensured the current model remains in place.

The result: reliable and efficient care, but instruments made from high-quality materials end up in the waste stream after a single use. Because sterilisation is not always technically or legally possible, hospitals often lack alternatives. In some cases, remanufacturing offers a solution. Where CSA stops, reprocessing continues: instruments are dismantled, checked, repaired and revalidated outside the hospital. This creates a product that can be safely reused without compromising on quality or functionality.

The HHMI project

The RAAK-MKB project on the reuse of high-quality medical instruments, led by Saxion University of Applied Sciences' Industrial Design research group, is investigating how medical devices can be made suitable for reuse – both through redesign and reprocessing. The focus extends beyond product design to the entire system: logistics, cleaning, quality assurance, and validation.

A broad group of public and private partners is involved, including Medisch Spectrum Twente (MST), the Association of Experts in Sterile Medical Devices (VDSMH), Santeon, Logic Medical, R-Solution, Oceanz, Implican, Vanguard A.G., First15 and Wittenburg Group.

Practical cases

The project takes a practical approach to learning. By working real-world cases, we gain generic insights into the reuse and reprocessing of medical instruments.

Implican is developing a reusable intestinal anastomosis device (used to connect two sections of intestine) based on an innovative healing technique. The focus here is on iterative design with attention to sterilisability and user experience.

How can reusability be integrated into medical device development?

Vanguard A.G. is investigating how the collection of single-use devices can be scaled up to a robust process to enable large-scale reprocessing.

What is needed to collect existing single-use devices for reprocessing?

First15 supplies emergency medical kits and is investigating within HHMI the extent to which their innovative tourniquet is suitable for multiple use.

How can you assess whether an existing product is suitable for reuse?

Wittenburg Group focuses on circular plastics that can withstand sterilisation and reprocessing, so that high-quality materials can be reused in the healthcare chain.

What properties are required for multiple sterilisation of plastics and in which medical instruments can these be applied?

In all cases, user research is essential. The involvement of surgeons, surgical assistants, CSA staff and purchasers is crucial in order to map out the context surrounding the circularity of medical instruments.

Challenges surrounding the reprocessing of instruments

Vanguard is an international company that repurchases used single-use instruments, cleans and reprocesses them, and reintroduces them as CE-marked products This extends the lifespan of high-quality materials while saving hospitals both purchasing and waste disposal costs.

Various **life cycle assessments** show that this also pays off ecologically. A Fraunhofer UMSICHT study (Schulte et al., 2021) showed that reprocessing electrophysiology catheters scores better than new production in 13 of the 16 impact categories, with more than 50% less climate impact. A follow-up study (Meister et al., 2022) showed CO_2 emissions per use are up to 60% lower with reductions of 57% over the total lifespan.

With the introduction of the Medical Device Regulation (MDR), remanufacturing was formally recognized and regulated at the European level. Depending on the category, a remanufacturer may be treated as an external service provider (CS remanufacturing) or as a full manufacturer (CE remanufacturing).

While this provides a clear framework, it also creates significant hurdles. Extensive documentation requirements and a structural shortage of **Notified Bodies** – the independent organizations that certify medical devices – result in high costs, long delays, and uncertainty. As a consequence, technically proven and ecologically valuable solutions often fail to scale.

Vanguard actively works to overcome these barriers: by investing in certification processes, sharing evidence from practice, and engaging with hospitals and regulators, the company helps demonstrate that remanufacturing can be safe, sustainable, and cost-effective. Yet the speed of adoption still depends heavily on national choices under Article 17 of the MDR, which vary across Europe.

Initial results

The initial results of this research can be summarised in two areas: the **opportunities and barriers** that determine the context of circular care, and the **design guidelines** that provide direction for the development of future-proof medical instruments.

Opportunities and barriers

Technical and system innovations must go hand in hand. Without regulatory adjustments and greater certification capacity, the potential of remanufacturing in healthcare will remain largely untapped.

It is important to note that reuse and remanufacturing are complementary and not competing. Together, they form a necessary backbone for circular healthcare practice.

Multiple value is an important advantage: reuse and remanufacturing not only save on hospital waste costs, but can also be more financially beneficial in the long term and reduce dependence on raw materials.

An adapted product alone is not enough. The entire system must adapt: return logistics, quality control, capacity at CSAs and operational processes must be adjusted. With the rise of single-use (disposable) instruments, CSA capacity has generally been scaled down. It also appears that different stakeholders have divergent interests. Whereas purchasers and insurers focus primarily on costs, CSA employees emphasise cleanability.

Small, modular steps are achievable. Early adopters such as MST and Erasmus MC play a crucial role in building trust and paving the way for others.

Circular care not only contributes to making the healthcare sector more sustainable, but also to the broader social transition to a circular economy.

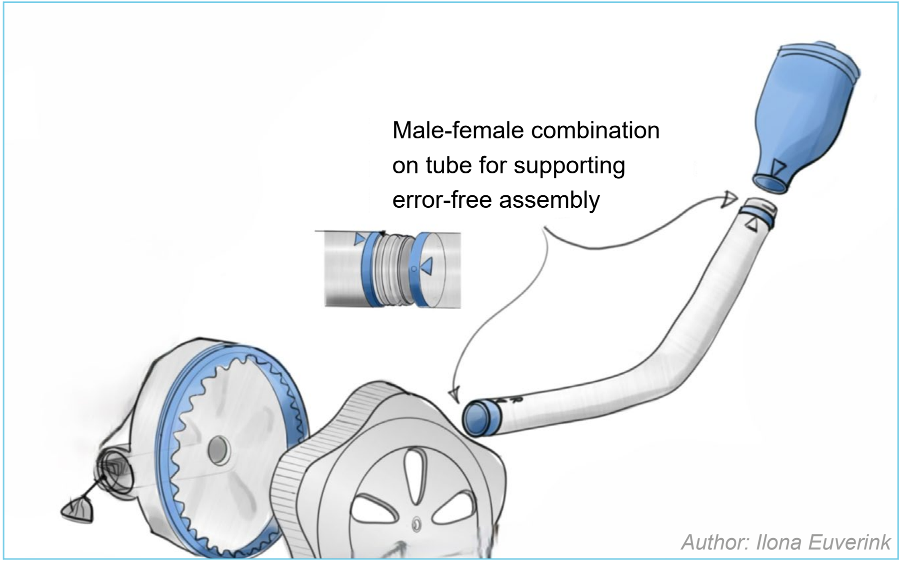
Design guidelines

Sterilisable and sustainable use of materials: materials must be suitable for repeated use without loss of quality.

Cues for foolproof assembly: components must be intuitively correct to assemble in order to reduce the risk of incorrect assembly in the CSA department, which causes delays and possibly even dangerous situations in the operating theatre (Figure 2).

Minimise the impact on CSA capacity: instruments should be designed to be modular and dismantlable, or equipped with sufficient flow openings, so that all surfaces are effectively accessible for mechanical cleaning and steam penetration during sterilisation. Dimensions and geometry must match the standardised dimensions of CSA baskets and trays to ensure compatibility with existing cleaning and logistics processes.

User involvement of all users from the outset: design choices must be in line with practice and increase acceptance among end users. For example, involve the CSA department from the outset in considering the cleanability of the device. Simple but fundamental choices for certain materials can sometimes be decisive in determining whether a product is suitable for reuse or not.



Author: Ilona Euverink

Towards a circular ecosystem

Every reused instrument has a positive effect on raw material scarcity, the enormous waste mountain and the carbon footprint of the healthcare sector. Circular care not only contributes to making the healthcare sector more sustainable, but also to the broader social transition to a circular economy.

Redesigning instruments for reuse and reprocessing single-use devices are part of a larger transformation in healthcare. The potential is significant: many medical products are still not designed with reuse in mind. The HHMI project demonstrates that, with collaboration and smart design, real progress is possible.

Knowledge sharing and collaboration are essential to further strengthening this ecosystem. Only in this way can healthcare be made sustainable and future-proof. ▪

The invitation for an exploratory meeting is open; this project started in August 2024 and will run until August 2026.

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AMC NU

CIRCULAR MANUFACTURING SYSTEMS PROGRAM (CMSP)

Powered by: **RegioDeal Twente**

The Fraunhofer Innovation Platform for Advanced Manufacturing at the University of Twente (FIP-AM@UT), in collaboration with the regional government and industry partners, has launched the Circular Manufacturing Systems Program (CMSP) to advance sustainable, automated, and efficient production processes. The program strengthens the high-tech manufacturing sector in the eastern Netherlands by promoting circularity across various industries, including energy storage and broader industrial applications.

CMSP focuses on optimising manufacturing through automation, material recovery, and modular product design, fostering collaboration between regional and international partners to drive sustainability and waste reduction. By integrating digital tools and innovative production techniques, the programme enhances efficiency, traceability, and resource management.

A key aspect of CMSP is industrial collaboration. Participating companies gain access to cutting-edge research, technological advancements, and cross-sector knowledge exchange.

Through demonstrators, pilot projects, and training initiatives, FIP-AM@UT ensures that innovations developed within the program are widely adopted, strengthening the region's manufacturing competitiveness and sustainability.

Supported by the RegioDeal Twente, with funding from the Province of Overijssel and the Dutch State, CMSP aims to position Twente as a European hub for advanced manufacturing. The programme stimulates economic growth, attracts talent, and encourages investment in sustainable technologies.

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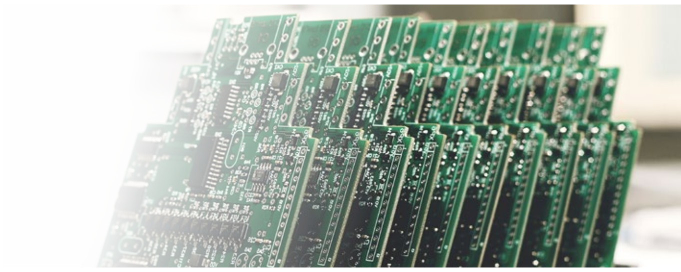
CyclePCBA

with DeltaProto



The CyclePCBA project, developed in collaboration between FIP-AM@UT and DeltaProto, aims to **modernise quality assurance in high mix, low volume PCBA production by enabling earlier and more reliable image-based defect detection.** As PCBAs continue to incorporate increasing numbers of miniaturised components, traditional visual inspection methods struggle to identify subtle faults in time to prevent unnecessary waste.

CyclePCBA addresses this challenge by developing a proof-of-concept software stack capable of extracting component-level features from surface-captured images and recognising failure types such as misplacements, misalignment and tombstoning. This early insight enables operators to intervene before electrical testing reveals faults that may already have caused irreversible damage, supporting greater circularity and digitalisation within electronics manufacturing.

The project strengthens automation, sustainability and efficiency by reducing material consumption, improving component reusability, and establishing a scalable digital inspection method suitable for regional manufacturing environments. It also generates valuable insights into rapid defect detection and intelligent surface inspection, supporting wider knowledge sharing and industry adoption.

CyclePCBA advances **UN SDG 12 by minimising waste during production and SDG 9 through enhanced industrial innovation.** Overall, the project helps build more resilient and resource-efficient electronics manufacturing processes.

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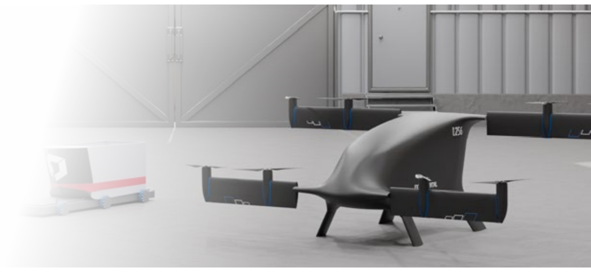
L-UCAS

with LogiXair



L-UCAS, a project partnership between FIP-AM@UT and LogiXair, focuses on **developing lightweight and recyclable composite materials for the next generation of unmanned cargo aircraft.** As UAV logistics platforms expand, there is a growing need for structural materials that combine low weight, high durability and improved sustainability. Conventional carbon-fibre thermoset composites provide strong mechanical performance but are energy intensive to produce, costly and difficult to recycle, creating clear limitations for circular aviation.

L-UCAS addresses this challenge by establishing a digital framework for virtually exploring bio-based fibres, recyclable thermoplastics and hybrid composite configurations. Through multiscale material modelling, topology optimisation and finite-element analysis, the project identifies material–structure combinations that reduce weight while meeting aerospace performance standards. This virtual-first approach enables rapid screening of sustainable materials, early optimisation of UAV components such as spars and fairings, and the integration of circular design principles through the development of digital material passports.

In doing so, the project supports broader regional ambitions to strengthen circular manufacturing capabilities, reduce environmental impact and encourage the adoption of sustainable, data-driven engineering methods. Its focus on recyclable materials, lightweight design and digitally enabled decision-making aligns with efforts to advance automation, sustainability and resource efficiency across the manufacturing value chain.

By improving understanding of recyclable composites and enabling energy-efficient UAV structures, L-UCAS advances **SDG 12 through responsible material use and SDG 9 through innovation in industrial design processes.**

Learn more about other CMSP projects on the AMC NU section from InnovatieNU 14th and 15th edition!

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RETHINKING WASTE

HOW SIMULATION IS POWERING A NEW ERA IN REMANUFACTURING

As sustainability pressures increase and resource scarcity becomes an industrial reality, remanufacturing is emerging as a cornerstone of the circular economy. No longer confined to refurbished electronics or remoulded car parts, the scope of remanufacturing is expanding. It is reshaping how we design, manufacture, and reuse materials across sectors. Nowhere is this shift more evident than in the packaging industry, where innovations in simulation and materials science are enabling companies to dramatically reduce waste while delivering uncompromised performance.

At the forefront of this transformation are projects like ***EcoCup*** and ***EcoTray***. The first focused on material usage for coffee capsules, and the latter, addressing medical-grade aluminium tray production. These initiatives demonstrate the profound potential of digital design and predictive modelling to bring recycled aluminium back into high-performance use in food and beverage packaging.

From EcoCup to EcoTray: Simulation as a Circular Enabler

Both EcoCup and EcoTray address the same fundamental challenge: how to reliably remanufacture precision-formed aluminium packaging using downgauged, high-recycled-content materials without compromising structural integrity, aesthetics, or compliance with strict regulatory and food safety standards.

Traditionally, forming such components through deep drawing, which shapes flat metal into precise, hollow forms, has relied on conventional, high-purity aluminium and iterative physical prototyping. This results in high scrap rates, excess energy use, and costly development cycles. In contrast, these two projects use simulation-driven remanufacturing to accelerate development and significantly reduce waste.

In *EcoCup*, the focus is on the growing coffee capsule market, where aluminium remains the material of choice for its barrier properties and recyclability. Using up to 90% recycled aluminium, the project demonstrated 10% material downgauging while maintaining capsule performance and visual identity. The anisotropic mechanical behaviour of recycled alloys was captured through tensile testing and integrated into finite element models. This enabled us to simulate the deep drawing process with high precision.

EcoTray, developed by the University of Twente and Amcor, was initiated after observing EcoCup's demonstrated potential and applies the same approach to medical-grade aluminium trays. It targets a transition from 160 micrometres to 130 micrometres using at least 30% recycled content. With realistic tribological models and advanced friction characterisation, EcoTray supports the use of thinner, lower-carbon materials. This leads to a reduction in raw material usage by nearly 20% and enables trays to be produced from low-carbon aluminium of 5 kilograms of CO_2 per kilogram or less. Most importantly, the simulation framework predicts forming defects before they occur, eliminating much of the trial-and-error and tool rework that typically characterises conventional manufacturing.

Together, these projects highlight the power of data-driven remanufacturing. They showcase a methodology that links virtual validation with real-world outcomes, allowing manufacturers to make sustainable design decisions early in the process and scale them efficiently.

From Single-Use Thinking to Systemic Circularity

These innovations also align with broader shifts in consumer and regulatory expectations. While packaging may appear to be inherently single-use, the principles behind its transformation — reuse, downgauging, and smart material usage — mirror those reshaping business models from linear to a circular approach. What unites these trends is a push for producing high-quality products with longer product lifespans, reduced material dependency, and greater transparency around production impact.

By converting recycled aluminium into high-performance components that match or exceed virgin standards, EcoCup and EcoTray show how remanufacturing can become a strategic enabler for circular business models.

Building a Circular Infrastructure

What makes these projects especially relevant is not only their technical success but also their collaborative framework. Initiated with the support of the Regio Deal Advanced Manufacturing Program (AMP) and further strengthened by M2i, they represent a new model for innovation. Academia, industry, and regional governments are working together to address pressing challenges with shared urgency and open data.

As the EU's Packaging and Packaging Waste Regulation (PPWR) raises the bar on recyclability and lifecycle performance, such partnerships will be critical. The frameworks developed in EcoCup and EcoTray are both scalable and transferable across sectors, offering a blueprint for manufacturers ready to lead in a circular future.

In a time when sustainability is no longer a side objective but a defining measure of competitiveness, remanufacturing has evolved from repair to reinvention. With the right tools, it becomes not just a regulatory response but a catalyst for innovation. ■

In a time when sustainability is no longer a side objective but a defining measure of competitiveness, remanufacturing has evolved from repair to reinvention.

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REMANUFACTURING AT SPEED

WHAT EUROPE CAN LEARN FROM CHINA'S TECH ECOSYSTEM

At the beginning of July, I embarked on an inspiring week in China, as part of a China Tech Tour (organised by INNO-APAC). In this immersive week-long journey, alongside 30 participants from diverse countries, I explored cutting-edge tech ecosystems across Shanghai, Hangzhou, and Kunshan (Suzhou).

We visited various industrial sectors, including biology, cosmetics, wastewater treatment, Photovoltaic (PV) panels, metaverse etc. Some of the companies I found the most impressive included e-commerce giants like Alibaba, GCL Perovskite, who make solar panels which are over 26% efficient, and Visionox, who produce flexible AMOLED screens. PV panel producers in China are piloting mechanical, physical, and chemical processes to disassemble decommissioned solar modules and recover high-value materials for reuse.

I was also very impressed by the ambitious developments in the Fengxian District and the Future Science City. These cities are being built specifically to accommodate tech companies and start-ups, while also aiming to create an enjoyable and sustainable place to live for people working in these companies. The concentration of industries in these hubs creates opportunities for industrial symbiosis, where the by-products of one process can become the input for another, a core principle in circular manufacturing.

There are great regional schemes, support and opportunities for such companies and people to come and set up their business in these areas. It was also fascinating to learn about the mindset driving this - where people with ideas which can benefit society are heavily supported. The processes to get started are highly streamlined. For example, you can get all of your paperwork done in a single visit. If it takes another visit to finish things, the administration reviews its processes to improve efficiency. Such speed and responsiveness could offer valuable insights for European approaches, where more extensive regulatory processes can sometimes lengthen the timeline for implementing sustainability projects, including remanufacturing initiatives.

The pace and scale of innovation in China is also on another level., In 2014, the idea to build the Future Science

City in Hangzhou was born, and by 2015, the construction had begun. In Europe, where remanufacturing policy is advancing but implementation is often slower, this capacity for rapid execution could help pilot new circular economy models at scale.

Chinese society is also deeply technological. Platforms like WeChat integrate communication, commerce and payments. In a remanufacturing context, such digital ecosystems could track products across their lifecycle, supporting Right to Repair goals by making repair histories and refurbishment details instantly accessible.

China has a population of over a billion people, which makes the Chinese market a very big one, with a lot of competition. But despite this, scientists and businesses are open to collaborating. This is a valuable trait when addressing shared challenges like electronic waste, PV panel recycling or battery refurbishment.

Chinese companies and universities are also highly open to international collaborations. I met and talked to numerous researchers and local government officials who expressed genuine interest in collaboration with Europe. For universities, there are specific grants to encourage these types of collaborations and partnerships. There are also companies which specialise in linking so-called “Talents” from abroad to researchers and leaders in China. In the field of remanufacturing, this could mean joint R&D projects, shared standards for refurbished goods, and knowledge exchange on consumer engagement strategies.

Overall, this trip was eye-opening. The diversity, speed and scale at which China is developing its tech industry, combined with its openness to collaboration, make it a key partner in the global shift toward remanufacturing and the circular economy. By combining China’s capacity for rapid scaling with Europe’s strong regulatory frameworks and quality standards, both regions stand to accelerate the move toward products the last longer, waste less, and serve more people for good. ■

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REMANUFACTURING FOR GOOD

EXTENDING COMPONENT LIFE THROUGH HYBRID ADDITIVE MANUFACTURING

The energy sector faces a pressing challenge on how to keep high-value components in service for longer without compromising safety, performance or sustainability. Traditional repair and replacement methods often mean scrapping parts that are mostly still functional. This consumes raw materials, energy and time.

Through the EU-funded project "3D Printing Optimised Production" (3DoP, project ID 101083997), f3nice, Valland and Trentino Sviluppo have been demonstrating how hybrid additive manufacturing can be a powerful answer. By combining advanced metal deposition with precision machining, damaged or outdated components can be restored or upgraded while significantly reducing environmental impact.

At the heart of this work is **Laser Directed Energy Deposition.** In this process a focused laser melts metal powder directly onto a part, rebuilding only the material that is needed. This makes it ideal for repairing and modifying high-value parts.

In this project, f3nice supplied recycled stainless steel and nickel-based alloy powders made entirely from scrap metal. Valland contributed by providing complex industrial valve components from its product portfolio. Trentino Sviluppo, operating the PROM Facility, shared advanced hybrid manufacturing capabilities and testing expertise. The work has gone beyond simple repairs, showing that additive techniques can also deliver functional changes to existing parts, avoiding the need for new manufacturing entirely.

Environmental Advantages Proven Through Life Cycle Assessment

The environmental performance of this remanufacturing route was quantified through a Life Cycle Assessment comparing the hybrid method to conventional replacement. The findings[1] were striking:

89% reduction in global warming potential (i.e., CO_2-eq emissions)

95% decrease in elements depletion and extraction of new metals from mining

86% reduction in fossil fuels utilization

73% lower impact on water scarcity

These savings come largely from avoiding the production of virgin steel and the associated energy-intensive processes. Matteo Vanazzi, Chief Technology Officer of f3nice, emphasises that by using recycled metal powder and repairing only what is necessary, valuable materials are kept in use and the environmental cost of maintenance is drastically reduced.

Towards a Future of Remanufacturing

The 3DoP project makes a compelling case for integrating hybrid additive manufacturing into mainstream industrial maintenance. By combining the precision of additive processes with the pragmatism of repair, the approach supports a ReManufacturing for Good mindset that values resources, extends product lifetimes and aligns with circular economy goals.

Trentino Sviluppo played a crucial role in developing and refining process parameters for each material, particularly when working with recycled powders from f3nice. Every stage was guided by the need for strong metallurgical bonding and defect-free deposits.

For Valland, the benefits extend beyond sustainability. Modifying existing components on demand can shorten lead times, reduce inventory needs and offer customers a tailored response

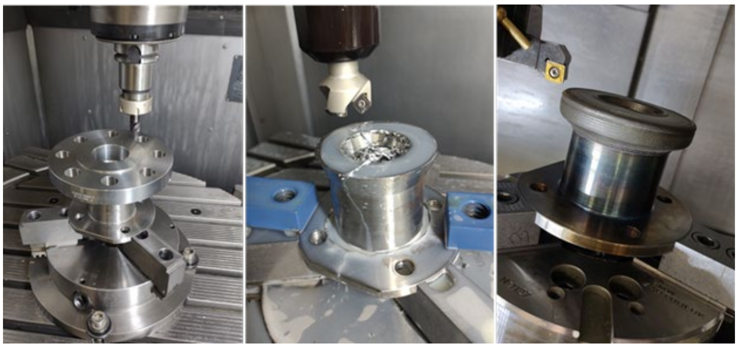
1) **Gholamzadeh, S., Cabrioli, M., Vanazzi, M., Giorgini, A., Brambilla, D., Acquistapace, G., Perini, M., & Amirabdollahian, S. (2025). Extending component life through hybrid additive manufacturing: Environmental assessment of a remanufactured valve component.** *ACTA TECHNICA NAPOCENSIS – Series: Applied Mathematics, Mechanics, and Engineering.* **(Under publication).**

without compromising performance or compliance. Gianluca Acquistapace, Additive Manufacturing Manager at Valland, notes that hybrid additive manufacturing is not only a greener way to work, it is also a smarter and more flexible approach to high-value component management.

The message is clear. In many cases the most sustainable part is the one you already have, given a new lease of life through innovation.

Case in Focus: Giving a Valve Flange a Second Life

The valve flange modification is a prime example of how hybrid additive manufacturing can deliver both performance and environmental benefits. Instead of manufacturing a new LF2 carbon steel ball valve flange from virgin steel, the team modified the existing part using recycled 316L stainless steel powder from f3nice and Laser Directed Energy Deposition.

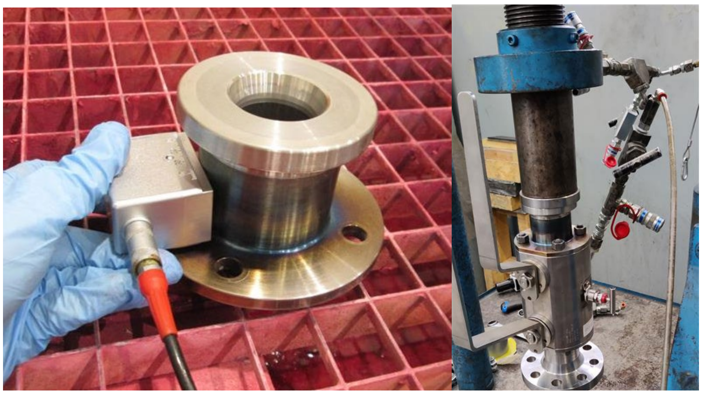


1. CNC milling removed excess material to prepare the flange for deposition

2. Laser Directed Energy Deposition added the new geometry

3. Precision machining brought the part to exact specifications

The remanufactured flange passed dye penetrant, ultrasonic, dimensional and pressure tests, achieving the same operational standards as a new component. This case shows how a targeted hybrid additive manufacturing approach can extend component life, reduce waste and support circular economy goals without sacrificing quality or safety.



This work was carried out within the 3DoP project funded by the European Community under the Vanguard Initiative Proposal ID 101083997. The views expressed are those of the authors and do not necessarily reflect those of the European Commission.

> By combining the precision of additive processes with the pragmatism of repair, the approach supports a ReManufacturing for Good mindset that values resources, extends product lifetimes and aligns with circular economy goals.

About the Partners

f3nice: Italian producer of 100% recycled metal powders for additive manufacturing, enabling sustainable production without compromising material performance

Valland: Designer and manufacturer of high-performance valves for the energy industry, integrating innovative manufacturing methods into its operations

Trentino Sviluppo: Regional development agency operating the PROM Facility, offering advanced manufacturing, prototyping and testing capabilities for industrial innovation

WHEN EQUIPMENT LIVES TWICE

innoboost

HOW REFURBISHMENT CREATES VALUE FOR BUSINESS AND THE EARTH

How refurbishment, inspired by Philips' Circular Edition, promotes sustainability and creates a strong business case

In today's world, consumption and production often still follow the linear "take–make–waste" model. Yet, industries are increasingly shifting towards circular business models. One of the most powerful strategies is refurbishment, the process of restoring used products to their original quality. Philips' "Circular Edition" shows how refurbishment can be both good for business and good for the planet.

1. Extended lifespan: revaluation instead of replacement

Philips Circular Edition systems undergo a rigorous, OEM-certified, seven-step refurbishment process. Defective or outdated parts are replaced with original Philips components. Cosmetic renewal and extensive testing follow to guarantee performance equal to new. The outcome is not simply a second-hand product but a device that is technically equivalent to a new one, sometimes even enhanced with customisations. This significantly extends the lifespan of complex equipment such as medical imaging and therapy systems, turning potential waste into renewed value.

2. Circularity made visible

Circular refurbishment has demonstrable environmental benefits. Philips reports that Circular Edition devices are on average **25% cheaper** than new systems, with **80% of the material weight is reused.**

A detailed example: the refurbished Azurion 7 C20 system has a **28% lower life-cycle carbon footprint** compared to a new model. This results in a saving of **25.76 tonnes of CO_2 equivalent and a 60% reduction in emissions in the supply chain** (Scope 3). This demonstrates that refurbishment not only reduces material consumption and costs, but also significantly reduces CO_2 emissions.

If renewable energy is used during operation, the savings increase to as much as **55%.**

3. Circular economy in practice

Refurbishment goes further than recycling. It preserves the original quality, knowledge and technical investment of products. It does not stop at recycling materials; it utilises the full operational value. At Philips, this means sustainable transition without loss of

> **Despite the challenges, the only way forward is to become more circular.**

functionality, perfectly aligned with the principles of a circular economy.

Unlike recycling, where material quality is often downgraded, refurbishment retains engineering integrity. A refurbished medical imaging system continues to deliver precision, reliability, and design excellence.

4. Comprehensive social added value

The impact of refurbishment is not limited to environmental and financial benefits. It also delivers organisational and social value. For example, Philips offers the same warranty, service, and training on refurbished systems as on new ones. This strengthens confidence in refurbished technologies and makes them an attractive and reliable option for clinical institutions.

5. Challenges and the way forward

Despite the benefits, refurbishment still faces obstacles. Customers and organisations sometimes have doubts about the quality of refurbished products; regulations can slow down acceptance and, based on a traditional linear business case, it does not initially look financially attractive.

Manufacturing for Good with Philips as an inspiring example

Philips' Circular Edition demonstrates that refurbishment is more than just reuse. It is a driver of sustainability, circular economy adoption, and long-term value retention. Through rigorous refurbishment processes, proven CO_2 and material savings, and inspiring communication, Philips shows what manufacturing *for good looks* like: not just technological innovation, but also ecological, economic, and social responsibility.

Refurbishment highlights that business and the environment are not opposites, but partners. It is a compelling call to action: produce with the future in mind, with products that circulate rather than disappear.

Patrick Lerou, Global lead Reclaim & Trade-In Management at Circular Lifetime Solutions summarises it well: *"Despite the challenges, the only way forward is to become more circular."* He also points out that transforming a traditional linear business into a circular one is often more complex than starting from scratch. It demands a fundamental shift in mindset, in day-to-day operations, and in how value is created.

This raises an important question: *Do we really need a separate sustainability department? Shouldn't circular thinking be integrated across the entire organisation rather than placed in one team?*

At Innoboost, we believe that the challenge is not only to make circularity possible, but to make it valuable for companies, their partners, and society. That is what we stand for: we make going circular work and worthwhile. ■

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ENABLING SAFE AND EFFICIENT *BATTERY DISASSEMBLY* THROUGH **DIGITAL BATTERY PASSPORT (DBP)**

empowered by NXT GEN hightech

Driving the Future: NXTGEN Hightech and the Smart Industry Transformation

As industries worldwide face mounting pressure to innovate, digitize, and decarbonize, the Netherlands is taking a bold step forward through the NXTGEN Hightech program. At the heart of this initiative lies Smart Industry (SI05) a sub-theme dedicated to paving the way for the factories of the future! Factories are becoming more autonomous, personnel more productive, and machines smarter. Production processes are becoming more efficient, and together we are developing the skills needed to move the Netherlands forward in digitalization.

Bridging Technology and Society

Smart Industry is not simply about automating factories, but it is about creating factories of the future production systems that adapt quickly, reduce waste, and deliver higher quality with fewer resources. At a time when the Netherlands and Europe face a shortage of skilled workers, Smart Industry provides digital tools and platforms that make supply chains transparent and resilient. This includes digital twins, real-time feedback systems, and standards for data interoperability. Together, these ensure that every step of the value chain from design to certification flows seamlessly.

The focus within Smart Industry05 is on integrating advanced digital tools and Industry 4.0 standards to make production systems more autonomous. Common components such as digital blueprints and architectures for autonomous manufacturing systems are being developed. The project aims to enhance flexibility and enable faultless production of complex products in small series. This will be achieved through automatic configuration and programming of production processes, including logistics, which will eliminate setup times and ensure continuous quality. The results will serve as national standards to strengthen the competitive position of Dutch companies.

University of Twente's Blueprint for Digital, Safe, and Efficient Battery Disassembly

As Dutch industry races toward smarter, cleaner manufacturing, NXTGEN Hightech and its Smart Industry SI05 sub-theme set the stage for adaptive and sustainable factories. Within this vision, the University of Twente (UT) is charting a practical path: turning the Digital Battery Passport (DBP) from a compliance concept into a working engine for safe, efficient disassembly of lithium-ion battery packs and for truly circular manufacturing system.

Bridging Data and Disassembly

UT is not just defining what a DBP is; it is showing how to use it on the shop floor and in second life applications. The idea is simple but powerful: if every battery carries trustworthy, structured, and connected data, then robots, technicians, and decision systems can perform disassembly faster, safer, and with fewer errors. That is the promise of Smart Industry, a data-driven autonomy that cuts waste, increase safety, shortens setup times, and boosts quality.

The Pillars of UT's DBP Initiative

1) A Proposed DBP Structure that Industry Can Use

UT has design a production-grade data model for the DBP, rooted in literature, current industrial practices and the guidelines by European Union whose structure is complete, interoperable, and future-proof.

Data domains: materials and chemistry, cell/module/pack design, manufacturing history, test & diagnostics, usage/SoX (SoH/SoC/DoD), thermal & safety events, service/repair, logistics, and end-of-life outcomes.

Relational integrity: clear foreign-key links across lifecycle stages (e.g., material → CAM → cell → module → pack) to preserve traceability.

Typed and validated fields: strong data types (Enums for chemistries and formats, numeric ranges for voltages/capacity, timestamps, geotags) and validation rules that make the DBP reliable enough for automation.

Access and governance: roles, permissions, and audit trails to meet safety, IP, and regulatory needs.

> **Smart Industry is not simply about automating factories, but it is about creating factories of the future production systems that adapt quickly, reduce waste, and deliver higher quality with fewer resources.**

2) A Working Prototype: Dashboard, Database, and Backend API

To move from research to real-world application, UT developed a working prototype that integrates a relational database, backend API, and operator dashboard into one coherent system. The database, implemented in PostgreSQL, stores lifecycle data in structured tables (e.g., material extraction, CAM, Cell manufacturing, module assembly, pack assembly), preserving traceability through foreign-key relationships. The backend API, built in Fast API, exposes secure, well-documented endpoints (e.g., /battery/{id}/material, /battery/{id}/modules), enabling role-based access for OEMs, remanufacturers, and recyclers. This ensures that authenticated actors can update or retrieve only the information relevant to their lifecycle stage. Finally, the dashboard provides a user-friendly interface where operators can access dynamic first-life data such as SoC/SoH trends, alongside stage-specific details like connector types, fastener specifications, isolation steps, hazard warnings, and torque sequences.

As illustrated in the figure, this prototype connects database queries, API responses, and dashboard visualization, enabling safe, efficient, and traceable disassembly and repurposing operations.

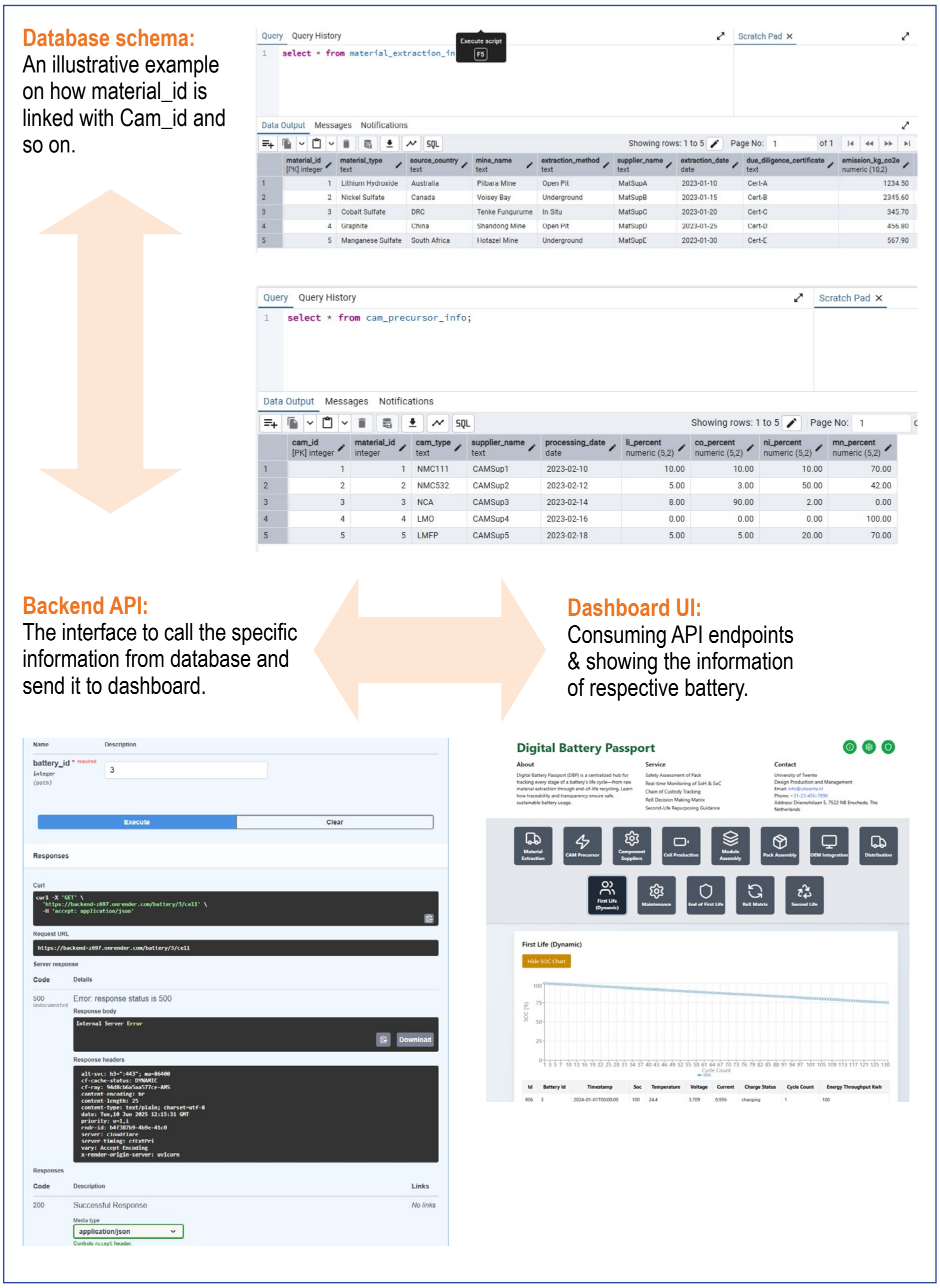

Fig.1 System architecture of the DBP prototype, illustrating the interaction between the operator dashboard (frontend), backend services (Fast API), and relational database (PostgreSQL). The architecture ensures lifecycle traceability, secure role-based access, and compliance with the EU Battery Regulation (EU 2023/1542).

3) From Data to Action: Safe & Efficient Disassembly

UT's core contribution lies in transforming DBP data into concrete decisions and operator-level actions. The system is designed around a centrally supervised database, where each lifecycle stage has restricted access and OEMs can authenticate to update only their relevant records. Once accessed through the dashboard, the prototype prioritizes safety by generating automatic lock-out/tag-out prompts, isolation steps, and thermal risk alerts, tailored to the specific pack configuration.

It also enables procedure generation, creating dynamic disassembly workflows that detail ordered steps, required tools, torque specifications, force thresholds, and PPE requirements directly derived from the pack's specification, joining methods, and recorded events. In parallel, a decision support layer leverages rules and ML-ready signals to suggest optimal pathways such as repair, module swap, cell harvesting, or direct recycling, complete with rationale, time/cost estimates, and expected yield. Finally, the system closes the loop through feedback capture, recording real disassembly outcomes (e.g., stripped fasteners, damaged tabs, time per step) to refine procedures and continuously

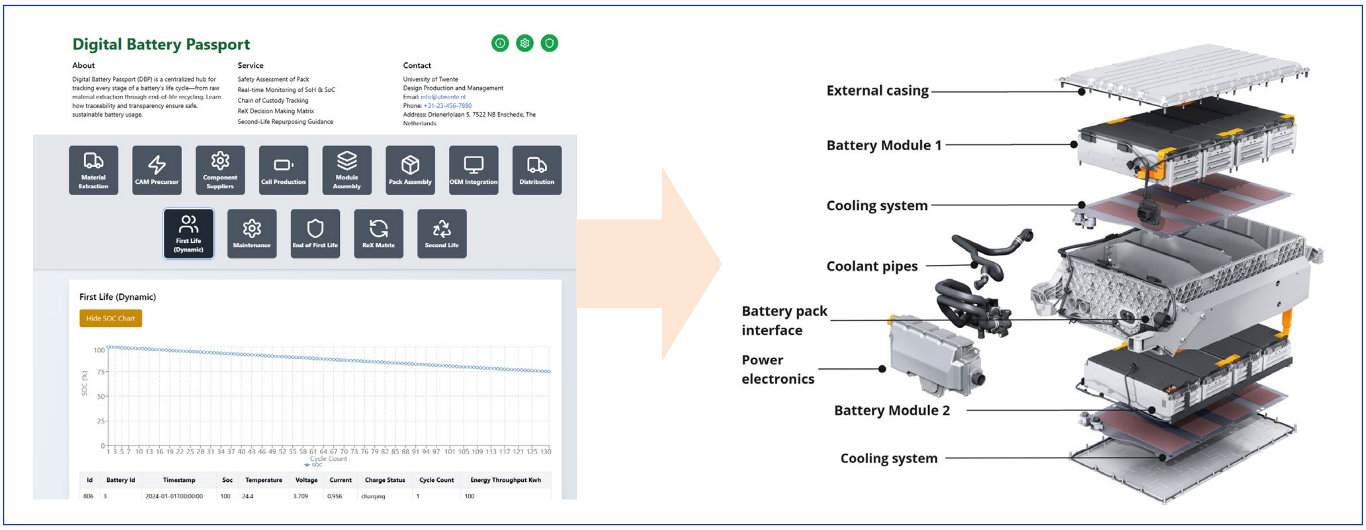

Fig.2. DBP dashboard linked to a pack-module level disassembly model. Lifecycle data captured in the DBP is translated into actionable procedures such as safety isolation, step-by-step workflows, and decision support for repair, reuse, or recycling tailored to the specific battery design.

update the DBP for subsequent life cycles. As illustrated in the figure 2, DBP data flows seamlessly from lifecycle records into actionable, pack-specific disassembly instructions, making the passport a driver of both safety and circularity.

The Road Ahead

By delivering a rigorous DBP structure and a hands-on prototype that turns data into safe, efficient disassembly, UT has provided Smart Industry SI05 with a tangible lever: data-driven circular manufacturing system. The prototype, with embedded smart-industry capabilities, can plug directly into autonomous factory concepts. Digital twins and traceability functions allowed DBP data to feed simulations and quality records for certification and compliance.

Crucially, the prototype demonstrates how batteries can be disassembled safely and efficiently by combining essential data from different lifecycle stages with dynamic information such as battery structural design, state-of-health, usage history, and safety events. This ensures operators no longer rely on incomplete manuals or guesswork but instead have access to precise connector types, fastener specifications, hazard warnings, and live diagnostics at the moment of intervention. In this way, the DBP evolves beyond a compliance instrument into a practical enabler of safe, consistent, and cost-effective circular practices.

How this Achieves Smart Industry SI05 Goals

Higher autonomy and productivity: machine-readable DBP data and API-driven workflows reduced setup time, errors, and manual lookups.

Quality and safety by design: validated data and prescriptive steps safeguarded operators and ensured consistent outcomes.

Circularity at scale: structured evidence enabled reuse, remanufacture, and high-value recycling, rather than defaulting to shredding.

Talent and ecosystem uplift: a concrete reference stack—schema, API, and UI—accelerated adoption across Dutch suppliers and training programs.

The Digital Battery Passport is more than a regulatory requirement. It acts as a catalyst for safer, smarter, and more sustainable manufacturing. By connecting data across the battery lifecycle and turning it into practical steps, the University of Twente's prototype shows how circularity can become part of everyday industrial practice. For the Dutch industry, this means greater resilience, new opportunities in remanufacturing, and a stronger role in the global transition to clean energy. As Smart Industry SI05 advances, the DBP offers a blueprint for transforming challenges to advantages. ▪

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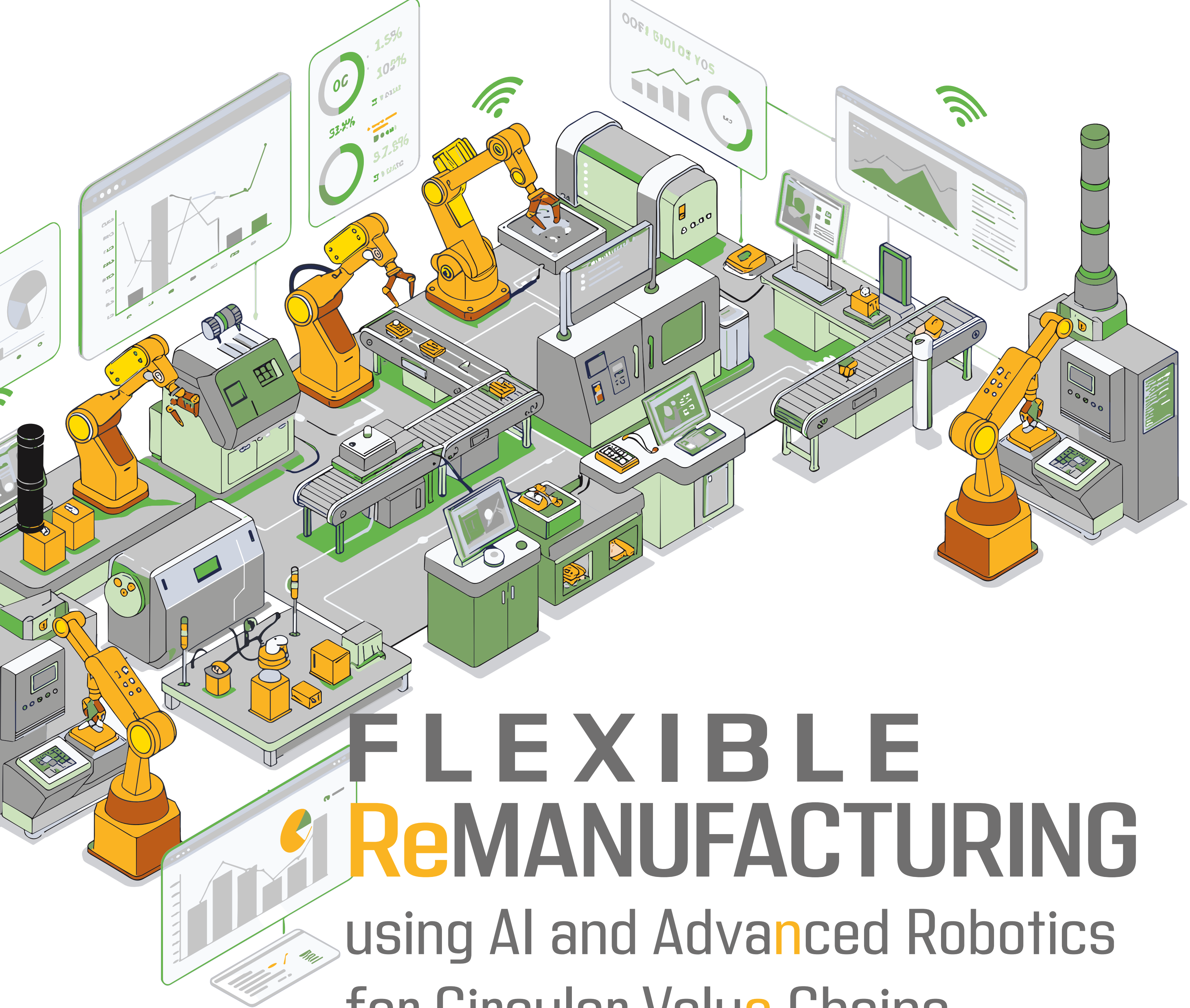

FLEXIBLE ReMANUFACTURING

using AI and Advanced Robotics for Circular Value Chains in EU Industry

RENÉE

Across Europe, manufacturing fuels prosperity and innovation. It generates jobs, strengthens competitiveness, and delivers the technologies that drive modern life. Yet, this strength comes with a challenge: industries remain resource-intensive, consuming raw materials and energy at unsustainable rates while producing significant waste. In an era marked by climate change, supply chain disruptions, and critical raw material shortages, one principle stands out as both a necessity and an opportunity — **remanufacturing.**

Remanufacturing is more than repair or recycling. It is a process of restoring used products and components to a "like-new" condition, ensuring performance, quality, and reliability comparable to new products. By doing so, it not only conserves resources and reduces emissions but also unlocks new business models and consumer value. In fact, remanufacturing lies at the heart of the circular economy, where value is retained and extended rather than discarded.

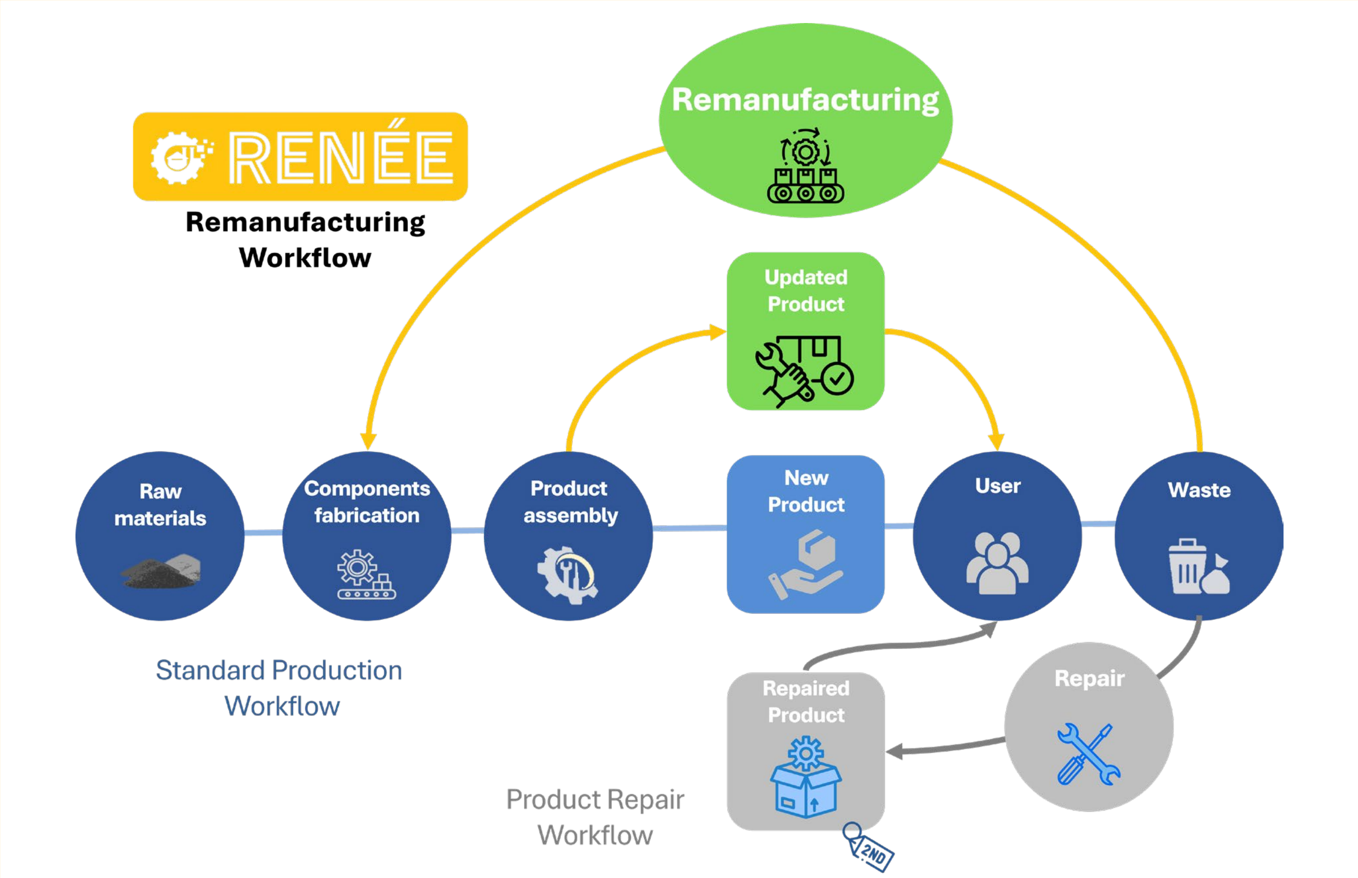

Figure 1. Remanufacturing Workflow (Source: [1])

Remanufacturing Challenges

Despite its promise, remanufacturing is not yet a mainstream practice. Uncertainty about the condition of returned products, variability in supply and demand, and the lack of standardized processes all present barriers. Inconsistent quality checks and reliance on manual operations often result in inefficiency and higher costs.

Moreover, industries face the task of ensuring that remanufactured goods meet the same safety and performance standards as new ones, a challenge that demands innovation in technology, operations, and educated operators.

Promoted Content

The RENÉE EU-funded project (GA 101138415), funded by the European Union's Horizon Europe research and innovation programme, is driving the adoption of circular economy principles through innovative remanufacturing solutions. Manufacturing remains a cornerstone of European economic growth, yet it is also a significant consumer of resources and energy. RENÉE aims to transform this landscape by addressing key challenges in remanufacturing, including resource scarcity, environmental impact, and variability in returned products.

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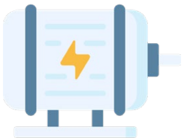
Lessons from RENÉE's Industrial Use Cases

Recent pilot initiatives across Europe demonstrate how these challenges can be transformed into opportunities:



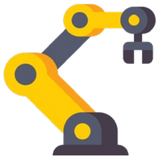
E-Mobility Motors

In France, remanufacturing of electric vehicle motors enables valuable rare earth materials to be reused. AI-driven testing identifies which components can be saved, while collaborative robotics support disassembly. The result is a cost-effective, lower-emission alternative to producing new motors.

Household Appliances

In Türkiye, a major appliance manufacturer is pioneering remanufacturing of refrigerators. Returned units are systematically refurbished, saving nearly 280 kg of CO_2 per unit compared to new production.

For workers, ergonomic risks are reduced through robotic assistance, turning physically demanding jobs into safer, technology-supported tasks.



Industrial Robots

In Italy, remanufacturing of industrial robots cuts costs by up to 40% while saving hundreds of kilograms of steel and aluminum. By creating digital twins of the remanufacturing process, operators gain real-time insights, while businesses can adopt new models such as "robot-as-a-service".

Bicycles for Circular Mobility

In collaboration with retail stores, automated systems evaluate and remanufacture used bicycles. The result is affordable, certified second-life mobility solutions, contributing to sustainable transport and reducing raw material needs.

These examples illustrate that remanufacturing is not confined to one sector, it is adaptable, scalable, and directly connected to the daily products that shape our lives.

Human Centric Remanufacturing

Remanufacturing is not only about machines. It is also about people. New processes demand new skills, from working with AI-driven diagnostics to operating advanced robotic systems. Workforce development, therefore, becomes critical. Tailored education platforms and operator support technologies ensure that workers are not left behind but instead are empowered by innovation. In this sense, remanufacturing strengthens both environmental and social sustainability.

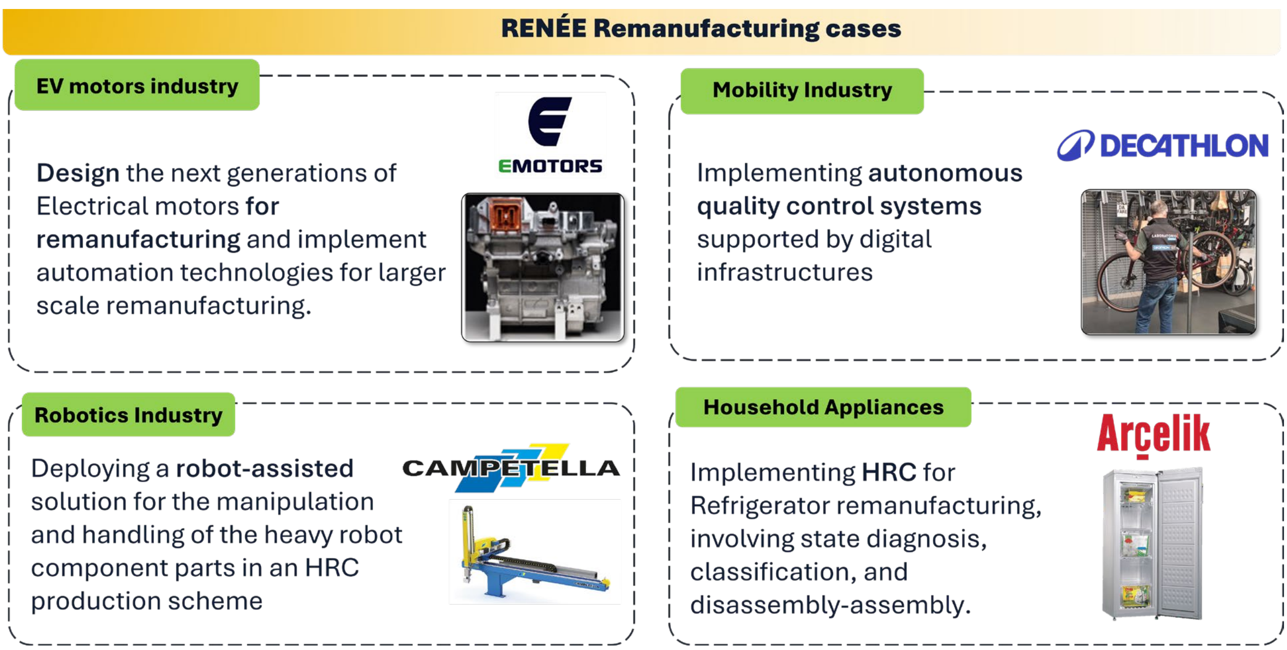


Figure 2. Remanufacturing Use Cases (Source: [2])

> **In the coming years, remanufacturing will not only shape how we produce and consume but also how we work and live.**

Looking Ahead

What does the future hold for remanufacturing in Europe?

Digital Integration: Tools such as Digital Product Passports (DPP) will enable full traceability of products across their lifecycle, ensuring that materials and components are easier to reuse and recover.

Generative AI in Industry: Adaptive AI will make it possible to design remanufacturing strategies on the fly, coping with the uncertainty and variability of returned goods.

New Business Models: From leasing to "product-as-a-service," remanufacturing will support more flexible ownership models, offering consumers affordable and sustainable choices.

Policy Alignment: With the Critical Raw Materials Act, and Circular Economy Action Plan, remanufacturing is gaining political and regulatory momentum. This creates a unique window of opportunity for industries to align innovation with policy support.

Conclusion

Remanufacturing demonstrates that industry and sustainability can go hand in hand. By extending lifecycles, reducing waste, and rethinking value chains, it contributes directly to Europe's journey toward climate neutrality.
The examples from electric motors, refrigerators, robots, and bicycles show what is possible when technology, business, and people come together.
In the coming years, remanufacturing will not only shape how we produce and consume but also how we work and live. It is a powerful reminder that the future of industry lies not in producing more, but in producing better — for people, for business, and for the planet. ▪

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Co-funded by the European Union

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[1] https://renee-project.eu/

[2] https://www.effra.eu/news/renee-advancing-flexible-human-centric-remanufacturing/

FROM SCRAP TO STORAGE

GIVING OLD LEAD-ACID BATTERIES A SECOND LIFE

Imagine a warehouse full of tons of discarded lead-acid battery cells—rusted, sulphated, destined for recycling. What if, instead of melting them down, many of them could be refurbished and used again as energy storage? That's the idea behind the ReLAB project, a collaboration between Riwald Recycling and the Fraunhofer Innovation Platform for Advanced Manufacturing at the University of Twente (FIP-AM@UT). Over the past half year, a framework was developed and tested to assess, and potentially recondition, salvaged flooded lead-acid batteries in real-world settings.

Turning Waste into Opportunity

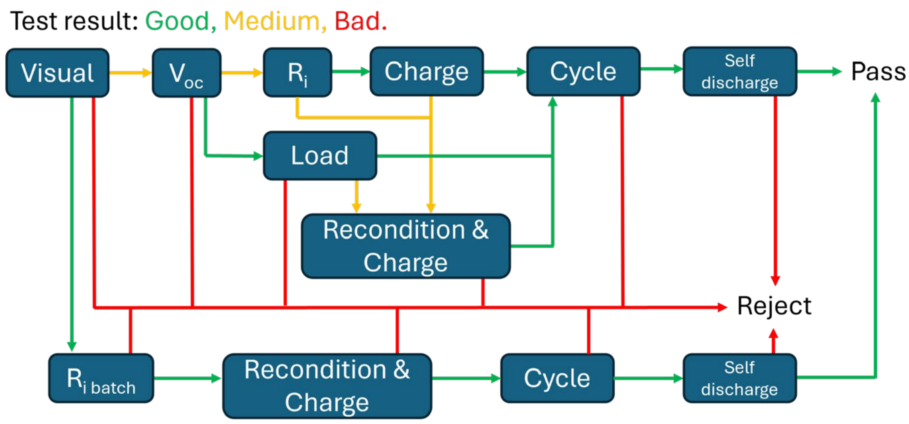
Lead-acid batteries are among the most recycled consumer products in the world, with industry-leading recovery rates in Europe and the U.S. But that doesn't mean reuse is common. Typically, discarded batteries are crushed and smelted—with no attempt to see whether they still hold useful capacity. As many cells are replaced "too early" to prevent failures, there's a real opportunity to extract extra value.

My research thesis takes on that opportunity through the development of a **decision-tree framework** that combines fast screening tests (visual inspection, voltage, internal resistance, and self-discharge) with deeper cycle testing and reconditioning steps. The goal: filter out cells that are truly dead while rescuing those that can offer years of secondary service.

What We Found: 43 Tonnes, Hundreds of kWh

Applying the framework to Riwald's stock, more than **500 cells** were screened. As expected, many were in poor condition—cracked cases, heavy

Decision-tree framework for discarded lead-acid batteries



sulfation and failed visual checks. But the results were surprisingly significant: **nearly half of the Hoppecke cell batch** showed enough potential for reuse (either directly or after reconditioning). This finding represents **several hundred kilowatt-hours** of energy storage capacity otherwise headed for the smelter.

Importantly, the framework allowed clear categorization: cells marked for reuse, cells to recondition, and cells to recycle—helping Riwald optimize logistics and avoid unnecessary transport of unusable material.

Real-World Trials: FIP's shopfloor & Off-Grid Tiny House

Two case studies were conducted to pilot the framework in real-world conditions:

At FIP's shopfloor (grid-connected), salvaged batteries were tied into a 12V storage system and a 24V UPS. The system managed stable charge/discharge cycles using commercial inverters; the UPS managed to bridge outages for 3D printers and this could be extended to other applications. While the battery size was small relative to FIP's energy demand, the demonstrations proved technical viability and offered valuable lessons in control, safety and monitoring. The system can now be used as a demonstrator at FIP.

At a tiny off-grid house, the system operated under variable solar input. Performance was modest—round-trip efficiency around 42%—but the results demonstrated that even in a small-scale setting, salvaged batteries can provide resilient energy, especially when cost and robustness are primary goals.

In both cases, key challenges emerged: cell imbalance skewed results, handling 100 kg cells needs special equipment and connections were imperfect. Nonetheless the experiments validated that second-life LAB systems can work outside the lab to provide real value.

Why It Matters: Profit, Planet & Practice

This work sits at the intersection of economics, sustainability and industrial practice, while maintaining societal (safety) considerations. For recycling firms like Riwald, it proposes a **value-add stream** beyond metal recovery. For renewable energy adopters, it offers a low-cost storage option that fits in stationary contexts where weight or size are less critical, such as for electrical cranes or construction site power solutions. And for the planet, it delays energy-intensive smelting and reduces raw material demand.

Of course, reuse isn't without trade-offs. Efficiency is lower compared to lithium technologies, and the weakest cell in a pack can drag down performance. But in applications that prioritize robust, fire-safe and cheap storage, salvaged lead-acid systems can serve niche markets and bridge gaps in the circular economy.

What Comes Next?

The next steps from here include:

Scaling up: testing the framework at other recycling facilities, with different cell types and larger volumes.

Economic modelling & LCA: building precise cost and environmental impact models using real operational data.

Policy & industry uptake: working with certifiers, energy regulators and battery manufacturers to validate reuse pathways.

Battery Design: Riwald is interested in using all salvageable cells in a big grid connected storage system, contributing to overall grid stability.

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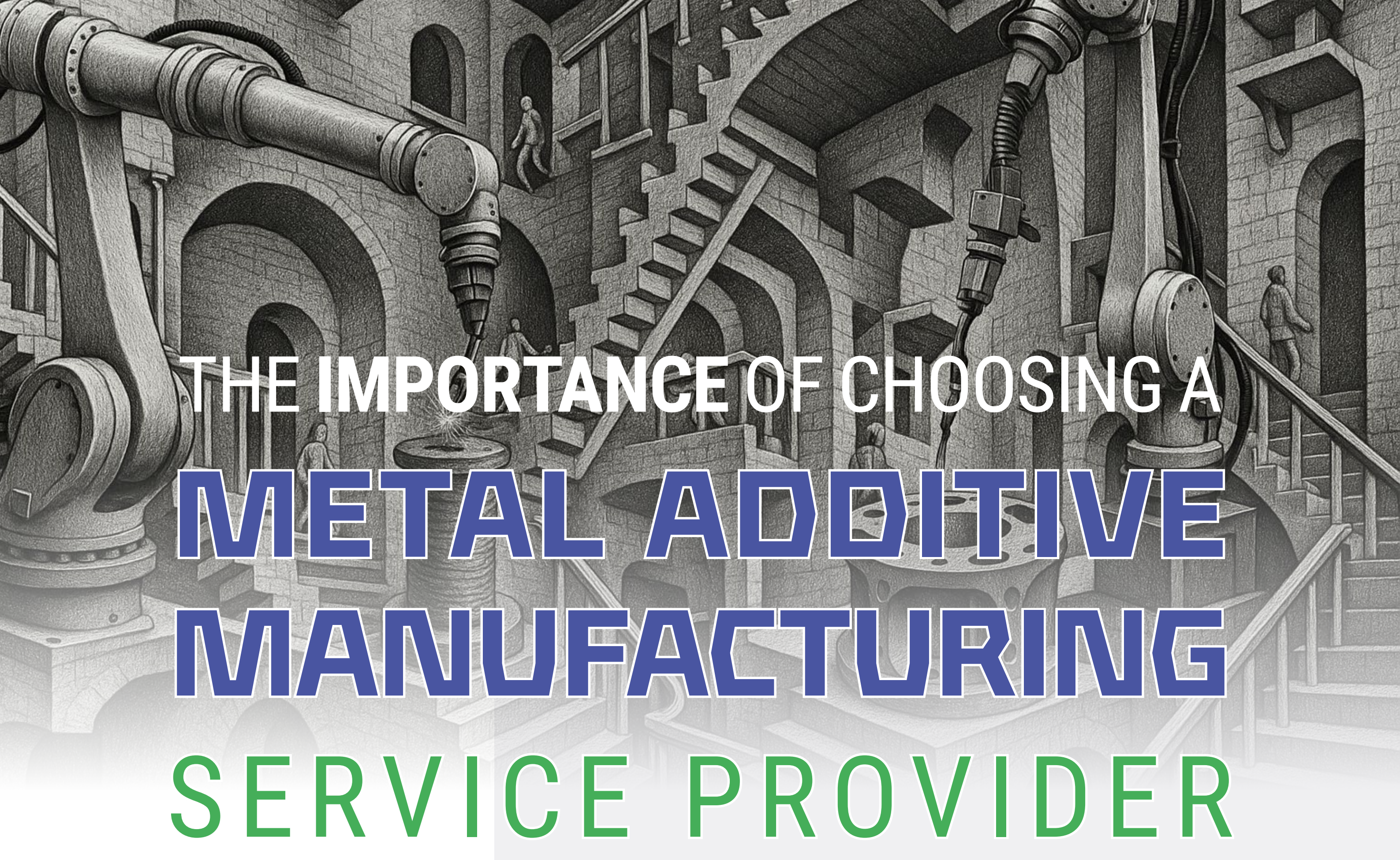


THE IMPORTANCE OF CHOOSING A METAL ADDITIVE MANUFACTURING SERVICE PROVIDER

While "value for money" is often the most analysed criterion, the truth is, working with a solutions provider should go beyond this important argument. Indeed, although the market of companies offering AM services has grown over the years, not all of them share the same industrial roots while others lack focus on quality and industrialisation.

Guaranteed

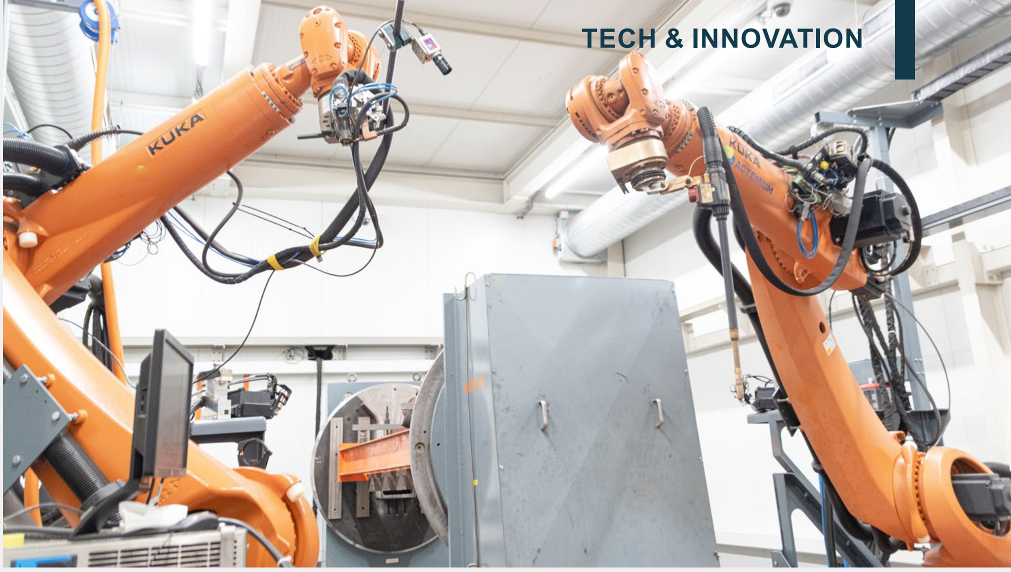
Over the last years, Metal AM has gradually seen a shift from prototyping towards mainstream production technology for several industries such as medical, aerospace and automotive.

Widespread industry adoption has however been focussed on relatively small sized components as the production of large sized metal parts wasn't technically possible or economically attractive using powder-based processes. As illustrated by the AMPOWER technology mapping, over the past few years wire-based DED processes and WAAM (wire arc additive manufacturing) in specific have consistently demonstrated a significant shift in both technological as well as market maturity and now allow large sized metal parts to be (serial) produced or remanufactured in a repeatable high quality manner.

Size does matter!

The **intrinsic benefits of AM** (small lot sizes, inventory reduction, obsolescence management, etc.) **are indeed particularly appealing for large sized metal components used in industries** such as oil & gas, maritime, energy, transport, mining, aerospace, defence, or heavy industry. These industries often use castings or forgings which, depending on the environment they are used in, could be made of carbon or stainless steel, nickel-based alloys or even titanium. The fact is, the more complex the geometry becomes, the more the casting or forging process itself results in significant material waste, but also suffers from extended lead times and non-negligible failure rates.

All of these constraints often lead manufacturers to explore manufacturing processes which could best meet these requirements.



> *"The combination of component size and functional complexity makes a compelling case for the wire based DED-processes (CMT and plasma) offered as a one-stop-shop manufacturing service by Guaranteed as it allows parts up to 10 x 5 x 6 meters and up to 20 tons to be produced near-net-shape within short lead times at a competitive cost. Currently the material database is already well populated (steel, stainless, Inconel, titanium, aluminium, bronze ...), but it can easily be expanded at the request of our customers", **Joachim Antonissen** CEO Guaranteed comments.*

From a cost standpoint, it should be noted that there is a wide choice of commercially available welding wires, which come at a considerably lower cost compared to their powder counterparts. Adding to this, parts are produced that are quasi 100% dense, which omits the need for a, as common for powder products, HIP-treatment. This makes wire-based processes such as WAAM an interesting choice from an economic point of view.

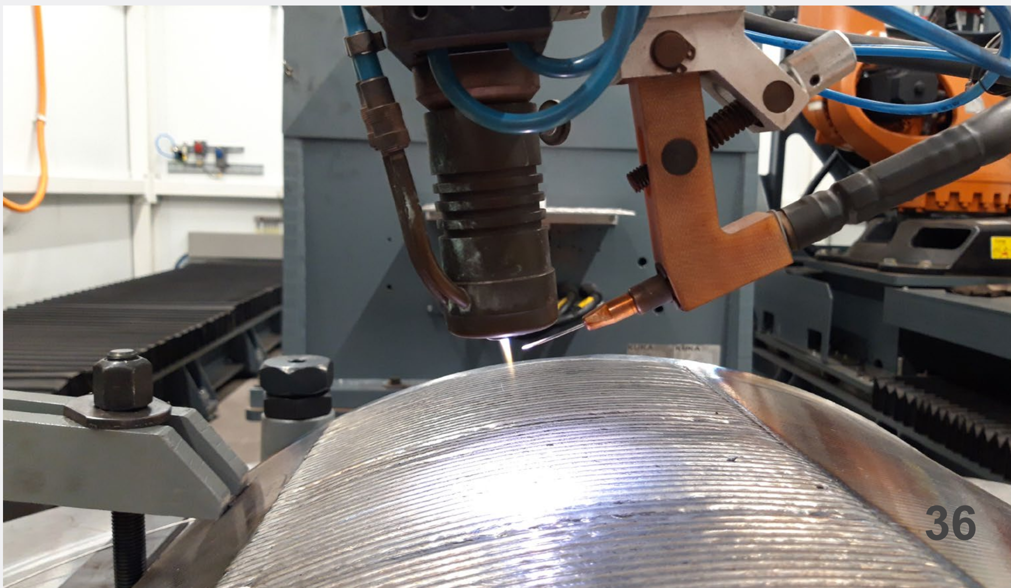
As Guaranteed's technologies allow a hybrid approach by depositing on top of an existing component (e.g. plate or cylinder) or even to repair an existing part, the business case is further improved even without taking into account logistic savings such as reduced lead times or stock keeping costs. Beside the resulting economic benefits, localized repair or on-demand near net shape production also contributes to sustainability as it significantly reduces the need for raw materials and transport.

Cost is important, quality is the best way to reduce it

When switching from Conventional Manufacturing (CM) to Additive Manufacturing (AM), the certification requirements imposed by the part's severe operating conditions obviously need to be considered when assessing the business case. Depending on the criticality level of the component, certification might impose a substantial amount of destructive test samples to be produced alongside the actual part. Through its process control software, Guaranteed is able to ensure part performance which significantly reduces the number of expensive trial-and-error loops. Being involved in various collaborative projects aiming at establishing clear certification guidelines for the use of AM in oil & gas, maritime, rail and aerospace industries, **Guaranteed is driving this further to turn certification into an inherent part of its quality assurance framework.**

Process qualification, rather than single part qualification, will broaden the portfolio of AM parts and components, to achieve faster qualification and/or certification than nowadays. In close partnership with leading universities, Guaranteed is developing the next generation of WAAM technology. The latter will allow for in-line non-destructive testing, deposition speeds to be increased even further without compromising on quality while dynamic mechanical properties will be enhanced beyond those of forged material by in-process microstructural manipulation technologies.

> *"Born from innovation, we use state of the art unique simulation, monitoring and inspection tools to guarantee first time right zero-defect production. Being raised in Industry, we guarantee one-stop-shop industrial reliability", **Michiel Debel**, CTO Guaranteed states.*



Is the best spare part a virtual one?

As installations operate in increasingly challenging environments, there is a larger likelihood of essential parts breaking down, becoming obsolete due to technological changes or changes to standards or going out of production before their end of life. The small series sizes and short life cycles of parts relative to the installations present a challenge in inventory management and further strengthen the case for the deployment of large size metal AM.

Traditional production technologies make it too costly and require too much time to produce parts on demand. The result is a significant amount of inventory of infrequently ordered parts. This inventory ties up capital for products that are unused. They occupy physical space, buildings, and land while requiring rent, utility costs, insurance, and taxes. Meanwhile the products are deteriorating and becoming obsolete. Being able to produce these parts on demand using AM reduces the need for maintaining large inventory and eliminates the associated costs while leading to greater asset longevity.

Today, Guaranteed is already actively participating to digital warehouse eco-systems in sectors such as oil & gas, railways and maritime industry.

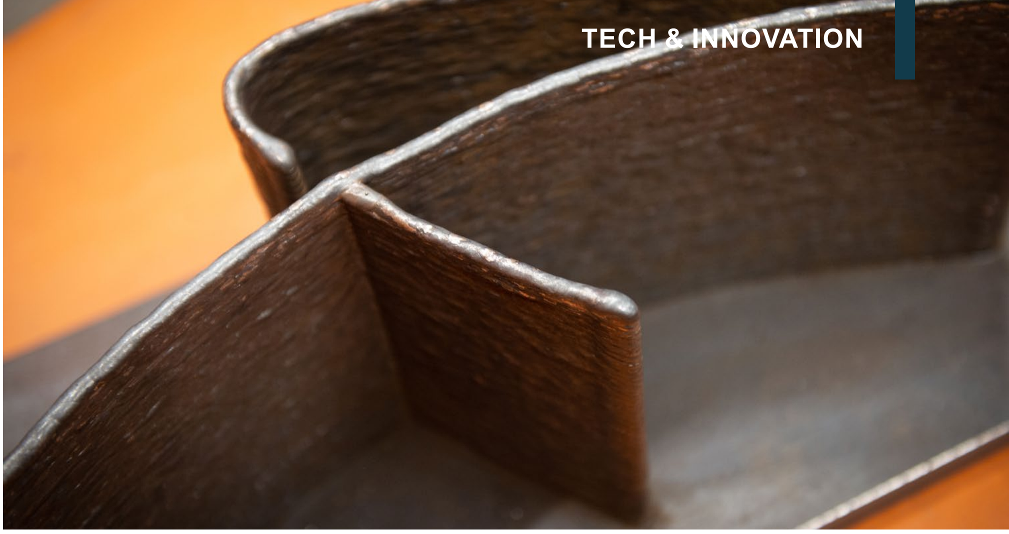
> *“AM supports our operations with shorter lead-time because it creates a shift towards buying parts just-in-time as opposed to just-in-case. The traditional way of buying spare parts at the onset of installing new equipment, may no longer be necessary if we can print the parts with the same or improved quality. Spare parts stored in a warehouse require proper storage and preservation which comes at a cost and does not provide agility when operating conditions change and the original spare parts may no longer be suitable. We believe that printing spare parts just-in-time eventually reduces the costs of sourcing specific parts, especially those that are critical for business operations”, A. Goh, Shell points out.*

Value the future, upgrade the past

Ageing installations are a common issue in many industries. Assets are increasingly used beyond their original design life, which results in parts becoming high-risk for downtime or failure. This can result in significant non-productive time which could cost upwards of hundreds of thousands of euros annually. Maintaining the integrity of equipment is difficult given that like-for-like replacements of parts are no longer available due to obsolescence of the equipment model or changes in engineering standards.

Guaranteed’s on-demand WAAM services allow such parts to be reproduced at an affordable cost, even for lot size one, repaired or refurbished. In the latter case, the original part design or material selection is given an upgrade which allows the refurbished part to have an increased performance or life time as compared to the original OEM part.

But Guaranteed is also going beyond the state of the art. Recent groundbreaking work now also allows high quality, complex shaped internal cavities to be included in such large size metal printed parts. This provides them with new functionalities, such as enhanced cooling or heating performance or the ability to feed sensors or cables though them without the need for expensive and high risk deep-drilling operations.



Less is more

With climate change as the central challenge of the 21st century, resource efficiency and reducing the carbon footprint have become vital challenges for today's manufacturing industry. Localized production to decrease transportation efforts and manufacturing products on demand to directly lower waste and avoid scrapping excess parts will eventually become necessities to avoid taxation or institutional penalties. Additionally, the demand to refurbish machines and products to extend their lifetime will continue to grow.

> *"AM and digital parts libraries will result in cost savings through smaller inventory volumes and reducing costs and risks of late life and obsolescence. As Equinor moves to zero carbon and increases its renewables presence, reducing the environmental impact of equipment production and the transport of parts through the supply chain will become increasingly important", Brede Laerum – Equinor adds.*

A study which has been performed by Guaranteed in close collaboration with DNV and Kongsberg Maritime, a comparative life cycle analysis was made for several parts. As compared to conventional manufacturing options such as casting or forging, the results of this study clearly demonstrate the significant savings which can be achieved in terms of carbon emissions and energy consumption for WAAM production and even more so for WAAM repair or refurbishment.

Proof, not promises

As the proof of the pudding is in the eating, Guaranteed works in full transparency and close collaboration with its customers worldwide to analyse, optimise and share the learnings in each business case. **For some of our customers this means that we will recommend considering repair or refurbishment rather than complete remanufacturing while for others the benefits of on demand spare part production will allow reducing warehousing costs and generate a direct impact on profitability** as working capital requirements will be lowered resulting in additional cash flow. Mitigating obsolescence issues either directly in ageing production equipment or indirectly in inventories by just-in-time manufacturing represents yet another way the services provided by Guaranteed can create value.
Last but not least, the resource efficiency and CO2 emission savings resulting from working with Guaranteed provide a pathway to a more sustainable future by reducing the amount of primary and secondary emissions. ■

Guaranteed is a Belgian leader in large-scale metal additive manufacturing. The company delivers advanced production, repair, and refurbishment solutions for heavy industry. Guaranteed provides XXL metal additive manufacturing services using its unique 10 × 6 × 5 m wire and arc additive manufacturing facility, ensuring efficiency, precision, and sustainability.

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RECYCLING AND REPAIR OF THERMOPLASTIC COMPOSITES AT TPRC

Recycling and repair of thermoplastic composites (TPCs) are essential for achieving a true circular economy, as these materials can theoretically retain up to 90–95% of their mechanical performance after reprocessing. The melt-reprocessable nature of TPCs enables remanufacturing with 40–60% lower energy use compared to producing virgin composites. This not only cuts CO_2 emissions, but also reduces industrial waste, advancing sustainable lightweight design and resource efficiency in mobility and aerospace sectors.

The ThermoPlastic composites Research Center (TPRC) aims to ensure that the repair and recycling of aerospace-grade TPCs deliver the highest possible recovery of mechanical performance with minimal energy consumption. This is achieved through cutting-edge research combined with the development of practical, industry-ready technologies. Below, an overview is provided of the repair and recycling activities at TPRC, highlighting the center's ongoing efforts toward sustainable and circular composite manufacturing.

Recycling of thermoplastic composites at TPRC

Looking ahead, a significant increase in aerospace TPC waste is expected in the 2030s. To handle this growing stream effectively, it is essential to develop and research more financially viable recycling approaches. For TPCs, different recycling methods lead to distinct microstructures in the recycled material. Internal microstructural features such as fibre length, fibre volume fraction, and constituents (polymer and fibre) behavior are crucial, as they strongly influence the material's performance and the properties that develop during processing. The recycling of thermoplastic composites can generally be divided into three main categories:

- **THERMAL RECYCLING**
- **CHEMICAL RECYCLING**
- **MECHANICAL RECYCLING**

Mechanical recycling involves shredding or grinding TPCs into flakes or powders, then remelting and remolding them.

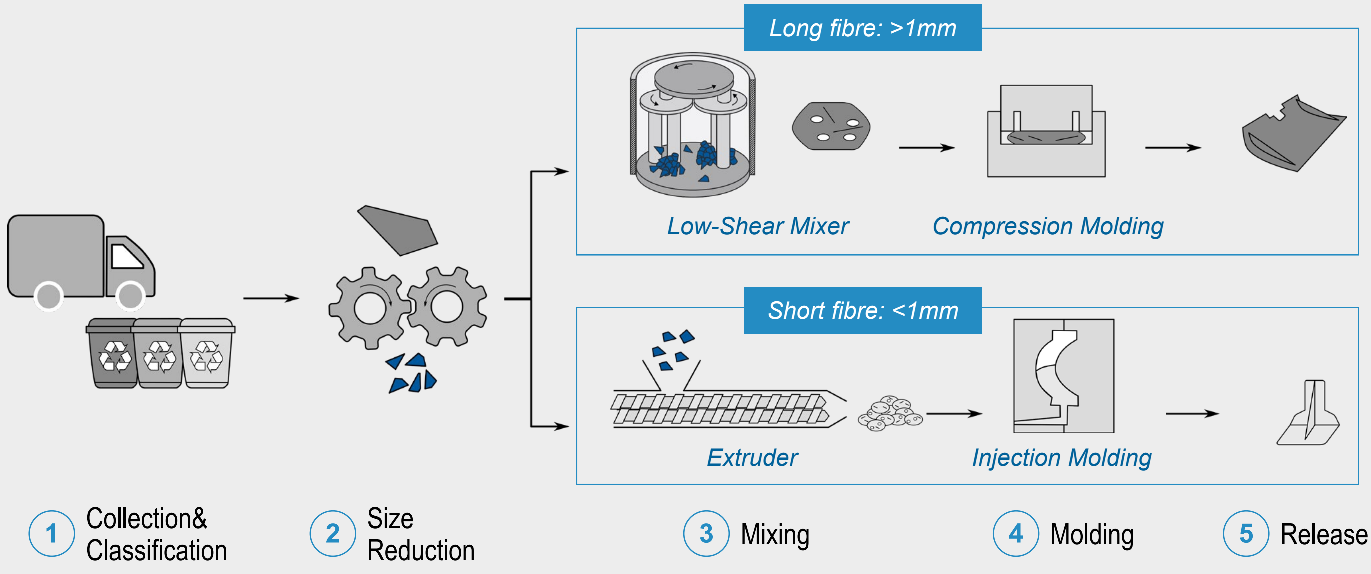

Figure 1: Short and long fibre recycling routes and equipment at TPRC.

This simple and cost-effective process recovers both fibres and matrix from end-of-life parts but can cause fibre breakage and matrix degradation, slightly reducing performance. At TPRC, we focus on recycling aerospace-grade TPCs with matrices like PPS, PEEK, and PEKK, exploring two routes: short-fibre recycling via extrusion and injection molding, and long-fibre recycling through low-shear mixing and compression molding, see Figure 1 for more details.

The low-shear mixer shown in Figure 2, developed as a prototype at TPRC for the first time, enables efficient blending of recycled composite flakes while minimizing fibre breakage. By applying reduced shear levels, it helps preserve fibre length and matrix integrity, resulting in reprocessed materials with high mechanical performance.

Characterization Methods

At TPRC, we perform extensive characterization to ensure that recycled components meet the mechanical and thermal performance standards required for industrial applications. This includes fibre length and fibre volume fraction analysis using digital microscopy or acid/microwave digestion, complemented by mechanical tests such as tensile and bending measurements to assess the quality and integrity of the recycled materials.

Figure 2: Low-shear mixing machine at TPRC.

> **The melt-reprocessable nature of TPCs enables remanufacturing with 40–60% lower energy use compared to producing virgin composites.**

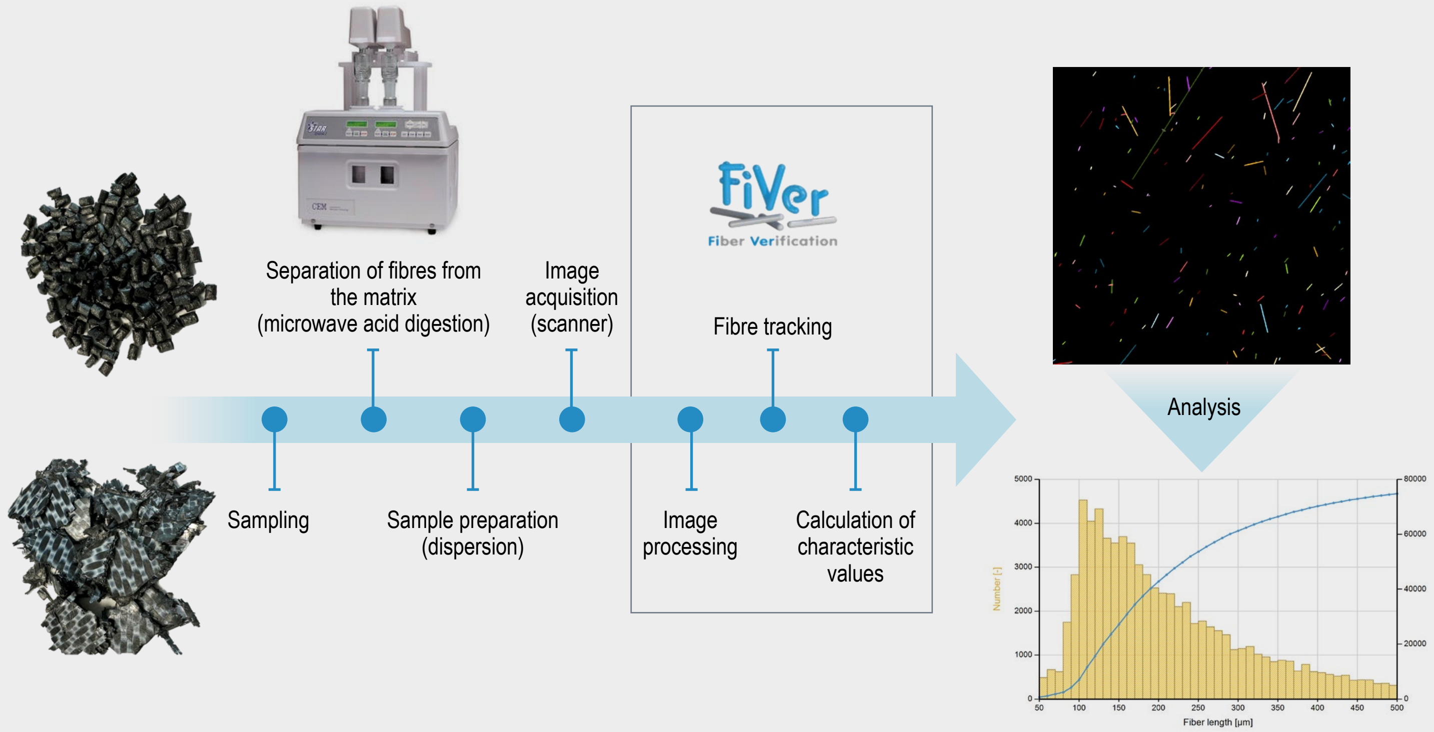

Figure 3: Fibre length analysis steps using FiVer methodology.

FIBRE LENGTH ANALYSIS

FiVer [1] is a dedicated system for precise fibre length measurement using a high-resolution flatbed scanner. Fibres are suspended in water, scanned, and analyzed with proprietary image processing algorithms. The process is shown in Figure 3. The measurement of fibre length distribution using FiVer generally involves these steps: Sampling, fibre separation, fibre preparation, Image acquisition, Image analysis.

SIMULATION

Achieving high-quality recyclates that meet strict thermo-mechanical requirements requires a good understanding and control of the entire recycling process, where simulations play a key role.

At TPRC, we perform various types of processing simulations for thermoplastic composites, including injection molding, injection overmolding, and compression molding. These simulations are conducted using Autodesk Moldflow 2025. Figure 4 shows the temperature field during compression molding of a disk-shaped charge into a rectangular plate at various time steps.

Repair for Thermoplastic Composites

As the aerospace industry explores the use of continuous fibre reinforced TPCs in exterior applications such as fuselage sections and wings, there is a pressing need for reliable repair strategies tailored to this advanced material class.

Unlike thermoset composites, which have established repair methods involving adhesively bonded patches or bolt-on metal plates, repairing TPCs with adhesively bonded patches poses challenges due to the material's low surface energy, resulting in poor interfacial adhesion and potential fracture along the bonding line. Consequently, TPC structural repair is currently based on metal bolt-on patches as shown in Figure 5. Despite the reliability of this method, mechanically bolted patches introduce stress concentrations at fastener locations, uneven weight distribution and affect aerodynamic performance.

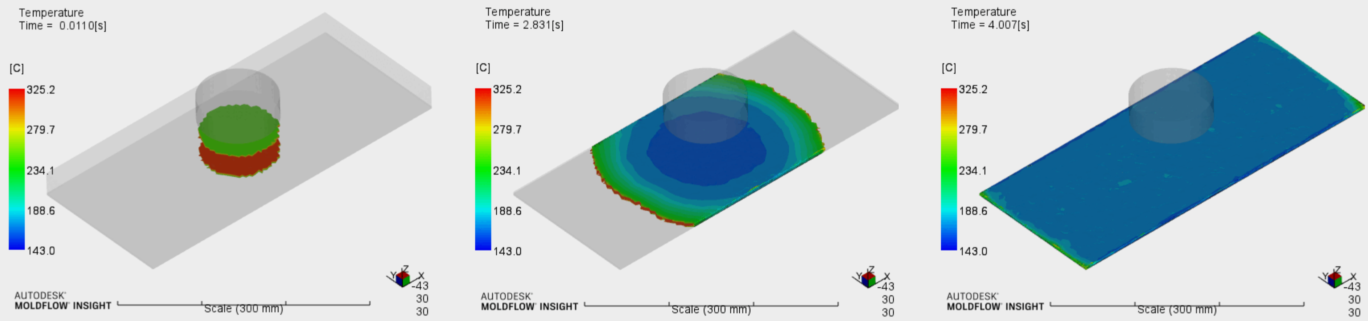

Figure 4: Evolution of temperature over time during the compression molding simulation of a C/PPS composite. The initial charge temperature is 325 °C, and the mold temperature is set to 143 °C. The simulation was performed using Autodesk Moldflow 2025.

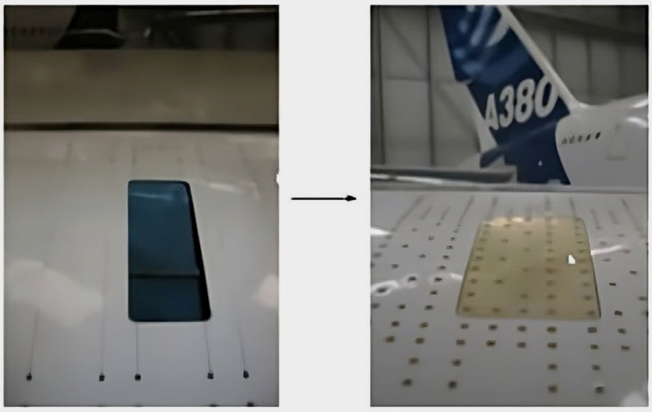

Figure 5: Repair of upper skin of Airbus A380 leading edge with metal bolt-on patch (GKN Fokker, SAMPE Webinar for repair).

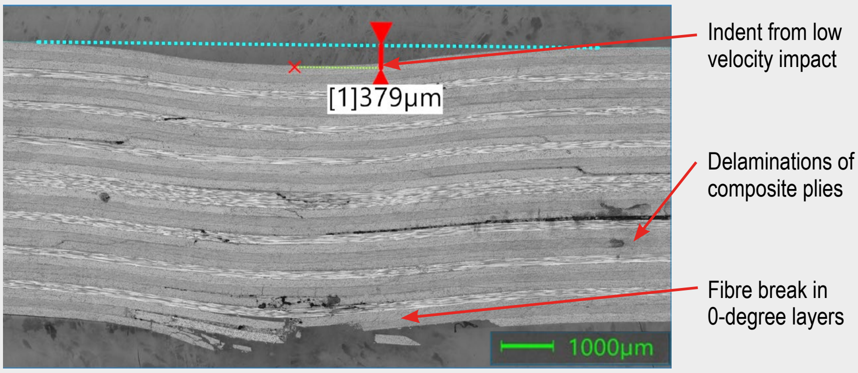

Figure 6: Common impact-induced damages visible in the cross-section of a TPC laminate.

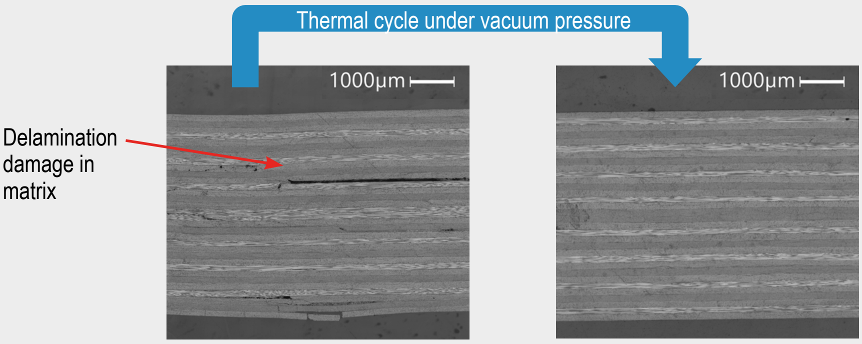

Figure 7: Micrograph of laminate cross-section showing damaged state (left) and post-repair condition after reconsolidation cycle (right).

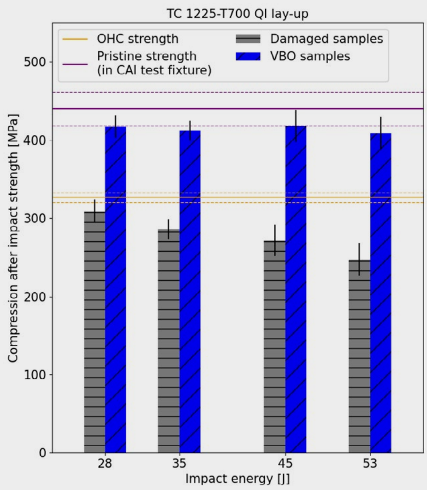

Figure 8: Mechanical performance for damaged and repaired samples.

Therefore, the development of suitable repair methodologies for TPCs is essential to further their use in structural applications. The ability to repeatedly melt and re-shape TPCs enables alternative repairing methods that do not rely on bolt-on metal plates or thermoset adhesives, but rather on fusion bonding techniques. Delaminations, transverse cracks and other matrix related damages (Figure 6) could potentially be healed by reheating the damaged area under sufficient pressure during a reconsolidation step, or by welding TPC patches. TPC fusion bonding-based repair technologies are still in a premature state, facing challenges in understanding the recovered mechanical performance and their practical implementation.

The repair of the impact damages was conducted by means of an out-of-autoclave process, more specifically the Vacuum-Bag-Only (VBO) method in a convection oven, chosen for its cost and energy efficiency compared to an autoclave. Micrographic analysis, shown in Figure 7-right, confirmed the hypothesis that matrix related damage types can be repaired via this method. In essence, Figure 7 clearly shows the damaged specimen (left side) and VBO repaired specimen (right), in the repaired state the matrix damages as delaminations were repaired.

The efficiency of the repair method also translates into an increased mechanical performance for the repaired sample over the damaged sample. This is shown in Figure 8, where it can be seen that the repaired sample's strength, i.e. VBO samples, is independent of the damage severity and outperforming the reference strength, which was set by Open Hole Compression (OHC strength).

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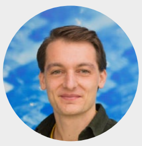

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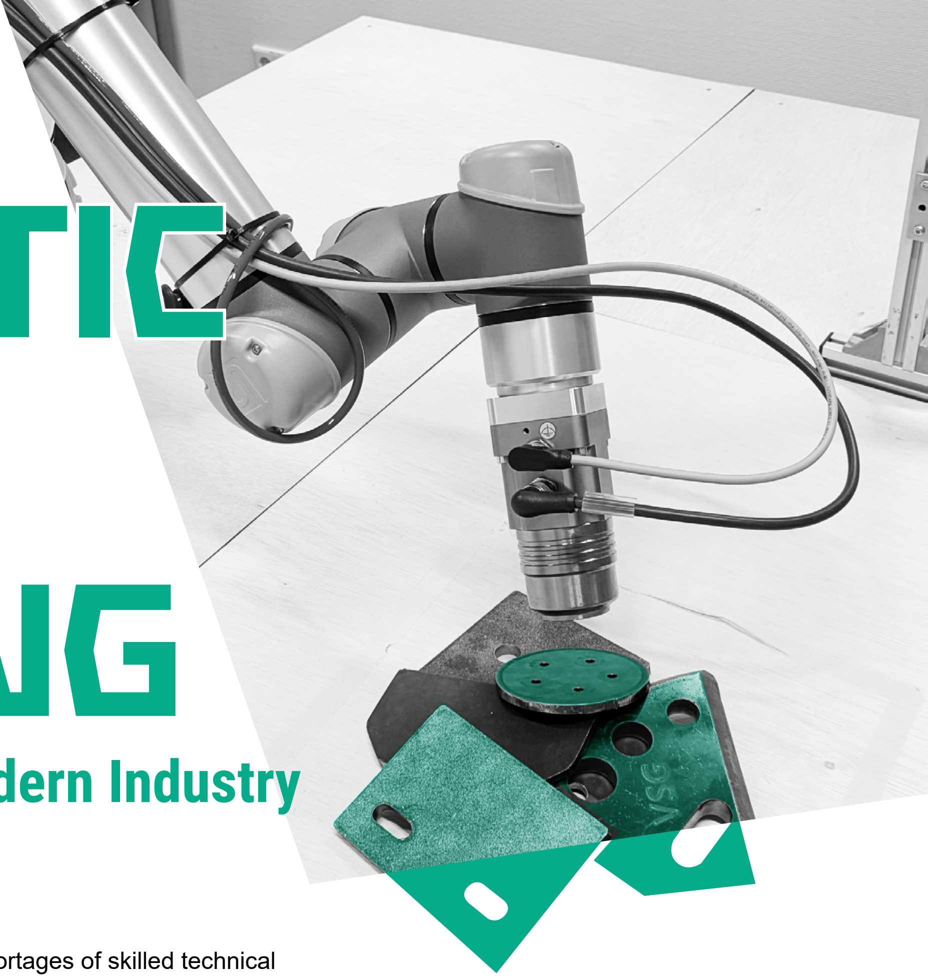
ROBOTIC BIN PICKING

Smarter Hands for Modern Industry



Modern production and logistics environments are racing toward greater automation and flexibility. One of the biggest remaining challenges is teaching robots to pick up randomly placed parts from bins — a task humans do instinctively but machines find extremely difficult. This process, known as bin picking, demands robots that can handle unstructured, unpredictable situations.

Parts in a bin are often jumbled together, overlapping, or partially hidden. Traditional robots thrive in repetitive, well-ordered settings, not in this kind of visual chaos. But thanks to rapid advances in 3D vision technology, image processing, and artificial intelligence (AI), robotic bin picking is becoming a practical reality. Today's robots can identify individual objects, determine their exact position and orientation, and grasp them accurately using the right grippers. Tasks that once required human hands, such as feeding parts to assembly lines or sorting goods in warehouses, can now be automated.

The demand for these systems is growing fast. Industries face pressure to increase efficiency, maintain quality, and reduce costs, all while coping with shortages of skilled technical workers. By automating repetitive, physically demanding jobs, companies can redeploy employees to more creative, value-added work. In short, bin picking is a key step toward flexible, fully automated production systems that can adapt to modern, high-mix manufacturing.

Current state of affairs

Many standard bin picking solutions still require fine-tuning for each specific product. The robot must recognise the correct object, decide which one to grab first, and calculate the best grip point. These steps depend heavily on the object's shape, material, and the type of gripper used. When bins contain mixed or irregular objects, even advanced systems often struggle. This is where collaborative research becomes essential.

Research within Tech For Future

To address these challenges, three Dutch companies within the TValley innovation cluster in the eastern Netherlands — Riwo, Viro, and Voortman Steel Machinery — teamed up with Saxion University of Applied Sciences' Smart Mechatronics and Robotics group. Together they launched an applied research project within the Tech For Future programme.

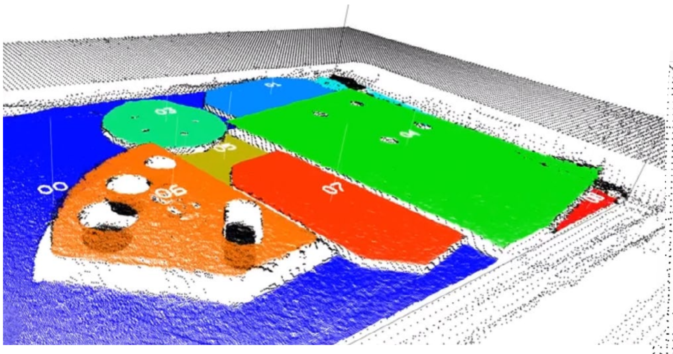
TValley brings together companies, researchers, and students in robotics, AI, and mechatronics. The goal is to develop practical, market-ready innovations through shared knowledge and collaboration.

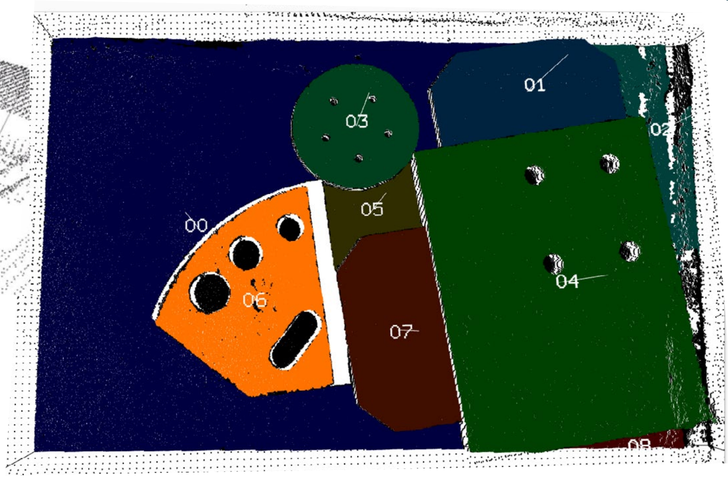
Tech For Future is Saxion and Windesheim's *Centre of Expertise* in the field of high-tech systems and materials. Within this programme, research groups conduct practice-oriented research in public-private partnerships, with a focus on co-creation and joint knowledge development.

The Robbin Project focused on use cases that lack suitable commercial solutions. Two applications were explored in depth and developed into a modular demonstrator:

PLASMA-CUT STEEL PLATES

Each plate has a unique shape and may contain holes or cut-outs. In addition to bin picking, the system has to identify the plate (by matching CAD data), detect which ones are free to pick up, and find a secure gripping point, ideally near the





centre of mass and away from any holes. Important challenges include determining which plates are free (i.e. not stuck under other plates) and finding a secure gripping position, ideally close to the centre of mass and not in or near a hole/cut-out.

IRREGULARLY SHAPED OBJECTS

Here the challenge was to determine the object's pose (its position and orientation) of the objects and calculate how the robot should pick up objects reliably.

The following research questions were central to the project:

> What is the current *state-of-the-art* in conventional computer vision algorithms, and what possibilities do recent AI solutions, such as deep learning, offer?

> Which gripper and sensor technologies are most suitable for the applications of the industrial project partners?

Development of the demonstrator

A modular demonstrator was developed to test various solutions. The setup can easily switch between different use cases, robot brands and types, sensors (including Zivid 2+, Wenglor MLBS, Zed 2, and Framos), and gripper technologies such as vacuum, magnetic, and two-finger grippers. Among other components, a Zivid 2+ structured light sensor, made available by the Fraunhofer Innovation Platform for Advanced Manufacturing, was used for the system. Thanks to its modular software architecture, the demonstrator allows results to be reused and extended in future projects involving bin picking and product handling.

For the conventional approach, a data pipeline was built around the open-source library Open3D. The results proved promising, bringing industrial application within reach. In the case of the steel plates, the system successfully distinguished between different plates regardless of shape, identified which ones were on top and therefore suitable for gripping, and calculated the optimal magnetic grip point — even for plates with holes in the centre.

The performance was both accurate and robust. However, developing this solution required substantial application-specific engineering. This challenge prompted the research team to explore what modern AI-based techniques could contribute.

Application of AI-based solutions to bin picking

To determine which recent AI algorithms are best suited for bin picking, the research team carried out a feasibility study on deep learning frameworks focused on object segmentation and pose estimation. Two promising candidates were identified: SAM-6D, based on Meta's Segment Anything model, and FoundationPose, developed by NVIDIA Labs. Unlike many common deep learning solutions, these models can recognise and orient objects with little or no task-specific training data (i.e. zero/one/few shot training).

Based on feasibility analysis, the team integrated FoundationPose into the demonstrator. Using only a few reference images or CAD models, the algorithm successfully guided the robot to pick and move various objects with different grippers.

The results were encouraging, showing that AI-based vision systems can significantly enhance flexibility in bin picking. However, further optimisation is still needed before the technology can meet industrial standards for robustness.

Conclusion and follow-up

The project has provided the partners with valuable insight into the possibilities and limitations of both conventional and AI-based bin picking solutions. The knowledge now serves as a foundation for developing smarter, more flexible gripping systems for the manufacturing industry.

The Smart Mechatronics and Robotics research group continues to refine these solutions. In future projects, they aim to build more robust and widely applicable solutions that contribute to fully automated, adaptive production environments. ▪

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We would like to express our gratitude to all contributors and readers. It is in this spirit that we send best wishes for the holidays and the new year to come.