D24.1
Sustainable Interiors, knowledge and opportunities intermediate report n°1

Project acronym:	Rail4EARTH
Starting date:	01/12/2022
Duration (in months):	48
Call (part) identifier:	
Grant agreement no:	101101917
Due date of deliverable:	Month 13
Actual submission date:	06/12/2023
Responsible/Author:	SNCF Robert DUMORTIER (WP24 Leader)
Dissemination level:	PU
Status:	Draft

Reviewed: (yes/no)

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101101917.

Document history		
Revision	*Date*	*Description*
1	04/12/2023	First issue
2	03/05/2024	Updated following the rejection letter
3	18/07/204	Updated following the rejection letter (05/07)

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1 Executive Summary

The interiors are based on a tailor-made design specific to each series Moreover, quick-fit fasteners are almost non-existent, limiting the range of reuse solutions and increasing purchase and replacement costs. The project Attractiveness is integrated in the European Research Program Rail4EARTH dedicated to designing the most sustainable railway system, the members mix operators and manufacturers. This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No: 101101917.
The objective is to reinforce train attractiveness, to stimulate modal transfer and to make train more circular.
The project is divided in two main topics: innovative modular and circular interiors.
Each topic is built in three main phases: knowledges, concepts, and demonstrators which aim to propose several mock-ups scale one as the final deliverable Phase 1 in 2026.
The main results of the first tasks of the project will be presented:

- *A crossed state of the art from operators and carbuilders to define the main issues of the current design*
- *First opportunities identified to develop in the next design phase*

2 Abbreviations and acronyms

Abbreviation / Acronym	Description
EPD	Environmental Product Declaration
EU-RAIL	Europe’s Rail : European research consortium
ISO	International Standards Organization
LCA	Life Cycle Analysis
MAWP	Multi Annual Work Plan
MID	Modularity In Design
MIP	Modularity In Production
MIU	Modularity In Use
USB	Universal Serial Bus

3 Background

The present document constitutes the Deliverable D24.1 “ Sustainable Interiors, knowledge and opportunities intermediate report n°1 ” in the Subproject 6 Attractiveness, Work Package 24 Sustainable Interiors, Knowledge and Opportunities, as described in the EU-RAIL MAWP and contributes as well to the Flagship Project 4 – Rail4Earth.

4 Objective/Aim

This document concerns the Work Package 24 and has been prepared to provide the state of the art of modularity and circularity of rolling stock. Based on this analysis, some opportunities have been identified for priority study in the next task.

5 Gantt

Task 24.1 – State of the Art (M1-M8).
Task 24.2 – Analysis of opportunities (M6-M12).
Task 24.3 – Proposal of the main aeras to develop (M10-M24).

6 Deliverables

Deliverable Number	D24.1	**Lead Beneficiary**	21. SNCF
Deliverable Name	Sustainable Interiors, knowledge and opportunities intermédiate report n°1		
Type	R — Document, report	**Dissemination Level**	PU - Public
Due Date (month)	13	**Work Package No**	WP24

Description
Intermediate results of WP24

7 Milestone tables

Milestone No	**Milestone Name**	**Work Package No**	**Lead Beneficiary**	**Means of Verification**	**Due Date (month)**
1	Sustainable Interiors Knowledge and Opportunities Mid-term analysis	WP24	21-SNCF	WP24 Progress meeting organisation	12

8 Introduction

According to 2021 Circularity Gap Report, global GHG emissions could be reduced by 39% with a circular economy. Rail transport is one of the most sustainable means of transport. However, trains consume material resources for their manufacturing and maintenance.
Current trains are not fully designed for modularity and for circular economy and need to be kept attractive during their 40 years lifetime. The interiors are based on a tailor-made design specific to each series. And each customers. Moreover, quick-fit fasteners are almost non-existent, limiting the range of reuse solutions and increasing purchase and replacement costs.. It also increases purchasing and replacement costs.
The primary goal of Subproject 6 (SP6) – Attractiveness is to enhance train attractiveness by promoting modal transfer and incorporating circular principles.

The project is divided in two main topics:

- Work Package WP 24: Sustainable interiors focus on innovative modular and circular interiors
- Work Package WP 26: User experience and user interface focus on new architectures and new human interfaces

Each topic is built in three main steps: knowledges, concepts, and demonstrators with the objective to offer several mock-ups scale one as the final deliverable Phase 1 in 2026.
In this report we will focus on the first step of work: state of the art and knowledges needed for starting the new design and only the WP24 is concerned.

Sustainability in railways comes with interiors dedicated to current passenger needs to increase modal transfer. Today, train layouts are defined once and for all at the start of the design phase and several years elapse between the beginning of the project and the train putting into service. Which means, the interior layout is already quite outdated in terms of passenger expectations.

One answer to this problem is modularity. By providing a quick and easy way of modifying interior layout, modularity allows operators to adapt interior more frequently which improves passenger service and rail's/railway's market share among other transport.

The first step before starting any research program is to analyse the state of the art and understand on which points, we should focus to be the most efficient.

9 State of the art – General

9.1 Modularity

9.1.1 Definition

Until the 1990s, priority was given almost exclusively on the quest for standardization with a maximum of common parts. As a result, interiors were generally identical, with an almost one unique interior's layout for all regions. The early 2000s marked a turning point, with layout differentiated by zones: 1st/2nd rooms, bike racks and a few services areas (vending machines or smoking areas, for example). Then, around 2008-2010, the differentiation became even more pronounced, with more areas dedicated by region, a layout could be for a same rolling stock more defined for passenger capacity or, on the contrary, designed for more comfort, to integrate services areas (bicycles/baggage, for example), as well as customized atmospheres which grew up market after market. However, we talk more about predefined layouts for predefined operations. Although the new requirements for operating the same rolling stock on the two dense regional lines. where the need for passenger capacity is the priority and the need for comfort is predominant on longer distance lines.

But there is no just one definition of modularity and it is important to clarify it.
There are 3 main families of modularity, as described in the book "Modularity-In-Design: An Analysis Based On the Theory Of Real Options" by Kim Clark and Carliss Y Baldwin, published in

1998: modularity in production (MIP), modularity in design (MID) and modularity in use (MIU).

Modularity in production (MIP) rationalizes a product into components and makes it possible to standardize parts: for example, all screws of the same size or the same thickness of sheet metal, the objective being essentially oriented towards purchasing and supply chain.
Modularity in design (MID) goes even further: the product is broken down into a set of independent sub-units, which can be mixed and matched to design a complete system, then referred to as a choice from a defined catalogue, for example the configuration of a car with its predefined accessories and finishes.
Modularity of use (MIU) whereby a product becomes "modular of use", consumers can mix and match components to achieve a functional whole, e.g., the high degree of customization offered by some furniture manufacturers, which allows products or spaces to be adapted to their needs, including changing them during the life of the product. A kind of “on-demand design”.
A significant degree of control over design is thus transferred from the company to its customers. In particular, the purpose and economic benefits differ, as summarized in the figure below, taken from the same book by Kim Clark and Carliss Y Baldwin.

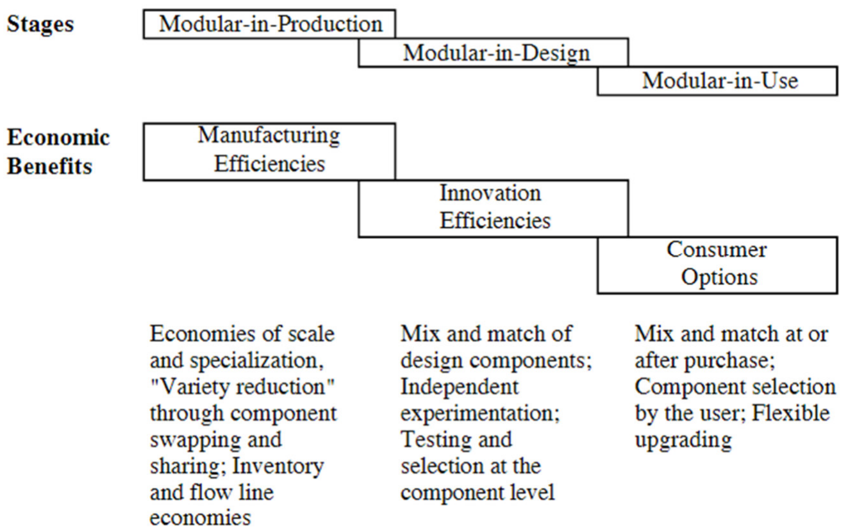

Figure 1 : Stages of modularity and associated economic benefits (extract of “Modularity-In-Design: An Analysis Based On the Theory Of Real Options – Kim Clark and Carliss Y Baldwin - 1998)

The project Attractiveness WP24 will work to propose new solutions and interiors design which will be identified from a very good Modularity in Design to a good or very good Modularity in Use.

Modularity and adaptability enable an effective response to market developments and demands throughout the rolling stock life cycle and not focus only on the demands specified during the tender phase.

9.1.2 Inspiring projects

- Shift2Rail PIVOT-2 TD1.7

The European project S2R PIVOT-2 TD1.7 has developed few concepts of interiors to increase modularity of interiors. The design to cost analysis and the LCA (Life Cycle Cost) analysis have been shared with partners so as not to start from scratch. This project proves that optimizing our design is clearly possible, besides, it cuts the overall cost of upgrading/modernizing a complete layout in half (time and recurrent cost).
The main lessons of S2R TD1.7 were at first that most of the time of a modernization is dedicated to unfixing the paneling dedicated to hide the fixing points and rails. The second main information is that interiors are not designed for refurbishment. It's designed for train construction and maintenance but not for replacing and/or upgrading part or all of the vehicle.
The last lesson is that we could change the interiors design to help evolving quickly an interior, especially with direct and visible fixation systems, with keeping keeping the atmosphere attractive to passengers. Two concepts have been proposed during the project as examples of new efficient design.

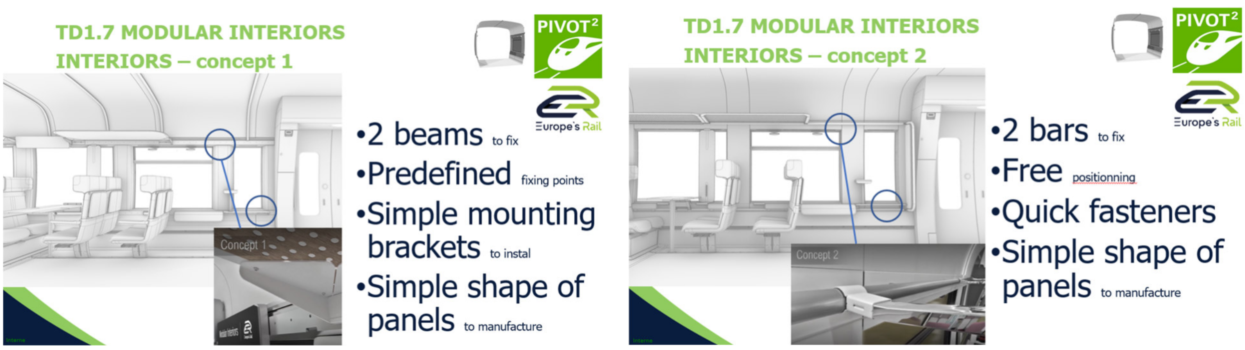

Figure 1 : S2R PIVOT-2 TD1.7 Concepts 1 and 2 – extract of the final conference, 13 of June 2023 - Bruxelles

It is important to precise that the project was limited in budget and in diversity of the actors: 2 main actors only, one operator (SNCF) and one interior panel manufacturer (Aernnova), the carbuilders Siemens and Alstom were partners but with very small budget, not enough to realize studies.
However, even the project shows the way to follow, most topics have not been studied: quick fasteners, redesign of the fittings (seats, etc …), floor fixations for example. The circular design was not in the scope of Shift2rail.

- IdeenZug DB

DB analyze that suburban trains of the future must greatly improve on three key aspects: comfort, capacity and reliability. There have designed the DB IdeasTrains to present its solution to this problem, with its IdeenzugCity and IdeenzugRegio. The project focused on addressing the three key areas of concern with a series of innovations that demonstrated the potential future of rail travel.

The IdeenZug proposes a large range of innovation from data collection from new seats or passengers' information. In terms of modularity few proposals are interesting for the state of the art of WP24. A concept of bike storage with a seating part convertible to bike support to allow the operator to increase the number of bikes on board. Another kind of modularity has been proposed with an automatization of change of the layout : seats are powered to move automatically for offering 2 different layout by rotative movement of the seats. It increases the capacity by 40% for the peak times and providing comfort for off-peak travelers.

Figure 2 : Ideenzug DB – sources Internet

The main lessons of this concept is to confirm the interest of evolving the layout for operators (DB is not partner of the WP24) and automatization could be a way for mass transit operation where the management of the piks of capacity could be a key factor.

- Mecanoo NS

The project Mecanoo/NS propose a vision for 2025 : "the train will be more than a means of transport. Travel time will become more attractive and will be part of travellers' 'own time'."
The hypothesis is to offer a variety of comfort and zoning of activity on board, with an interior design flexible by a list of modules with various seating.
"With the flexible twelve-module furniture system, a suitable combination can be made for every type of train for an optimal travel environment. The components follow a fully circular production model, with reusable fabrics and easily disassembled, interchangeable modules. The NS thus flexibly accommodates travellers' needs and is prepared for the sustainable mobility of the

future."

Figure 3 : Mecanoo/NS – sources internet

This project helps the WP24 to think in terms of module and combinations, but also shows us that new comfort is a new way of the interiors design.

9.1.3 Current issues

From operators, the lake of MID and/or MIU limit the offers and the main technical lock is the adaptability of rolling stock to the unknown during all the periods of use :

- Not easy-to-change the layout (MIU)
- Many different window heights, interfaces levels and sidewall angles (MIU)
- No standard heights are defined, leading to specific layout for each project (MID + MIU)
- Multiple architectures lead to multiple the ways of fixing (MID + MIU)
- No standard of fasteners leading to less interchangeability between element and less modularity (MID + MIU)

It is important to take this into account in the design process and to design for entire life of the rolling stock greater scope for adapting interiors.

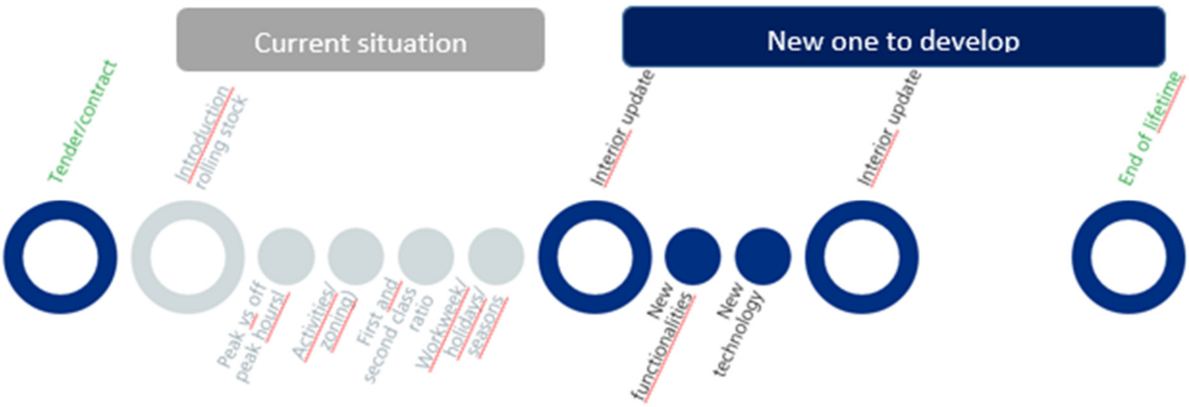

Figure 2 : Design for all the period of use - sources ERJU FP4 SP6

To reenforce the knowledge and identify the main issues, the method 5 Whys has been used and focused on few key questions.

Why are new interiors costly to produce and integrate into a new train? (MID+MIU)

Why are there so many components in an interior design (floor to floor) ? (MID+MIU)

WHY is the time to market too long ? (MIU)
Why are new seats costly to produce and integrate? (MID)

Why is it expensive to design and integrate new interiors (or refurbish old one) into a refurbishment project? (MID+MIU)

Why is refurbishing old seats so much more expensive tanh producing and integrating a new seat? (MID)

As shown in the figure 3, each partner has shared their vision and answer these questions.

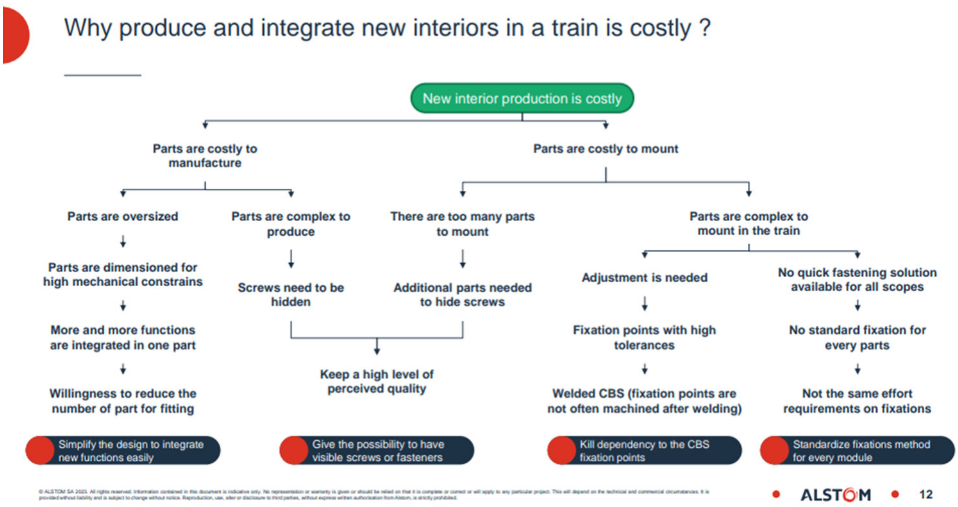

Figure 3 : example of 5whys analysis done by a partner - sources ERJU FP4 SP6

In synthesis, the main results by question WHY :

Whys linked to MID mainly :

- WHY IS REFURBISHING OLD SEATS SO MUCH MORE EXPENSIVE TANH PRODUCING AND INTEGRATING A NEW SEAT?

supply chain complex with several industrial flew

quality perceived more complex to manage

Validation process not adapted

not designed for easy reburbishment

Adjustments and reworks needed

small market in volumn

- WHY ARE NEW SEATS COSTLY TO PRODUCE AND INTEGRATE?

Design of new parts, no carry over

Aesthetic and customization

Validation process is long

tailored design and materials

High number of accessories

Volume constraints

Whys linked to MID+MIU :

- WHY ARE NEW INTERIORS COSTLY TO PRODUCE AND INTEGRATE INTO A NEW TRAIN?

Design of new parts

no carry over

too many parts

Adjustment and reworks needed

Validation process long and costly

Customization

- WHY ARE THERE SO MANY COMPONENTS IN AN INTERIOR DESIGN (FLOOR TO FLOOR) ?

No modularized design

assembly constraints

constraints from other systems

Adjustment from aestetic demands

geometry constraints from the vehicle gauge

additional parts to hide screws or rails

- WHY IS IT EXPENSIVE TO DESIGN AND INTEGRATE NEW INTERIORS (OR REFURBISH OLD ONE) INTO A REFURBISHMENT PROJECT?

Lot of pieces to defix and fix

Costly in time, not designed for refurbishment

Adjustments and reworks needed

produce new parts to hide screws or rails

Short obsoloscence time of new technology

small market in volumn

Whys linked to MIU mainly :

- WHY IS THE TIME TO MARKET TOO LONG ?

Design of new parts, no carry over

Layout and interiors defined too early

Validation process is long

New toolings and supply chain

New materials and/or functions

Short obsoloscence time of new technology

The first phase of work give us the main issues to solve as the key points of the project :

Design of new parts, no carry over

Adjustments and reworks needed

Validation process

supply chain complex

quality perceived and customization

Short obsoloscence time of new technology

These 6 points should be consolidated with data to be collected. This was the second phase of the work done in 2023.

9.1.4 Data collected and opportunities

- Fixation system

Interior fittings (seats, tables, luggage racks, …) are mainly fixed to the car body shell directly. Standardised interfaces would speed up the design of interior parts as some parts could be reusable, or interior design could begin at the same time as the body design, rather than afterwards.
To understand better up to which extent fasteners are currently standardized in interiors assemblies, a study has been performed on a single deck commuter. Fasteners have been isolated from other parts of each assembly and then compared with each other. Results for Alstom X'Trapolis single deck are displayed in below figure 4 and show a low rate of standardization. Each assembly has at least some unique fasteners, some up to 82% of unique references.

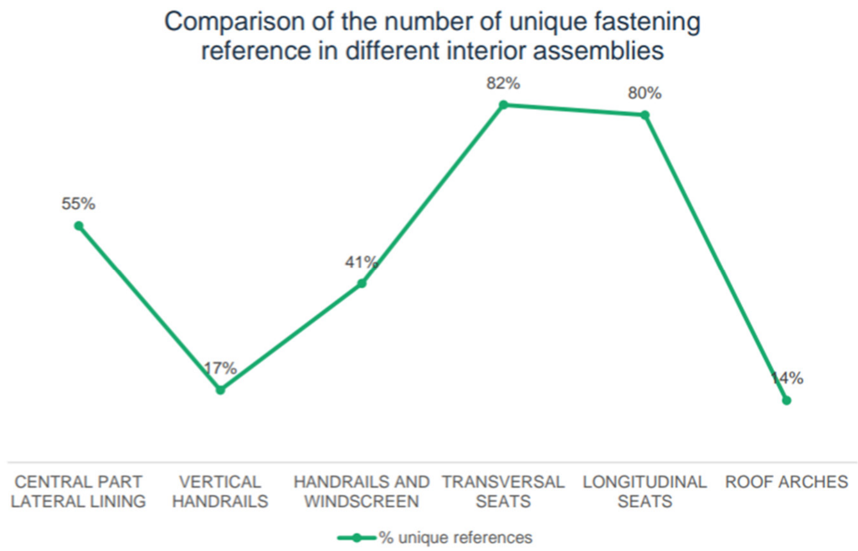

Figure 4 : analysis of fasteners done by a partner (ALSTOM) - sources ERJU FP4 SP6

In one hand, there is no real standard of fastener to reduce the number of references and in other hand it is needed to facilitate the carry over or the design of fittings by the standardization of the interfaces.

OPPORTUNITIES: work on a standard of fixation system for the main fittings, it could be imposed to the suppliers (seats, tables, luggage racks, …).

- Fixation lines

Before starting studies, it was important to identify the potential of standardization of the positioning of the fixing lines to help standardize the interfaces.
The lack of carry over and re-uses has been identified in the first phase of the state of the art, find a common positioning of the lines of fixation could be a first work of the development of the new concepts of interiors.
As explained above, increase of the carry-over goes through a high standardization of interfaces,

therefore the position of fixation lines. For example, a seat structure can be designed to be fastened to two interfaces lines with a certain center distance. If this center distance is modified in another rolling stock, the seat structure cannot be re-used without modifications, new calculation, and validation: a long and expensive process.
Each partner has worked to find fixation lines data from single and double deck, aluminum and steel carbody shell by analyzing train 2D and 3D. Data were then cross-referenced to identify issues and potentials.

The main result of this data collection is synthesis by the following figure 5.

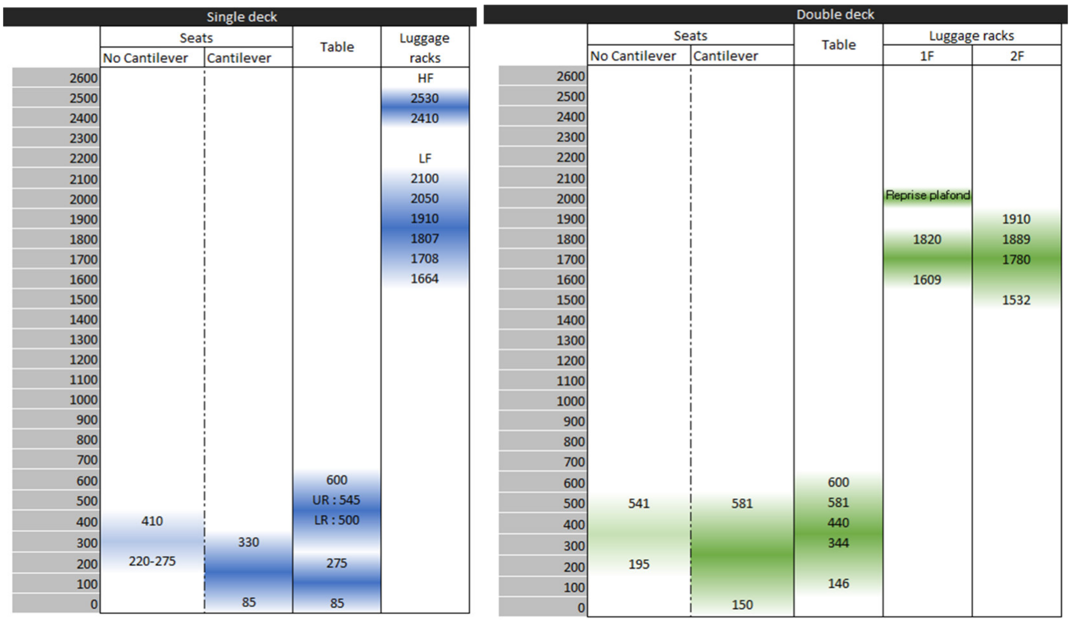

Figure 5 : global view of the several heights of the fixing lines associated to fittings – sources ERJU FP4 SP6

Color saturation represents the probability of a fixation line being located at this height. The more saturated, the higher the probability. This representation helps us determining which position of fixation line could fit most application. Written values are extremums gathered on some rolling stocks.
We can observe that we could find a common height for seats fixings because the range is small between current single deck and double deck. The conclusion seems to be the same for table. For luggage racks, it seems also possible to find common lines even if the ones from double deck seems slightly lower. High floor fixation lines can be seen as an upward offset of the low floor fixation lines, the local distance with the floor remains the same.

Main data collected :
Alstom :

- single deck X'Trapolis (Commuter)
- double deck X'Trapolis (Commuter)
- double deck Twindexx (Regional)

- single deck Coradia Stream (Regional)
- double deck Coradia Stream (Regional)

HITACHI :

- single deck Masaccio, and other vehicle for English market (Regional)
- single deck V250, IC4, Class 72 (Intercity)
- double deck Caravaggio TAF and Vivalto (Regional)

SNCF-V :

- single deck AGC (Regional)
- single deck Oxygène (Intercity)
- double deck TER2NNG (Regional)

OPPORTUNITIES: standardize the positioning of seat and table fastering lines and searching if we could optimize seats and tables with a common line.

The data collection is defined from single and double deck rolling stocks in the market (for example : Coradia for Alstom, AGC and TER2NNG for SNCFV, Masaccio and Caracvaggion for Hitachi)

- Weight :

During the phase 2 of the state of the art, we have searched to evaluate the portion of weight by main fittings to identify the main contributors and so the next main drivers of the design.
The following figure 6 shows that 4 items are the key factors of weight : seat, ceiling, luggage rack and side wall.

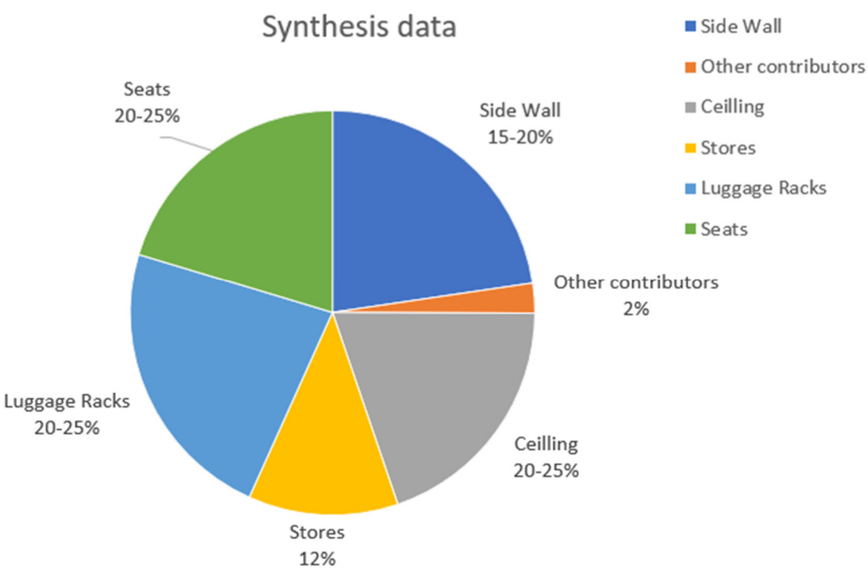

Figure 6: global view of the weight by main fittings - sources ERJU FP4 SP6

OPPORTUNITIES: in complement of the work of seat, working of new materials and/or new design for trim parts (ceilings and side wall) could have the same impact with less complexity. Working on weight could also help for sustainability and time to change a fitting (1 worker instead of 2, etc …).

- Cost :

The cost is a key factor to be aligned with the market. We have so identified the main items which could influence the global cost and identify if we could be challenged in our new design.

The data collection has shown that part of the global cost dedicated to interiors is currently around 7-15% for new train. And the seats represent 40%-50% of the interiors cost.

For refurbishment, the impact is almost the double, with a part of 20-30% of the global cost of a modernization. The proportion dedicated to seats remains at around 50% of the global cost.

OPPORTUNITIES: seat is a key factor. Start by a design to cost analysis could be very useful before starting the design phase to understand what we could simplify during the production and what we could imagine to design to reduce the cost of refurbishments.

- Time :

The time to implement fittings for a new train and the time to change or replace a complete layout during a refurbishment phase show two main key factors : the first one is that we have too much parts and most of them are dedicated for one interiors design, there is a way for optimization : The figure 7 shows that only 33% (in red) of the global time to change a layout is dedicated to replace the part you wanted to. So, the main part of the time needed is to allow the access to the part focused on.
The figure 8, the time to change the part "rail cover" is a good example of a non-adapted design for an evolving interiors : the portion dedicated to the rail cover represents only 8% of the global time needed to change it because you must unfix several fittings before (seats, tables, …).
These figures come from the S2R TD1.7 analysis (Design to cost study done by SNCF-V for a regional train)

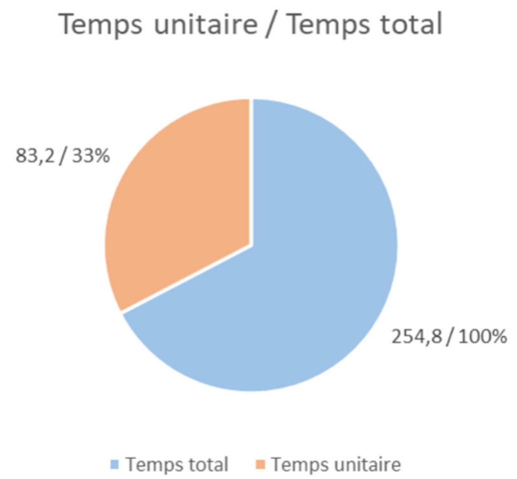

Figure 7 : global view of time to change a layout - sources S2R TD1.7

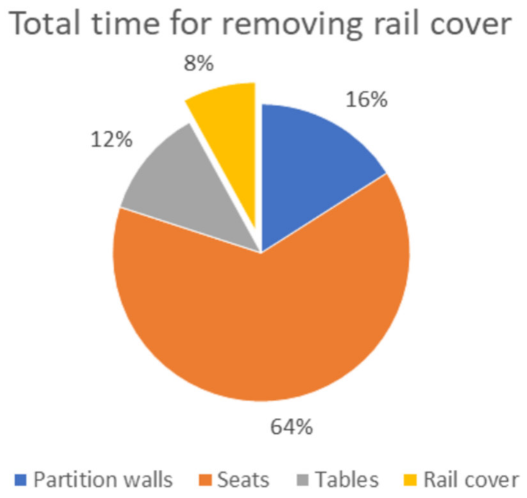

Figure8 : global view of time to change a the rail cover - sources S2R TD1.7

The second key factor is that we must work about the logistic time which impact a lot the global time to change a layout during a refurbishment. There are 2 kind of supply chain cost : one is the input/output to transfer fittings from the storage to the train (and storage to train for new interiors) and the second one is all the cost need to design the kitting and guarantee the good allocation of each piece. Specially for refurbishment, each fitting or part of fitting is dedicated to a specific vehicle and in the vehicle a specific room and in the room a specific position. Most of current interior are tailor-made by design. However, some parts that were not originally tailor-made become so over time due to deformations. It is therefore not always possible to replace them with parts manufactured according to the original drawings. It imposes added cost of supply chain to be sure to be able to deliver the right part at the right precise place. The figure 9 gives an example of the portion of the supply chain cost in this case.
These figures come from a refurbishment analysis done by SNCF-V for a single deck (Regional).

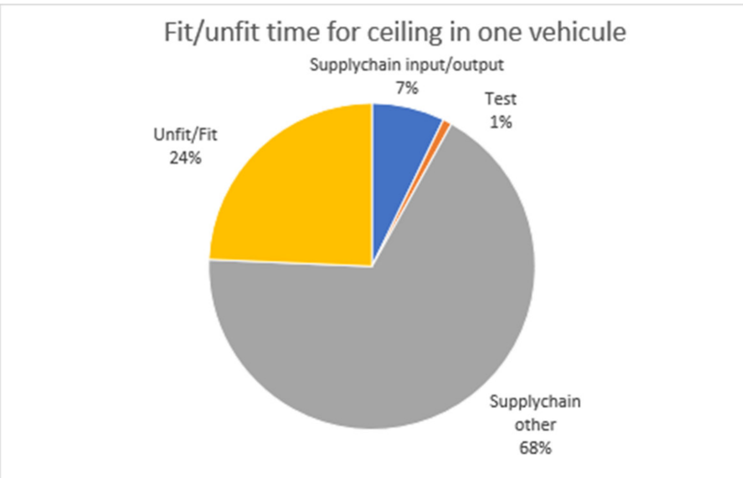

Figure 9 : example of the impact of supply chain for a refurbishment of ceiling - sources SNCF V

- Transversal challenges of modularity :

The challenge of time to market : the aim is not only to reduce the time to design and develop interiors, but also to define the interiors requirements the latest possible to be as close to the need as possible.

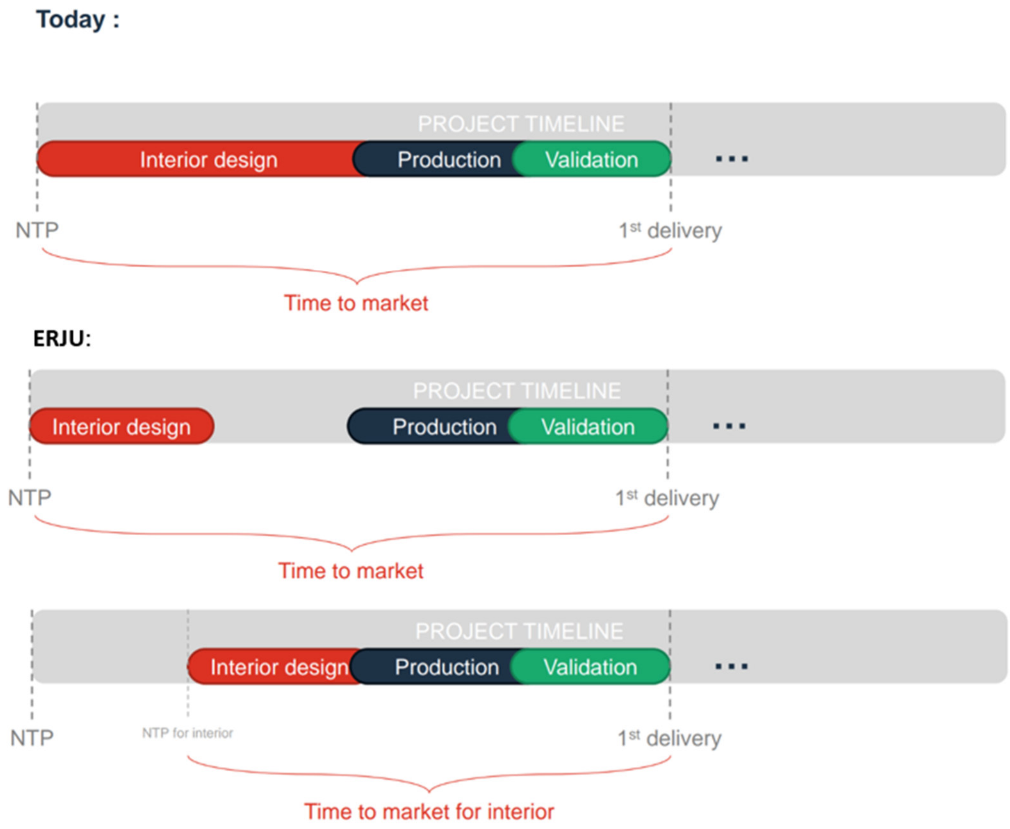

Figure 10 : global view of time to change a layout - sources ERJU FP4 SP6

The challenge of the design for second life and so adapted to the constraints and cost of a refurbishment.
The challenge of the carry over with interiors modules independent from car bodyshell.
The challenge of the validation process to reduce time to authorize a new layout and reduce the time to market. The standardisation of the fixation system could be an interesting the way to explore.
The challenge of forgetting the tailored design with an interiors design simpler in terms of shape or finishing.
The challenge of the just viable technology to reduce the obsolescence and facilitate the carry over.

9.2 Circularity

9.2.1 Definition

We can find several definition of Circularity and it is a new for railway which indicates the specification on circularity for Rolling stock (Eurospec published in January 2023). In 2024, new

standards are coming, specially the ISO 59 004 Circular Economy – Terminology, Principles and Guidance for implementation 2024.
The main guide is to design with the R-strategy defined in the following figure.

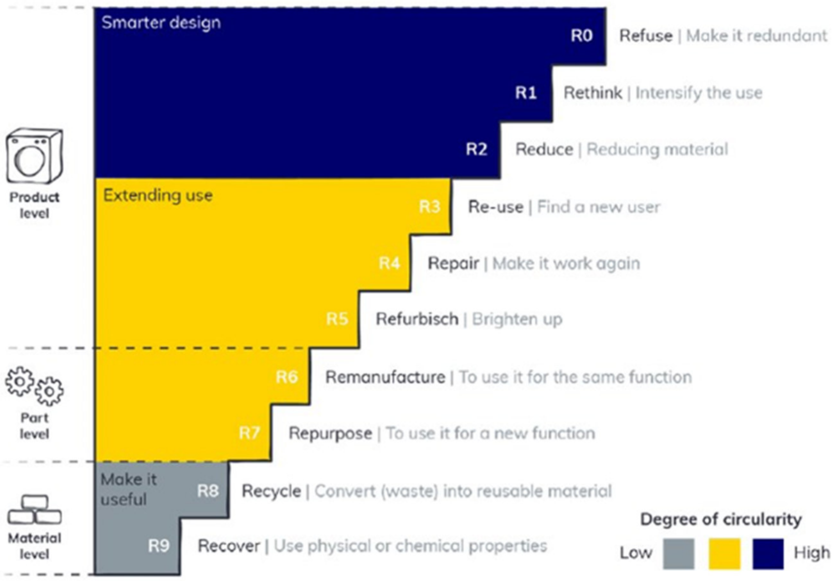

Figure 11 : the R-strategy, principles of circularity – sources ISO 59004

The aim is to adapt a strategy for designing products with long life. It changes the design guide of the interiors.
Lessons Learned (R-strategies) :

1. **PROCES:**
   - Integral design approach (from the start)
   - Material data is key to realize circular trains
   - Material data collection internal and (sub)suppliers from the start
   - Registration of circular design approach necessary (so proper R-strategies can be employed during lifetime)
   - Design for multiple R-strategies (Design for maintenance, adaptation during lifetime and end-of-life)
2. **DESIGN:**
   - Low-material design (REDUCE)
     Example: Side-walls (kg/mass)
     Example: 3D printing (kg and stock)
   - Dare to be critical (REFUSE)
     Example: Newspaper-racks
   - Irreversible connections make recyclable materials non-recyclable
     Example: Train floor wood & linoleum (glue /double sided tape)
   - Strategies for optimal use can require compromises
     Example: thicker layers to allow REPAIR and/or REFURBISH conflict with REDUCE
   - Able to adapt product to changing environment
     Example : color, new safety insights, technology updates like integrated power sockets moving from USB-A to USB-C

3. **MATERIALS:**

- **Non-recyclable materials/products**

  Examples: Thermoset composites, composites materials, HPL (low quality recycle), batteries and accumulators, hazardous waste; oil, chemicals, asbestos, oil binder, air filter, tar, bitumen, foam from fire extinguisher, steelgrid paint, varnish, grace, nitric acid, glue, resin, sealant, solvents

- **Circular inflow experiences**

  Examples: 100% recycled metals (wheelsets), 40% recycled safety glass (train windows), 50% recycled aluminium (carbody)

9.2.2 Current issues

As for modularity, to reenforce the knowledge and identify the main issues, the method 5 Whys has been used and focused on few key questions.

WHY THERE IS ALMOST NO RECYCLED MATERIALS IN INTERIORS DESIGN ?

WHY IS THERE ALMOST NO NATURAL MATERIALS IN INTERIORS DESIGN ?

WHY IS IT DIFFICULT TO INTEGRATE INTERIORS FROM A TRAIN TO ANOTHER ONE ?

As shown in the figure 12, each partner has shared their vision and answer of these questions.

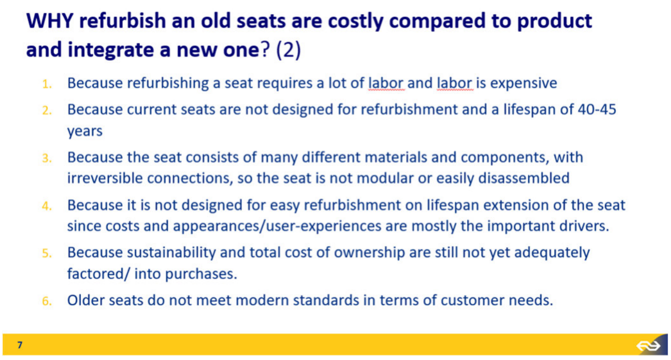

Figure 12 : example of 5whys analysis done by a partner - sources ERJU FP4 SP6

In synthesis, the main results by question WHY :

- WHY THERE IS ALMOST NO RECYCLED MATERIALS IN INTERIORS DESIGN ?

Size of the market too low

mechanical performances not adapted

Certification done for virgin materials

design not adapted for second life

finishing and qualiy perceived to rethink

industrial recycling chain not ready

- WHY IS THERE ALMOST NO NATURAL MATERIALS IN INTERIORS DESIGN ?

lake of products ready for market

safety demonstration

no real strong industrial chain

design not adapted for these materials

new material = risk

more costly

- WHY IS IT DIFFICULT TO INTEGRATE INTERIORS FROM A TRAIN TO ANOTHER ONE ?

tailored design not available for

New functions and technologies

Validation process

no standard

Adjustments and reworks

Customer requests

The first phase of work give us the main issues to solve as the key points of the project :

Railway's design not adapted

Market not ready for railway

Validation process

supply chain complex

quality perceived and customization

Short obsoloscence time of technologies or functions

These 6 points should be consolidated by data to collect or opportunities to identify. This was the second phase of the work done in 2023.

9.2.3 Data collected and opportunities

Some data collected from EPD (environmental declaration) to put in place the figures for circularity. The data presented is going to be shown from the general view until the interior sections.

The materials are classified in these 16 different categories according UNIFE Methodology - UNI-LCA-001.00 and following the Recyclability and Recoverability Calculation Method Railway Rolling Stock of UNIFE-UNI-LCA-001.00.

Approximately, only 2,5-3% of the train components after end of life is considered as waste.

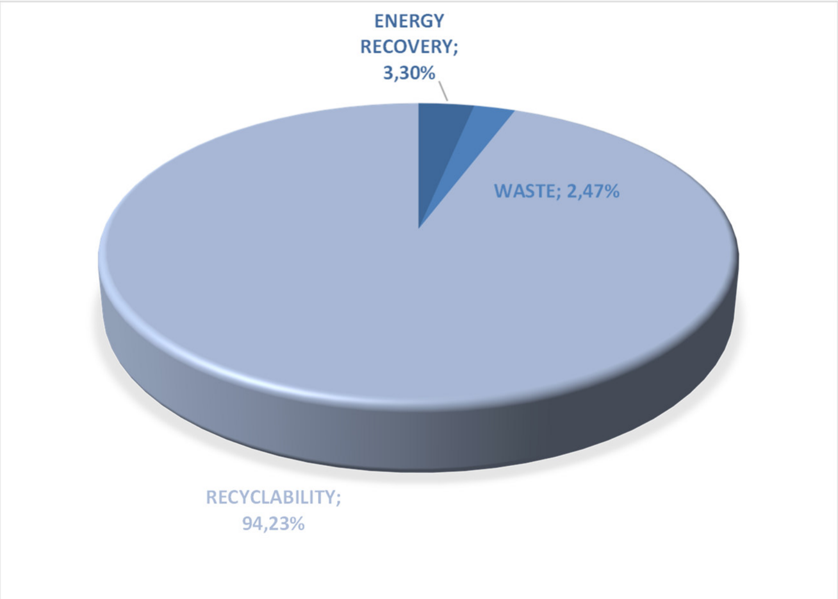

Figure 13 Portion of waste of a train - sources ERJU FP4 SP6

If we see the representative masses of the train, ca. 20-25% of the mass of the train is represented but the interiors.

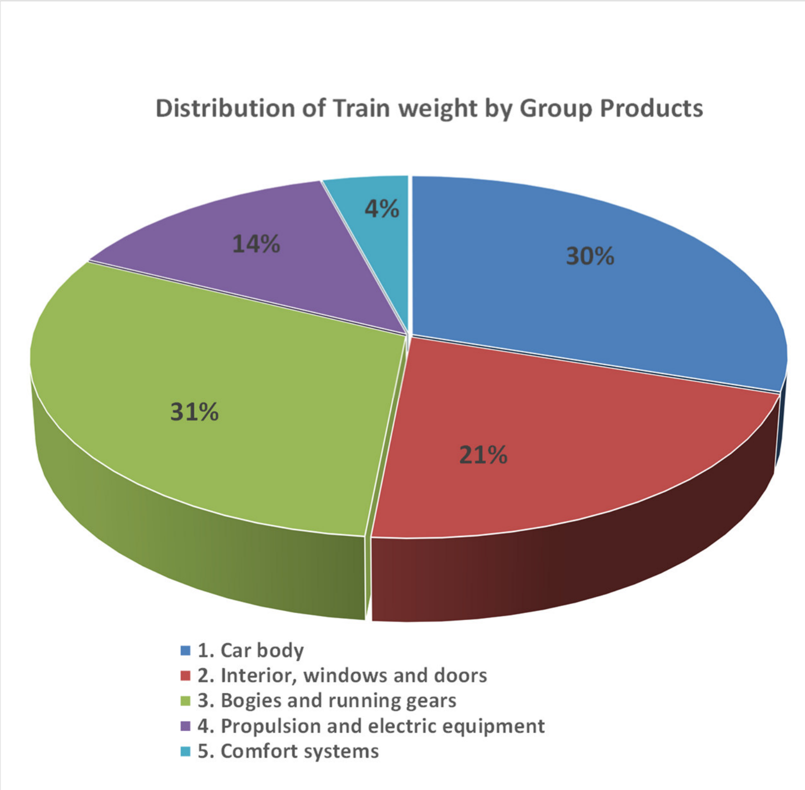

Figure 14 Distribution of train weight by group Products - sources ERJU FP4 SP6

Then we analyse which material is used for interiors according to the classification of UNIFE.

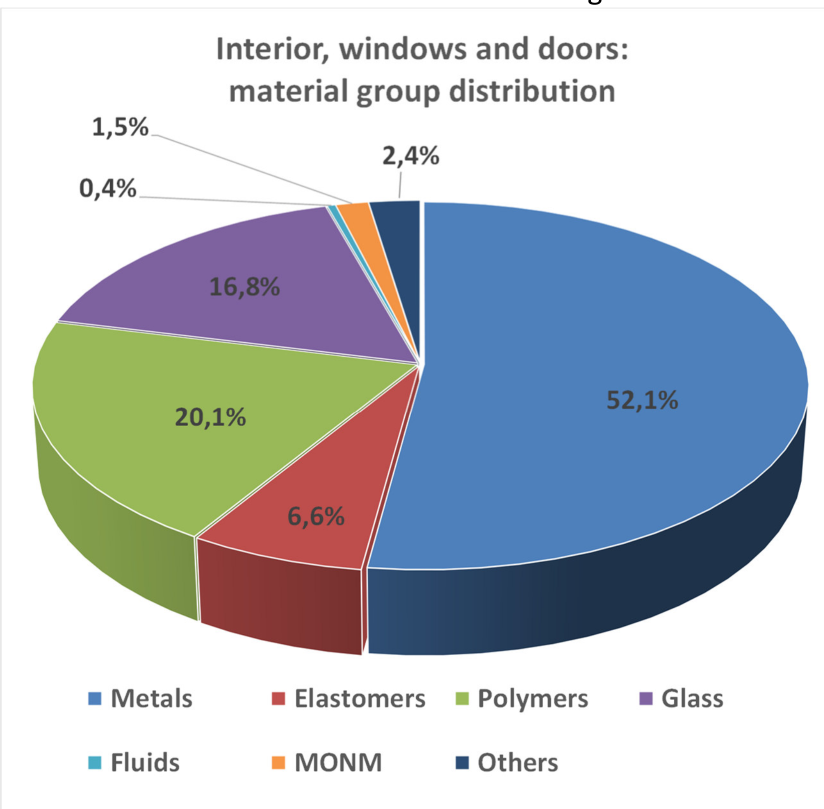

Figure 15 : Material group distribution - sources ERJU FP4 SP6

Applying the methodology of UNIFE specifically for the interiors, it is obtained the following:

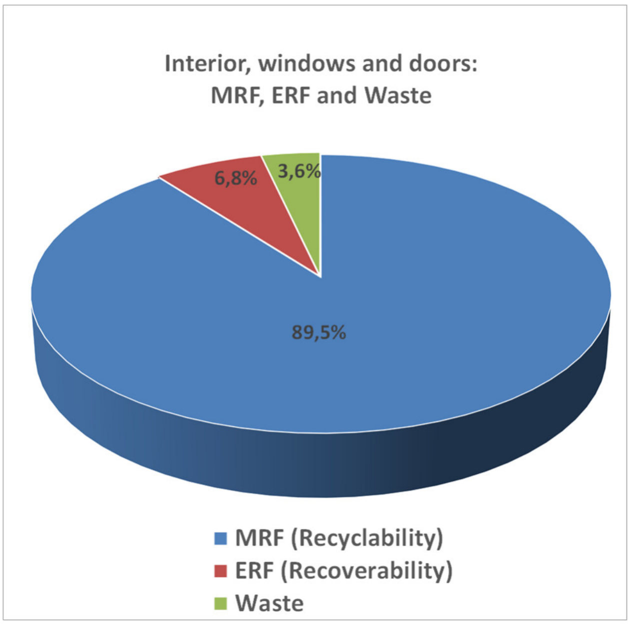

Figure 16 Interior's materials - sources ERJU FP4 SP6

Comparing the figures obtained at complete train and interior, the value of recyclability has decreased ca. 5-6% mainly for the major proportion of polymers and elastomers.

It is clear the big opportunity we have to work on the interiors materials to increase circularity.

- **TRAIN SEATS**
    - Composite materials (like HPL)
    - Non-recyclable materials (like Polyurethane (PU) foam, fabric with fireblocker)
    - Not able to separate into mono-materials
    - Leather (concerns on quality of inflow with reuse)
    - Artificial leather (PVC, PU) is a composite material (after use can basically only be repurposed for other uses)
    - Ecological leather is in use (hybrid of residual products from leather production and artificial leather) provides limited lifetime extension of leather products
    - Metal structures are recyclable
    - Integrated electric products, limited reuseable (not after broken -> E-waste)

- **TRAINFLOOR**
    - Various materials
    - Not able to separate into mono-materials (glue)
        - Multiplex: downgrade reuse cycle
        - Isolation, rubber, floor cover => difficult to separate into mono-materials, has to be repurposed in its sandwich construction
    - Wood floors degrade over time (cannot become a new floor in a train due to risk

assessment, ex. Trains are designed for 5G)
    - Partly destructive removal from train (takes time to remove, economical feasibility?)
    - DDZ: aluminum floors with foam in sandwich. Used in many industries, also outside of the train sector. Opportunity to create widely-used modular parts to build products from?

- **SIDE PANELS**
    - Thermoset composite, difficult to recycle
    - Used in limited amount: GRP,
      (glass)fiber reinforced polyster, problem for circular. Composite,
      can't be reused. Only granulate and downgrade (vulmateriaal beton/cement).
      However extremely long lifetime and won't break (can be part of
      circular economy by having it as long lifetime product, with modular design for extended use over multiple lifetimes of different trains and/or for other uses in the train branche and outside)
    - Aluminum is circular (however not great for comfort (cold to touch), vandalism sensitive (dents), poor sound quality/no noise dampening)
    - ABS polycarbonate (vacuum shapes). Granuleerbaar, downgradeable (limited inflow in virgin product construction possible).
    - HPL low recyclebility rate

- **LIGHTNING**
    - Not able to separate into mono-materials
    - Both sealed and non-sealed lamps on the market (ex. fluorescent tube replacements), sealed units limit maintenace opportunity and increases waste (make REPAIR of subparts possible)
    - Metal of luminaire re-useable
    - Covers made from polycarbonate
    - PCB's with the led's. Current trend is towards less modular PCB's. More and more large singular PCB's (limits maintenance opportunity, not modular products)
    - E-waste, not circular

- **ENERGY SUPPLY**
    - USB cover plastic
    - Electrical parts; E-waste, how to make circular?

9.2.4 Opportunity : Biomimicry as a method to innovate

In search of circular and modular train designs, biomimicry offers a valuable approach. Biomimicry is a growing field that takes nature as a model, mentor and measure for sustainable, even regenerative innovation. It is based on the premise that (the rest of) nature has already built up 3.8 billion years of evolutionary knowledge, and we can emulate and mimic its forms, processes, and systems to solve societal challenges. An important factor that sets biomimicry

apart from bio-inspired design is that it aims to create designs that function like nature. Besides a design tool, biomimicry is also a philosophy, aiming to design in a way that creates conditions conducive to (all) life on Earth - without overshooting its planetary boundaries, and to deepen our relationship with nature.
The biomimicry practice follows a highly iterative design process, applicable to any kind of design challenge. Roughly, there are four stages in the 'Challenge to Biology' approach to achieve a biomimicry solution:

- Scoping, where the context of the design challenge is defined, as well as the function(s) the design solution must have in order to be successful.
- Discovering, where natural models that address the same functions and context as the design solution are explored, and their strategies are studied.
- Creating, where natural strategies are abstracted into principles that can be applied to the design solution
- Evaluating, where the design solution is measured against the criteria and constraints of the design challenge.

Studying how nature builds with minimal use of materials, while maximizing design effectiveness and strength, can guide the design of train interiors with lower material costs. Furthermore, nature transitions materials in continuous loops, and designs optimally with available resources to avoid unnecessary waste, paving the way for circular train designs. Additionally, a more comfortable travel experience can be offered by maximizing space and hygiene in innovative ways.
All participants took part in a biomimicry workshop to get familiar with this process.
As part of the scoping phase, different design challenges linked to each work package were defined, as well as the function(s) linked to each challenge. A preliminary literature study on the possibilities of biomimicry for circular and modular train interiors revealed the biomimicry potential of each challenge. The challenges with the highest biomimicry potential are input for the following research phase.

WP	Challenge
24	Create circular seating
24	Create lateral and ceiling structures with biobased/renewable materials
24	Create circular flooring with biobased/renewable materials
24	Adapt lay-out to seasonal demands (e.g. for bikes)
26	Improve hygiene by reducing smells and preventing graffiti adhesion
26	Maximize the number of train passengers

Fig. 17. The challenges identified during the first step of the project - sources ERJU FP4 SP6

10 Conclusions

The phase 1 of the WP24 was dedicated to state of the art and define main opportunities.
The current designs are not design for refurbishment and not design to evolve during entire life of the train the pre-defined and not designed for facilitate the refurbishments.
The 5 Whys methodology has helped to define the main issues for an interior designed for modularity during the entire of life and designed for circularity. 6 actions have been selected for the design phase of modularity and 6 for circularity.
This first phase of work taught us the gap between what is done and what we could do.
These results will help to build the roadmap of the project and clarify the objectives between partners.

11 References

Clark Kim, Baldwin Clarliss Y - Modularity-In-Design: An Analysis Based On the Theory Of Real Options – 1998