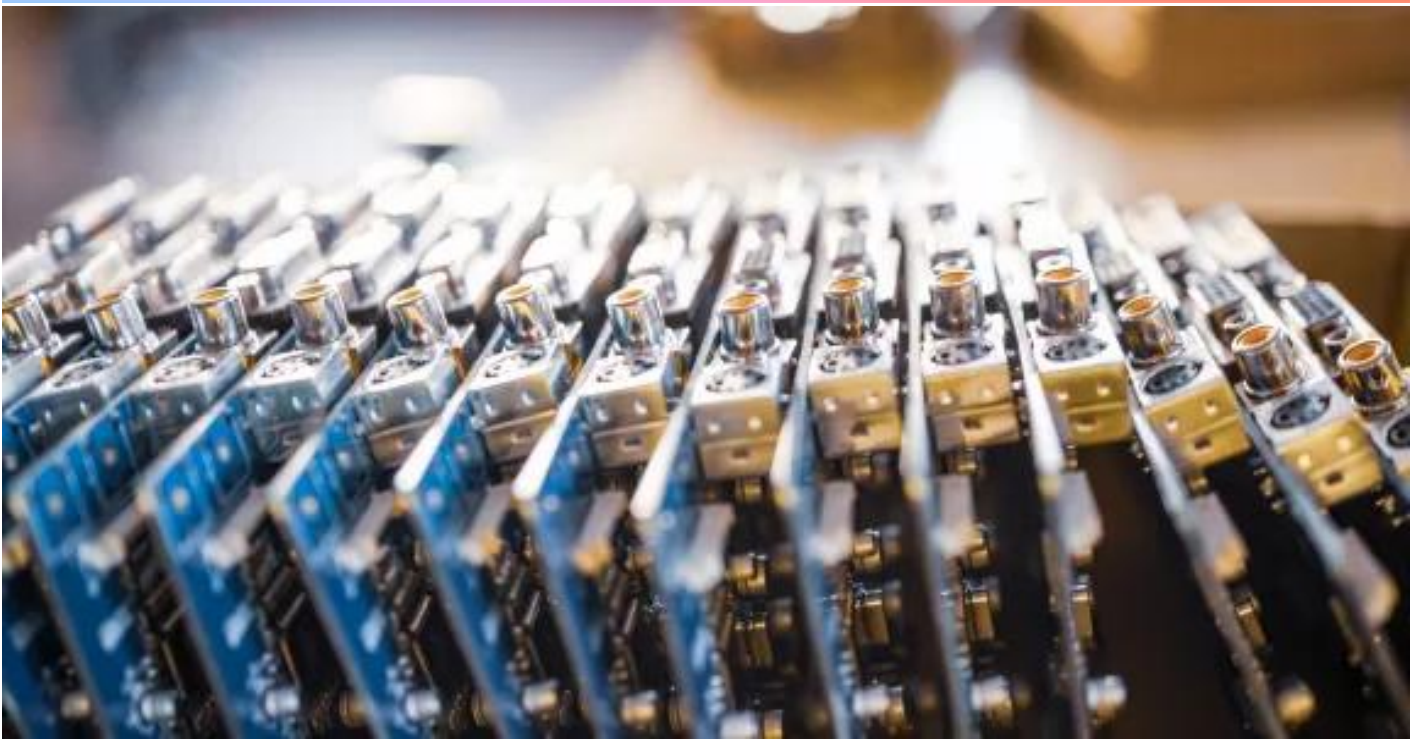




Reusing components: only if it's a good fit!

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In the transition to a circular economy, **ReX is gaining in importance**. The industrial reuse and refurbishment of used products or components has both **economic and environmental benefits**. This is particularly true of many **mechatronic systems** – systems in which mechanical, electronic and software components are integrated in complex ways. An important question that arises here: to what extent can components from different product generations, versions or variants be reused or interchanged with each other?

In this article, we explore the **importance of compatibility for ReX**, the typical **pinch points** encountered in mechatronic systems, and **potential solutions**. We illustrate these insights with a **real-life case study** of residential heat pumps: Daikin's Altherma range.

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The importance of compatibility in ReX

Compatibility is the extent to which a part from a reclaimed product can also be effectively deployed or reused in another context: in a new product or as a replacement part for an existing similar model or one of a different generation. The FFF principle often comes into play here, which stands for fit, form and function. In practice, all three of these dimensions are essential. For mechatronic products, compatibility often also entails a software component: the extent to which the embedded software, firmware and interfaces are compatible with the hardware to deliver correct operation and optimal functionality. In cases where compatibility can be ensured, a higher share of components can be reused, the need for technical adjustments and extra inspections is reduced and reverse logistics and inventory management can be organised more efficiently. This is important not only for the operational implementation of remanufacturing, but for its economic efficiency. Moreover, high levels of compatibility facilitate product life extension as well as upgrades and retrofits.

To assess compatibility and ReX correctly, we distinguish between three levels:

1. **Version** – functional configuration
Differences in system structure or application.
Example: monoblock vs split, heating with or without domestic hot water.
2. **Generation** – technological platform
Fundamental changes in technology or architecture.
Example: transition to a different refrigerant (e.g. R410A ? R290) or a new control platform.
3. **Variant** – performance differences within the same platform
Derived implementation with identical architecture.
Example: different power classes (6 kW, 8 kW, 12 kW).

In the case of heat pumps, for example, temperature and pressure sensors and fans can be deployed across generations, versions and variants. In contrast, other components, such as compressors or electronic expansion valves, are highly dependent on refrigerant, sizing and software, and therefore have limited compatibility: see the illustrative table below. In Chapter 5, we discuss the compatibility of heat pumps in more detail.

Component	Version	Generation (~refrigerant)	Variant (e.g. power)
Temperature sensor	?	?	?
Compressor	?	?	?

Table 1: illustrative overview of the compatibility of a heat pump's temperature sensors and compressors. ? = compatible / ? = not compatible

Typical compatibility drivers in mechatronic systems

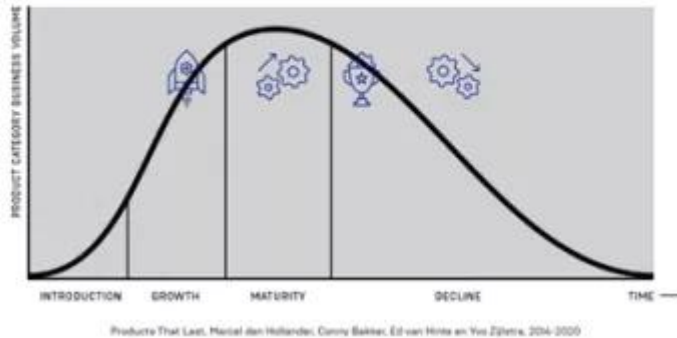
For mechatronic systems, mechanical, electronic and software aspects can all affect compatibility.

The first reason for incompatibility across different versions/generations of a mechatronic product is **technological change**. Typically, this change takes place at a rapid pace in the initial lifecycle stages of a product category (introduction and growth), before stabilising in a mature and declining

Product market context

▪ The product category life cycle stage

- Introduction & Development
- Growth
- Maturity & saturation
- Decline



▪ The technology change rate

- Upcoming technology
- Mature technology
- Outfacing technology

Changing legislation may be an additional driver of technological change. For example, the gradual phasing out of refrigerants with high greenhouse gas impact (transition from R-410A to R-32 or R-290) has an immediate and major impact on heat pump design. The reason for this is that as well as different GWP (global warming potential) coefficients, different refrigerants also have different physical and thermodynamic characteristics (heat capacity, boiling point, etc.). This means that many components such as compressors, valves and heat exchangers cannot simply be reused between generations of heat pumps, even if at first glance they have the same rated output.

Especially **in the field of electronics and software**, the impact of technological change is often significant. An ever-increasing 'need' for computing power, data storage, communications and higher-performance operating systems typically means that electronic components grow obsolete faster than mechanical ones. Old printed circuit boards may not be compatible with modern control software or communication protocols. Even when the physical connection is identical, differences in firmware, signal interpretation or security mechanisms can cause components to malfunction if they are reused. In such cases, recycling is often the best option.

Second, there are **design and engineering changes**. Interfaces, tolerances, materials and assembly methods can alter from generation to generation and even between more incremental versions of a product. Such developments are often initiated by improvement suggestions from users, but changes in the availability of materials and components on the market can also be a trigger. Minor changes in housing, screw positions or connector configurations can result in physical incompatibility.

On the other hand, **extensive standardisation** will tend to increase compatibility. OEMs often develop products with specific, unique components. Without modular architecture or standardised interfaces, interchangeability is limited. This leads to a fragmentation of parts that in themselves are of little value for reuse.

Finally, **good, traceable access to the necessary information** facilitates the assessment of compatibility and reuse of components. After all, without access to original parts lists, technical

datasheets or configuration data, it is difficult to determine whether a particular part is suitable for redeployment in another product.

Potential solutions: towards an integrated approach

A first and fundamental possibility is to apply **design for remanufacturing (DfRem)**, which takes into account the possible reuse of parts right from the design phase. For example, modular product architectures might be used, interfaces standardised or configurable control software provided. This approach significantly increases the chances of compatibility between generations. As a result, it often reduces the cost of developing and producing new generations too. The biggest challenge here often lies in dealing with uncertainty about the future: what feedback will come back from users, how technology and/or legislation will evolve, etc.

Digital tools also play an important role. Product lifecycle management (PLM) systems such as Siemens Teamcenter or PTC Windchill enable product structures, versions and relationships between parts to be managed systematically and transparently.

A **fictitious but realistic example** of a compatibility matrix can be found in Table 2 below. This looks at the compatibility of the electric drive components of a Gazelle Ultimate C8 bike.

Donor Component ID	Component	Target Assembly	M
CMP-BES2-MTR	Motor Active Line Plus	Ultimate C8 BES2 (2021)	
CMP-BES2-MTR	Motor Active Line Plus	Ultimate C8 Smart (2023)	
CMP-SMART-MTR	Motor Active Line Smart	Ultimate C8 Smart (2023)	
CMP-SMART-MTR	Motor Active Line Smart	Ultimate C8 BES2 (2020)	
CMP-BES2-BAT500	Battery PowerTube 500	Ultimate C8 BES2 (2021)	
CMP-BES2-BAT500	Battery PowerTube 500	Ultimate C8 Smart (2023)	
CMP-SMART-BAT750	Battery PowerTube 750	Ultimate C8 Smart (2023)	
CMP-SMART-BAT750	Battery PowerTube 750	Ultimate C8 BES2 (2020)	
CMP-BES2-DISP	Display Purion	Ultimate C8 BES2 (2021)	
CMP-BES2-DISP	Display Purion	Ultimate C8 Smart (2023)	
CMP-SMART-DISP	Display Kiox 300	Ultimate C8 Smart (2023)	
CMP-SMART-DISP	Display Kiox 300	Ultimate C8 BES2 (2020)	
CMP-BOS-HARN-BES2	Wiring Harness BES2	Ultimate C8 BES2 (2021)	
CMP-BOS-HARN-BES2	Wiring Harness BES2	Ultimate C8 Smart (2023)	
CMP-BOS-HARN-SMART	Wiring Harness Smart	Ultimate C8 Smart (2023)	
CMP-BOS-HARN-SMART	Wiring Harness Smart	Ultimate C8 BES2 (2020)	
CMP-SPEED-SENS	Speed sensor	Ultimate C8 BES2 (2020)	
CMP-SPEED-SENS	Speed sensor	Ultimate C8 Smart (2023)	

Table 2: Illustrative compatibility overview for reusing parts only of a Gazelle Ultimate C8 electric bike. The

Legend:

- ? Compatible – Technically and systemically usable in the target system; reuse possible within this platform
- ? Conditional – Mechanically suitable, but additional validation, calibration, configuration or approval required
- ? Incompatible – Not usable because of limitations due to protocol, firmware, authentication or lack of approval

This example shows that **compatibility** is not a technical detail but a **system requirement**. It is not a simple yes/no property of a component, but a directional relationship between a specific donor component and a specific target system.

Simple, platform-neutral components (such as sensors) are often easily reusable, while system nodes such as motors, batteries, controllers and displays are highly platform-specific. Authentication, firmware pairing and communication protocols can make reuse between different platforms almost impossible. In practice, this often means that units have to be completely replaced. ReX feasibility is thus not a property of the component per se, but of the system, governance and design choices in which it is used.

In cases where original BOMs are missing, reverse engineering can help. Reverse BOM reconstruction can be used to find out which parts are reusable. Tools that analyse compatibility based on fit, form and function (FFF) provide support to engineers in finding suitable alternatives or substitutes.

In addition, it is **crucial to integrate obsolescence management** into the ReX process. Databases such as SiliconExpert or IHS can be used to find out which parts are end-of-life and what replacements are available. Cross-reference tables for components enable replacement relationships to be managed (e.g. component A123 is replaced by A456), which facilitates compatibility decisions.

In summary, an **approach** usually consists of the following **three steps**:



Analysis 'as is'

- Within current production family
- Across generations/versions
- Techniques:
 - PLM
 - Reverse engineering

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Illustration: Compatibility challenges in the Daikin Altherma Series

Daikin's Altherma heat pumps are a representative case study. There are several compatibility issues between the third generation (Altherma 3) and the fourth generation (Altherma 4 H).

- The switch from R-32 to R-290 refrigerant has an impact on the whole thermodynamic design of a heat pump, and thus on its sizing, control, sensors and safety system. This inevitably means that a lot of components are incompatible between product generations.
- Within the same generation, control boards may contain differences in software and communication logic, meaning that they are not readily interchangeable.

ms have different pump characteristics

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Overall, **compatibility is improving**. For example, temperature and pressure sensors are standardised in many models and therefore widely applicable. Fans or fan motors are also often compatible across multiple power classes. In addition, **Daikin is committed to establishing a systematic compatibility matrix**. Indicating compatibility as ? (fully compatible), ? (conditionally usable) and ? (not compatible) provides practical guidance for remanufacturing teams.

Conclusion

Compatibility is not a side issue but a **core requirement** for scalable and cost-effective remanufacturing of mechatronic systems. Without its management, remanufacturing is confined to ad hoc harvesting of individual components, with limited structural added value.

By integrating **design-for-compatibility principles**, using **digital tools** for visualisation and analysis and systematically **managing lifecycle and variant data**, companies can take remanufacturing to the next level. Especially in sectors such as HVAC, industrial automation, mobility and consumer electronics, compatibility will become a fundamental design criterion.

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