Casting Optimization and Robust Design Considering Composition Uncertainties of Secondary Alloys in the Horizon Europe Project RecAL

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Alberto Vergnano and Hamed Rezvanpour
University of Modena and Reggio Emilia

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RecAL - Recycling Technologies for Aluminium

Horizon Europe CL4-2023-Twin-Transition-01-42

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AUSTRIAN INSTITUTE OF TECHNOLOGY

RecAL 13

PROJECT FACTS

- HEU **Research and Innovation Action** project call CL4-2024-TT-01-42
- Total budget of **10.9 M€**
- **48 months** from **01.01.2024**
- **Leichtmetallkompetenzzentrum Ranshofen** – Austrian Institute of Technology leads consortium of 19 partners

PROJECT OBJECTIVES

- **Digital circularity platform (HUB)** for the entire aluminum recycling value chain
- Optimize **scrap purity** by advanced **sorting and refining** technologies
- Maximizing the **impurity tolerance** of next-generation alloy designs
- Data for **CO_2 footprint** and **product passport** via blockchain

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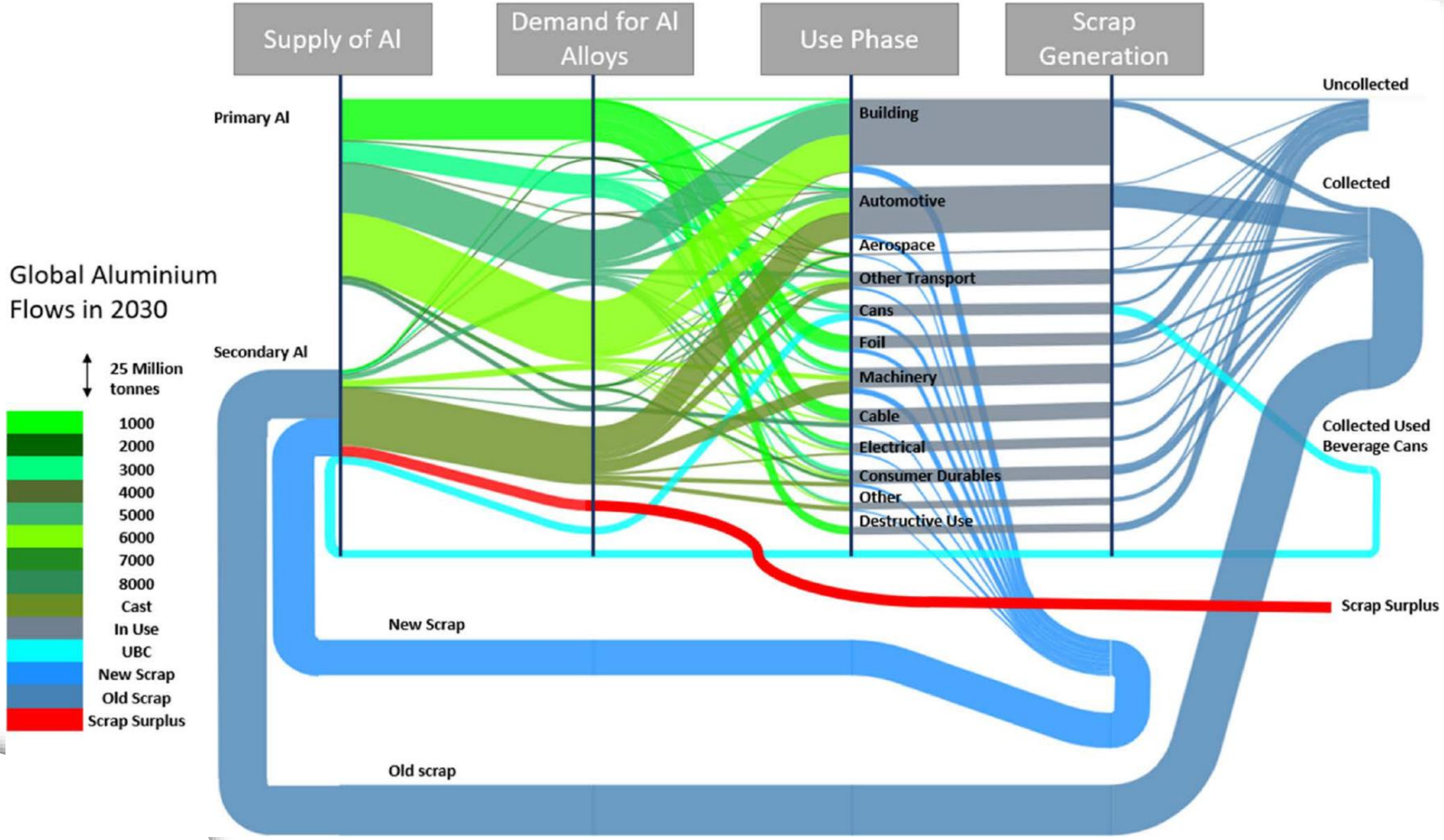
Global AL flows in 2030



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S. Van den Eynde et al.: "Forecasting global aluminium flows to demonstrate the need for improved sorting and recycling methods", Waste Management, 137, 2022, https://doi.org/10.1016/j.wasman.2021.11.019

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Project Consortium

19 Partners
8 EU Countries
+ UK

AIT Austrian Institute of Technology – Tomorrow Today
AELS – We love aircraft
ALTEK – A Harsco Company
Alumil – Building excellence every day
BENTELER – makes it happen
CANCOM
ceit – Member of Basque Research & Technology Alliance
CELSA Group
CERTH – Centre for Research & Technology Hellas
DLR
Fraunhofer LBF
KU LEUVEN
LEITAT – managing technologies
RTDS Association
STENA Aluminium
SWERIM
Università degli Studi Firenze
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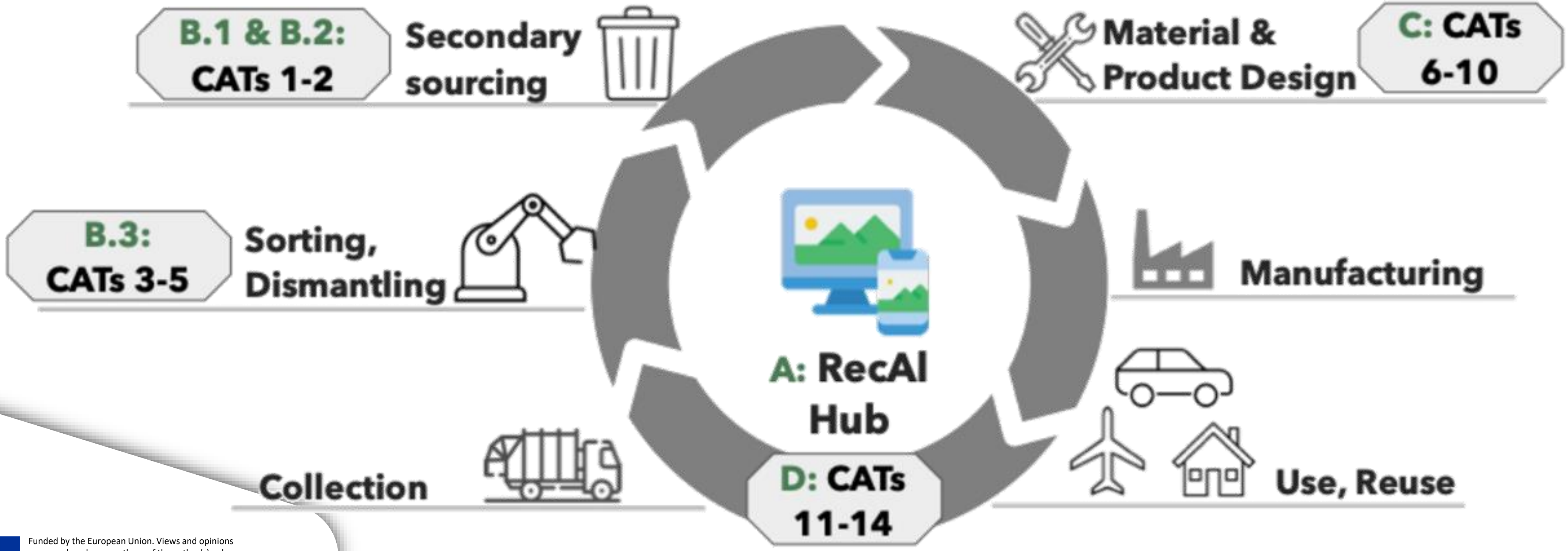
RecAL CATs

- CATs ‘**Circular Amplification Technologies**’ for up- and recycling technologies



Adapted from K-Businesscom AG, April 2023 https://www.k-business.com/ueber-uns/open-circularity-platform

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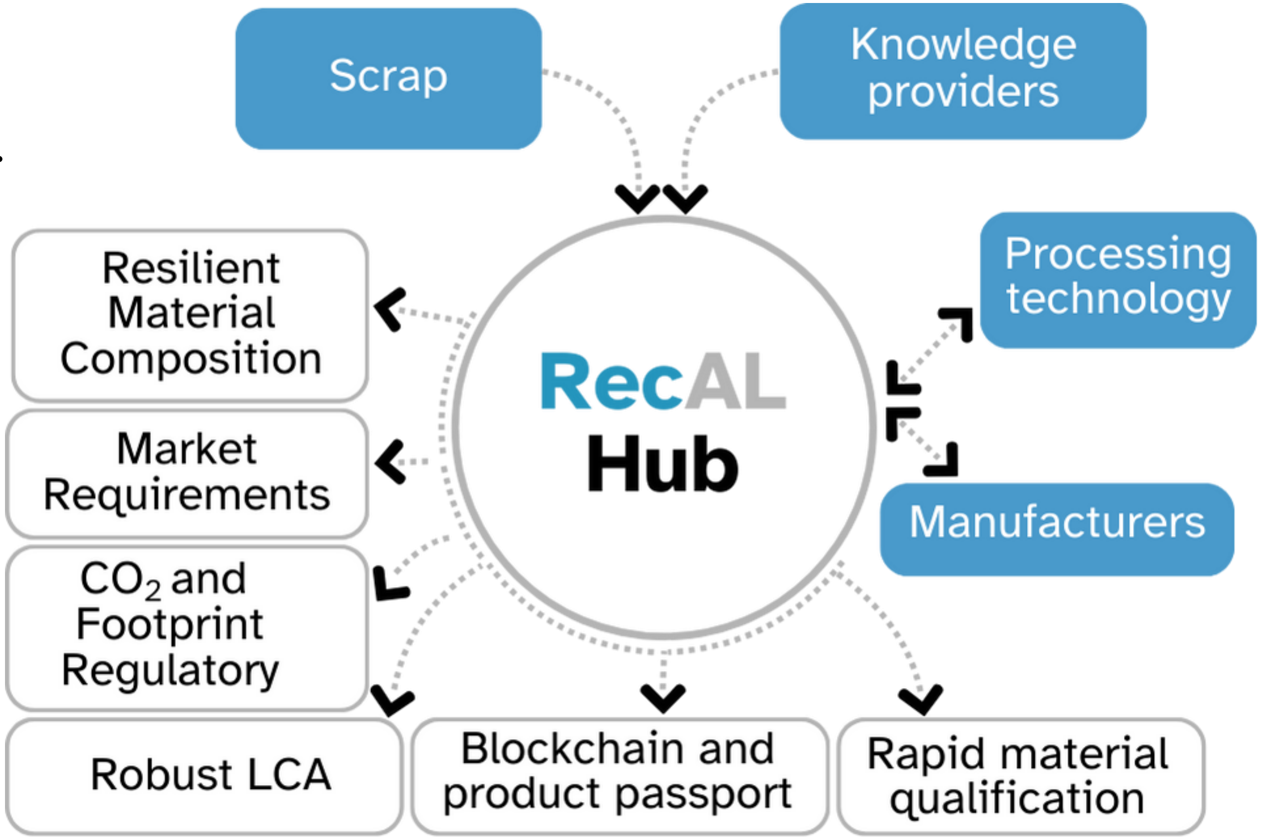
Cluster A - HUB and Interface

- **Digital cockpit** that will connect the 14 CATs.
- **RecAL Hub connects suppliers with buyers.**
- **Circular processing chain**, from design to scrapping to manufactures demands.
- **Anonymised data sharing architecture** to secure the marketplace.



RecAL Hub schematic with stakeholders and outputs

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Clusters B* - Melt Refinement, Salt Slag Upcycling and Sorting Automation

Compressed aluminum scrap, © shutterstock

- **CAT 1. Melt refinement by salt**
  - Improve yield and refining capacity of new upgraded types of Al-scrap
- **CAT 2. Salt slag refinement**
  - Upcycle hazardous salt slag residue generated when aluminium scrap is melted
- **CAT 3. Robotics for sorting**
  - Robots with more flexibility to sort a wider range of scrap sizes and shapes
- **CAT 4. AI for Sorting**
  - AI feedback loop for melted material data to enable self-regulating process
- **CAT 5. Robotic Dismantling**
  - Robots equipped with artificial vision cameras to dismantle rivets from fuselage

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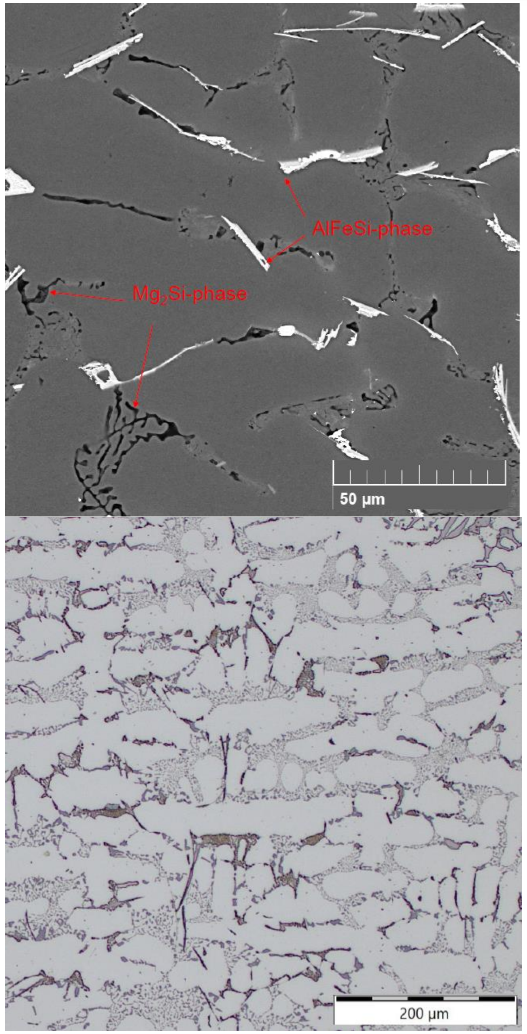
Cluster C - Formulas

- **CAT 6. Formula 6xxx Wrought**
  - A hybrid 6xxx-alloy with widened composition range for improved recycability
- **CAT 7. Formula Physical Properties**
  - Conductor alloys for automotive cable applications from 6xxx to 1xxx scrap
- **CAT 8. Formula 7xxx Wrought**
  - 8-12% aviation and scrap from 5&6xxx (from CAT 5) to reach 50% scrap rate
- **CAT 9. Formula High Tolerance AM**
  - High-strength Al alloy for AM, based on the aeronautic scrap/improved recycability
- **CAT 10. Formular Casting Nano & A226**
  - Advance circularity potential of future cast aluminium alloys from H2020 SUSTAINair



Microstructure of as-cast alloy based on the AlSiMg system with additions of Fe, Mn and Cu reflecting relevant EoL scrap contents. Above: backscattered electron image, below: optical micrograph ©LKR

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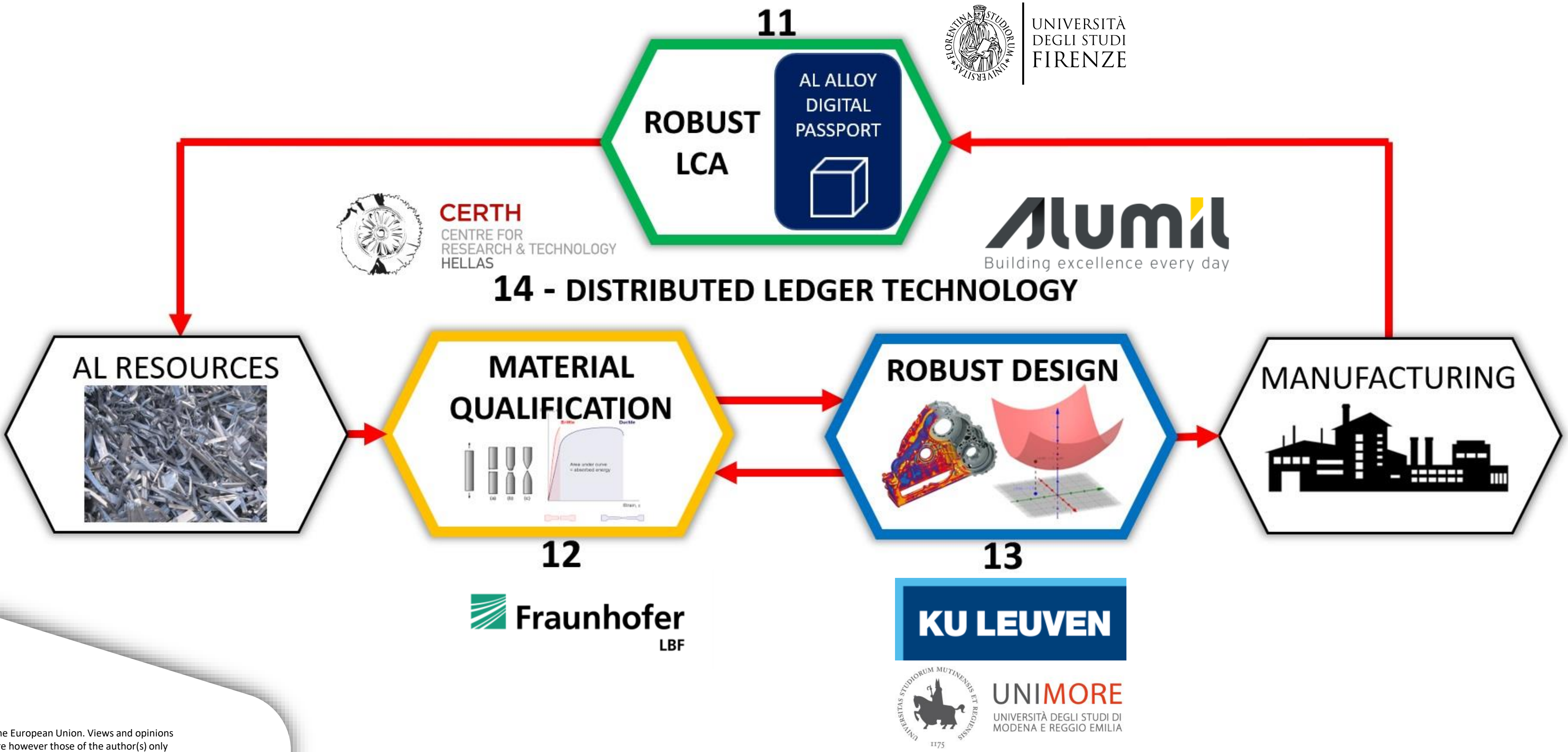
Cluster D - Paradigm Shift



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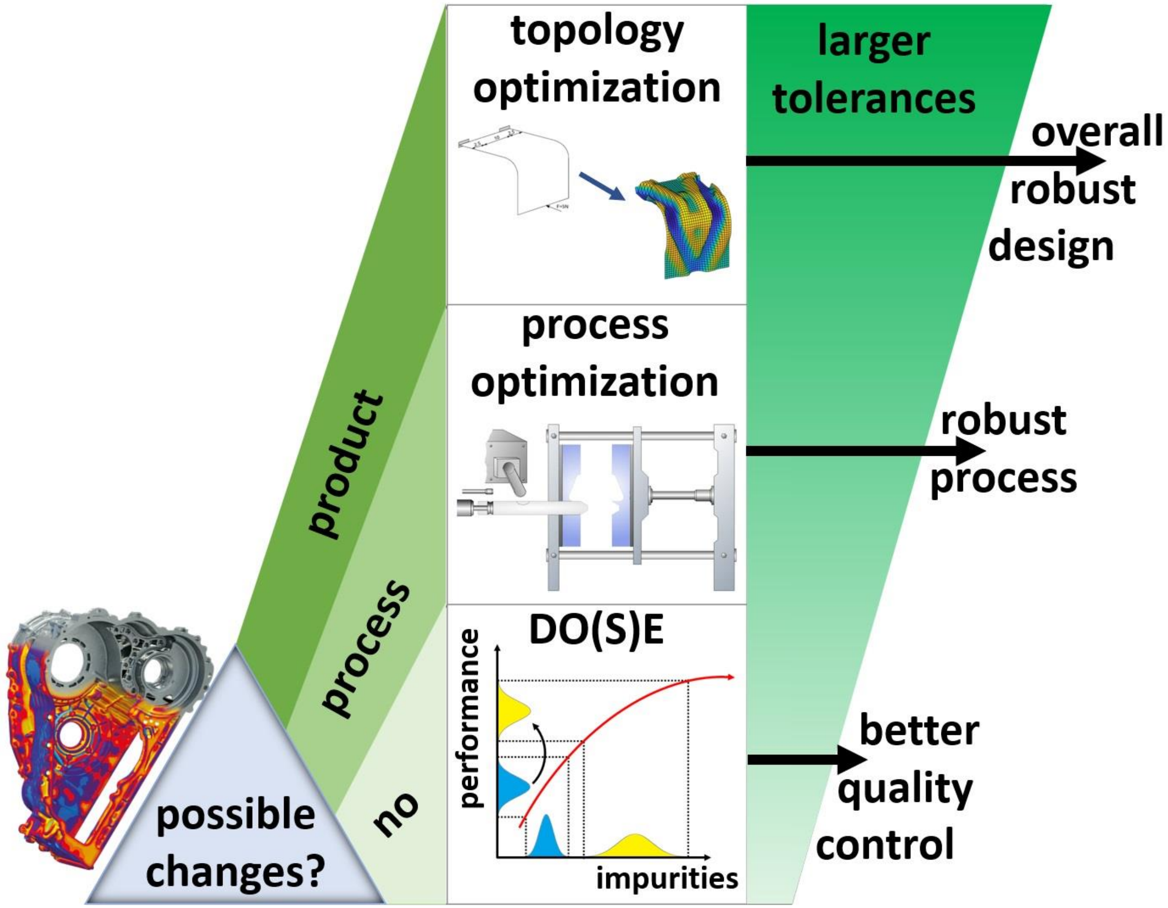
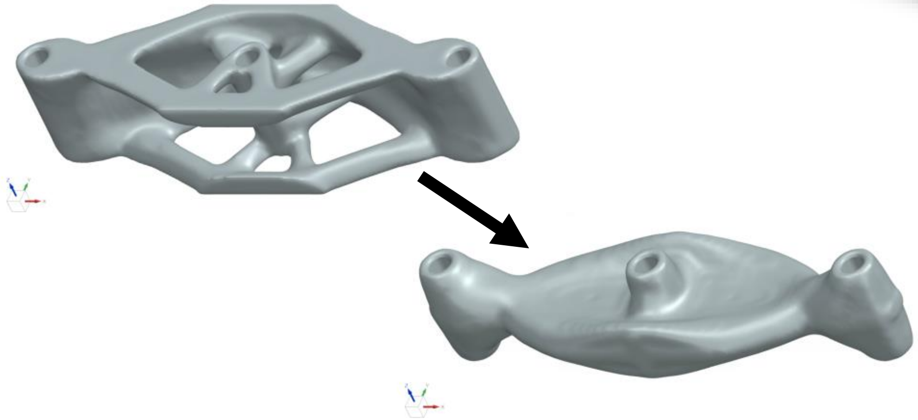
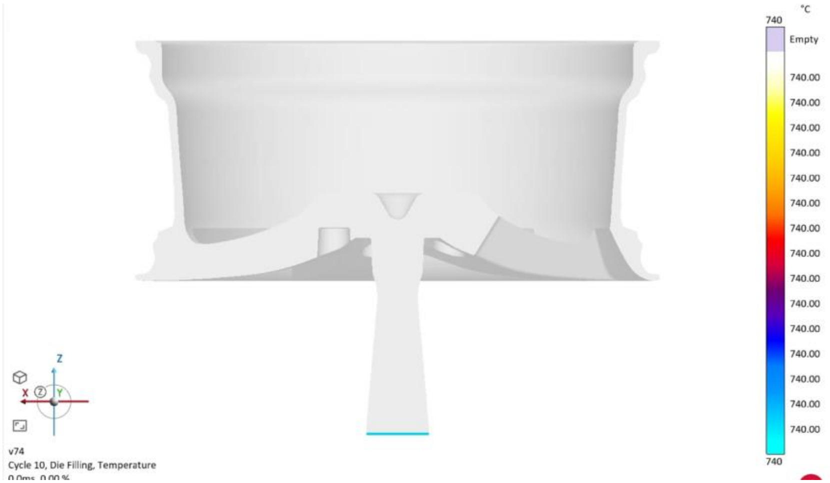
CAT 13. Robust Design







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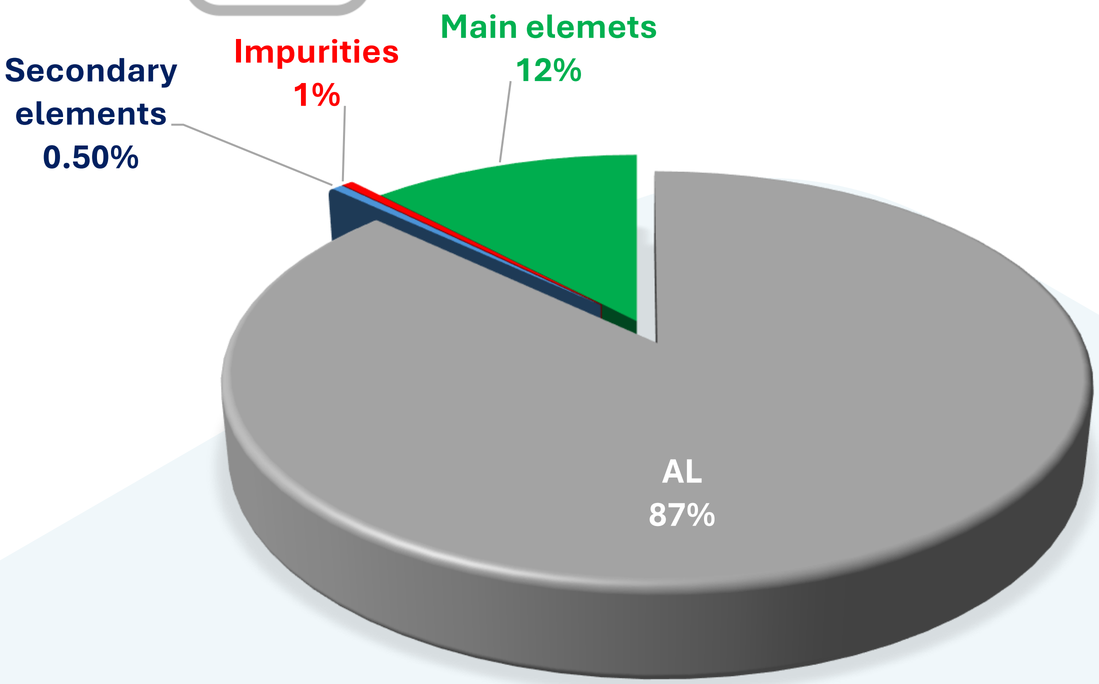
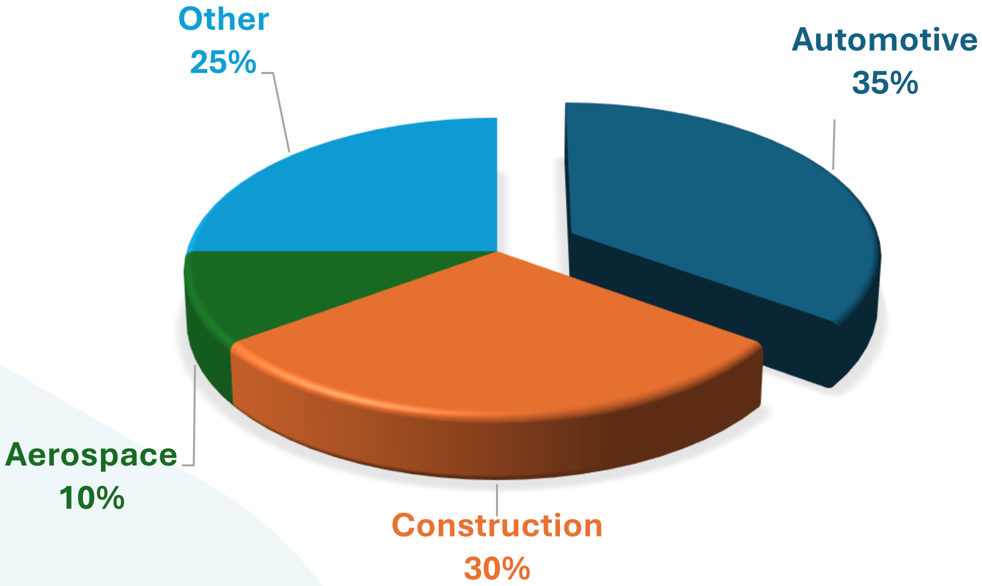
Types of Alloying compositions





1- The main elements are the additives that control the mechanical properties and castability (Si, Mg, Cu, Zn, Mn, Li)

2- The secondary elements are mainly used for solidification behavior control, microstructural and grain refinement (Ti, Sr, Zr, B, V, Sc, Cr)

3- Impurities are unwanted elements that should be controlled or eliminated (Fe, Na, Ca)

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Robustness Assessment in the Optimization of LPDC Subject to Variations in Secondary Alloy Composition

RecAL

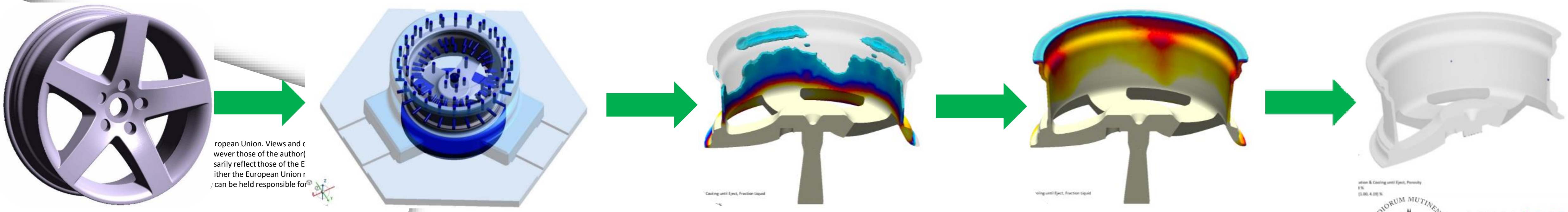
CAD design

Casting Simulation

Process parameter optimization

Sensitivity analysis

Final design ranking



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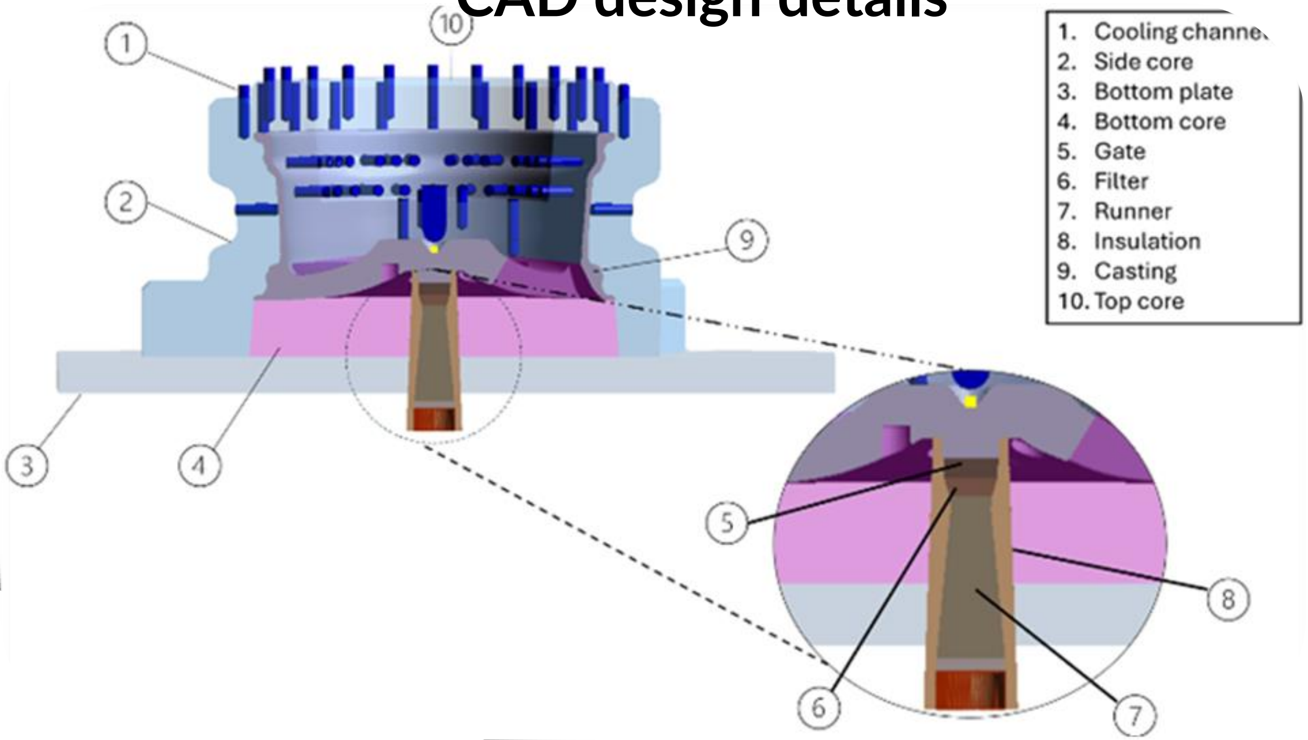
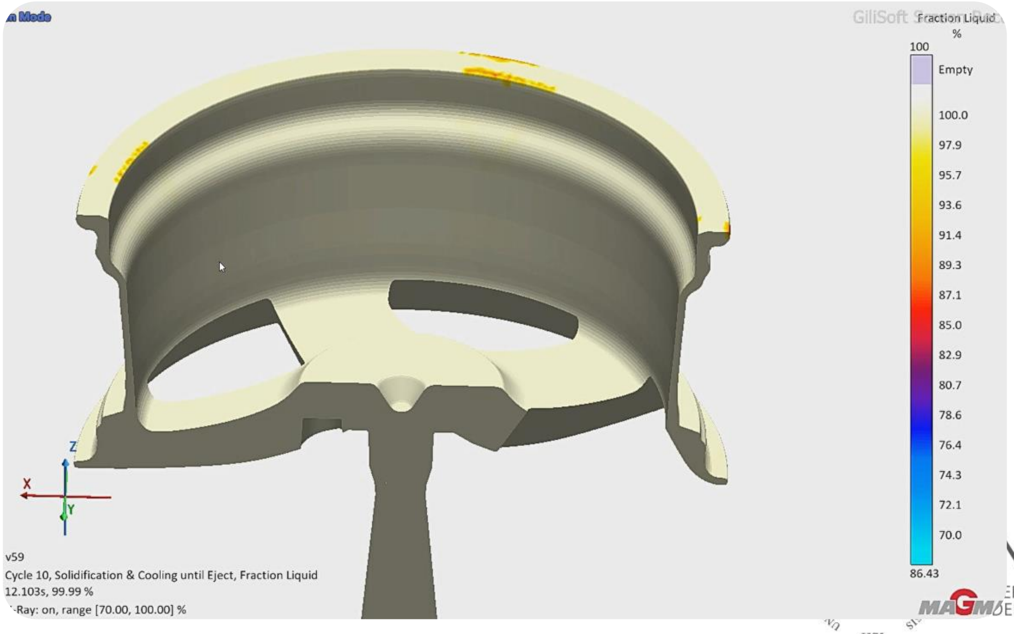
CAD design and Casting simulation in MAGMA

CAD design details





Casting simulation using MAGMA

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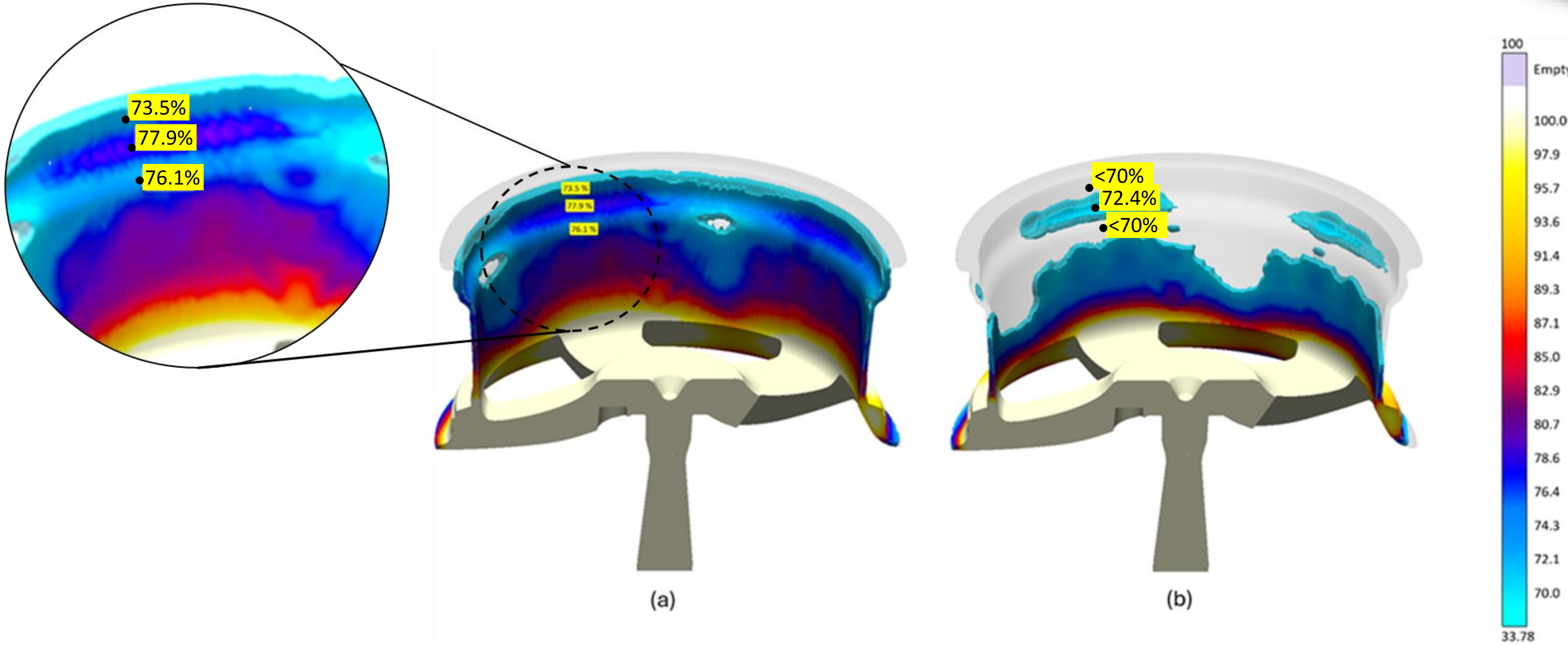
Why porosity occurs?

- The porosity occurs because of the non-sequential solidification phenomena

- It can be controlled by controlling solidification stage parameters



shrinkage porosity occurrence (a)before the separation; (b)after the separation

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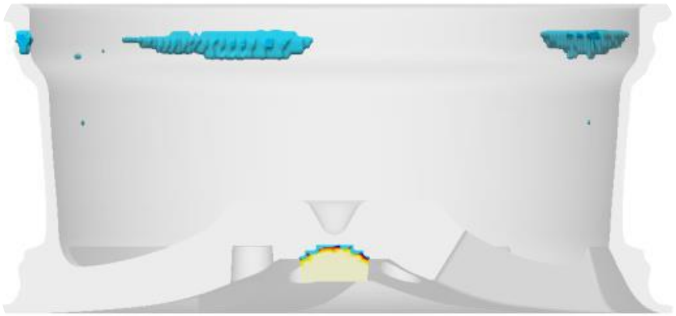
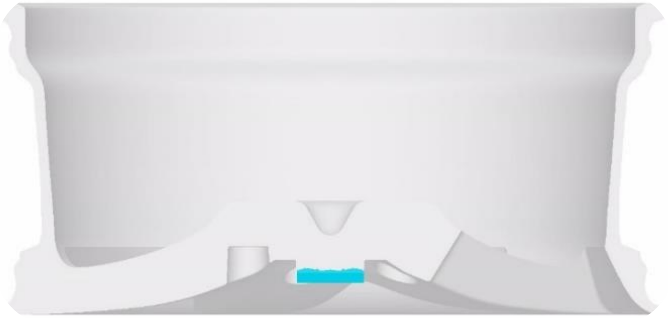
Optimization parameters

Objective:

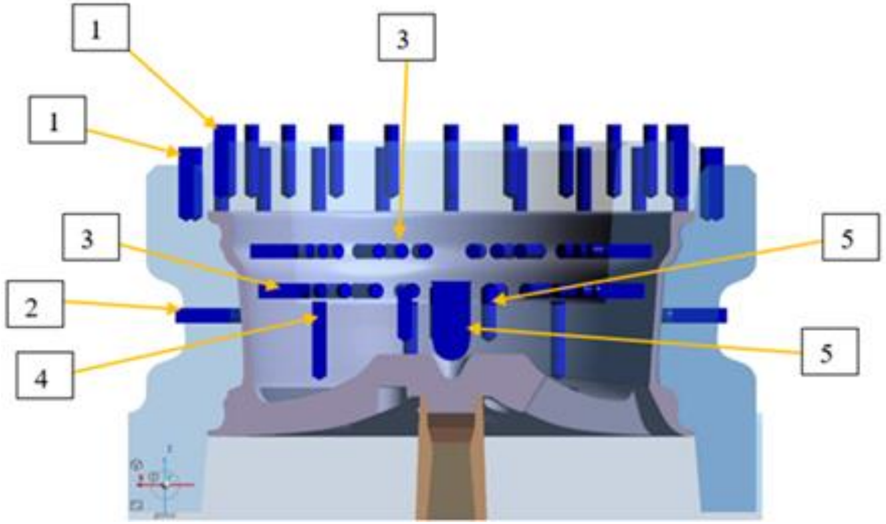
- **Minimizing porosity to Less than 5%**





Control factors

HTC Category	Parameter levels	Number of levels
1- COOLING CHANNEL UP	500 - 2500 W/m^{2}K (step size = 500)	5
2- COOLING CHANNEL SURFACE EXT	100 - 900 W/m^{2}K (step size = 200)	5
3- COOLING CHANNEL SURFACE INT	0.001- 400 W/m^{2}K (step size = 100)	5
4- COOLING CHANNEL DOWN	500 - 2500 W/m^{2}K (step size = 500)	5
5- COOLING CHANNEL DOWN INT	2200 - 3000 W/m^{2}K (step size = 200)	5
POURING TEMPERATURE	700 - 740 (step size = 10)	5



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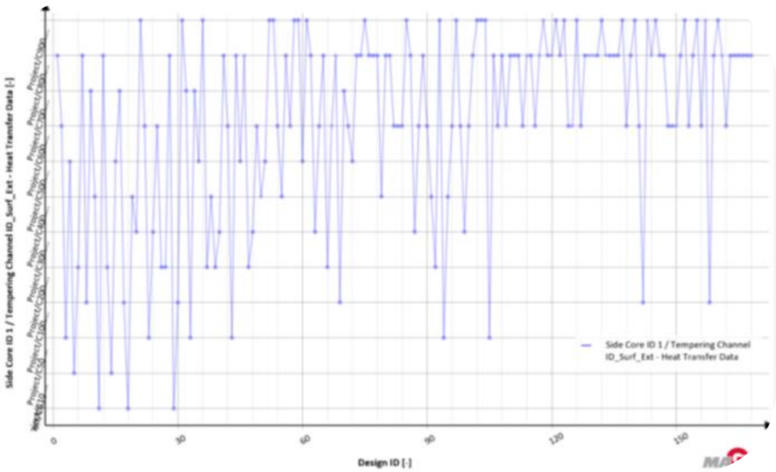
Genetic Algorithm optimization

- The total search space is $5^6 = 15625$
- The optimization runs for 10 generations
- The initial population size is 16

$$NIP = N_{obj} \times N_{dv} \times 2 \begin{cases} \text{If } N < 16 & N_{IP} = 16 \\ \text{If } N > 16 & N_{IP} = N \end{cases}$$

Rank	Design	Up_ext	Surf_ext	Down_intern	Down	Up	Surf_int	Down_center	Up_in	Surf_up_in	Initial Temperature
1	147	1800	900	3000	1500	1900	300	2500	2800	300	720
2	160	2300	1000	3000	2100	1900	300	2300	2800	200	730
3	149	1000	700	3000	1500	1900	300	2500	2800	200	720
4	152	200	700	3000	1400	2000	200	2500	1000	200	720
5	146	200	900	3000	1500	2200	200	2500	2800	200	720
6	107	200	700	3000	1500	1900	300	2500	2800	200	720



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S/N ratio calculation and QL function

Signal to Noise ratio calculation:

Nominal is better:

$$SN_n = -10\log[\,(Y_0 - \mu)^2 + \sigma^2] \quad (1)$$

Higher is better:

$$SN_l = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{\{(y\}_i)^2}\right] \quad (2)$$

lower is better:

$$SN_s = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\{(y\}_i)^2\right] \quad (3)$$

Quality Loss function:

$$\mathrm{QL} = \mathrm{L}(Y) = \mathrm{K}[Y - Y_0]^2 = (\mu - Y_0)^2 + \sigma^2 \quad (4)$$

Fe	Si	Cr	Zn
0.5	7	0	0.1
0.5	7.25	0.075	0.15
0.5	7.5	0.15	0.2
0.65	7	0.075	0.2
0.65	7.25	0.15	0.1
0.65	7.5	0	0.15
0.8	7	0.15	0.15
0.8	7.25	0	0.2
0.8	7.5	0.075	0.1

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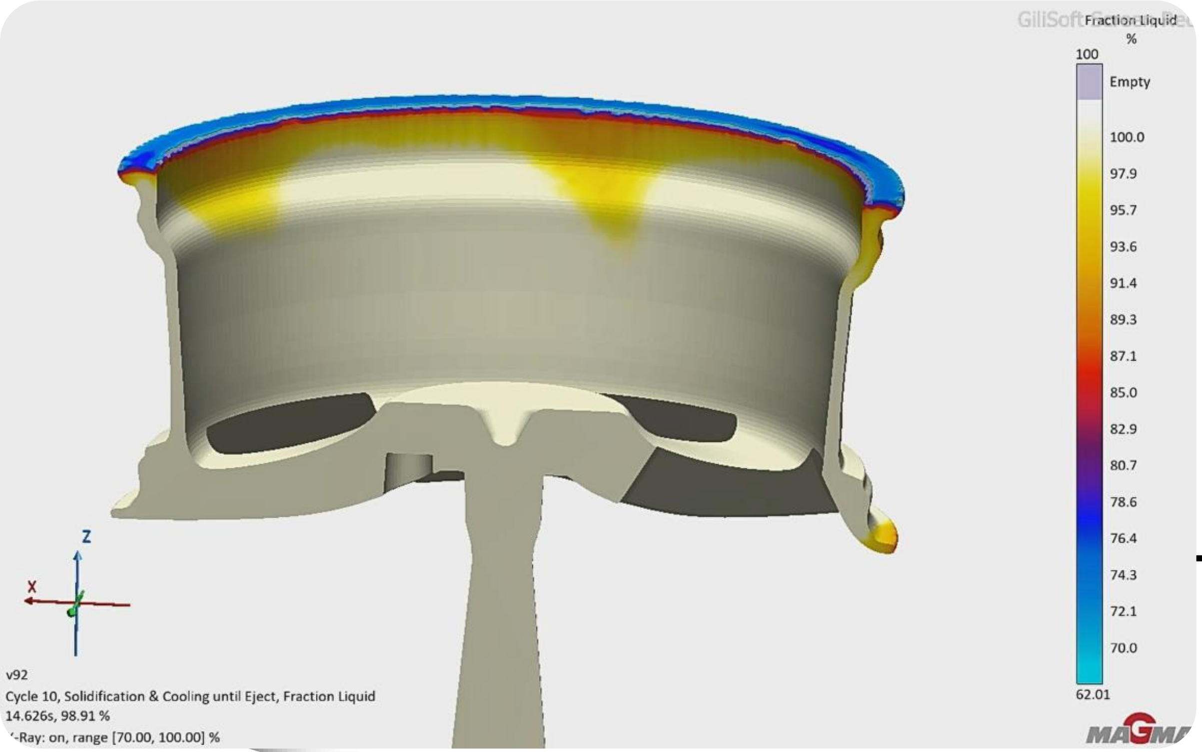
DOSE S/N and QL analysis



Design	Mean	Standard Deviation	Variance	Quality Loss	**S/N Ratio**
Design 1	1.391	3.934	15.479	17.414	-12.409
Design 2	0.989	2.797	7.823	8.801	-9.44538
Design 3	2.664	4.406	19.413	26.512	-14.2344
Design 4	5.613	9.273	85.325	116.834	-20.6757
Design 5	2.262	2.399	5.756	10.871	-10.3627
Design 6	1.967	2.939	8.637	12.504	-10.9706
Design 7	2.701	3.209	10.299	17.592	-12.4531
Design 8	2.009	3.936	15.491	19.527	-12.9064
Design 9	2.411	2.188	4.787	10.597	-10.252
Design 10	8.621	8.492	72.114	146.438	-21.6565

Material / **Levels**	**Fe**	**Sr**	**Cr**	**Zn**
1	-5.929	-10.445	-4.798	-8.94
2	-17.662	-12.84	-14.15	-14.103
3	-12.843	-13.148	-17.485	-13.391
Delta	11.733	2.702	12.686	5.163
Rank	2	4	1	3

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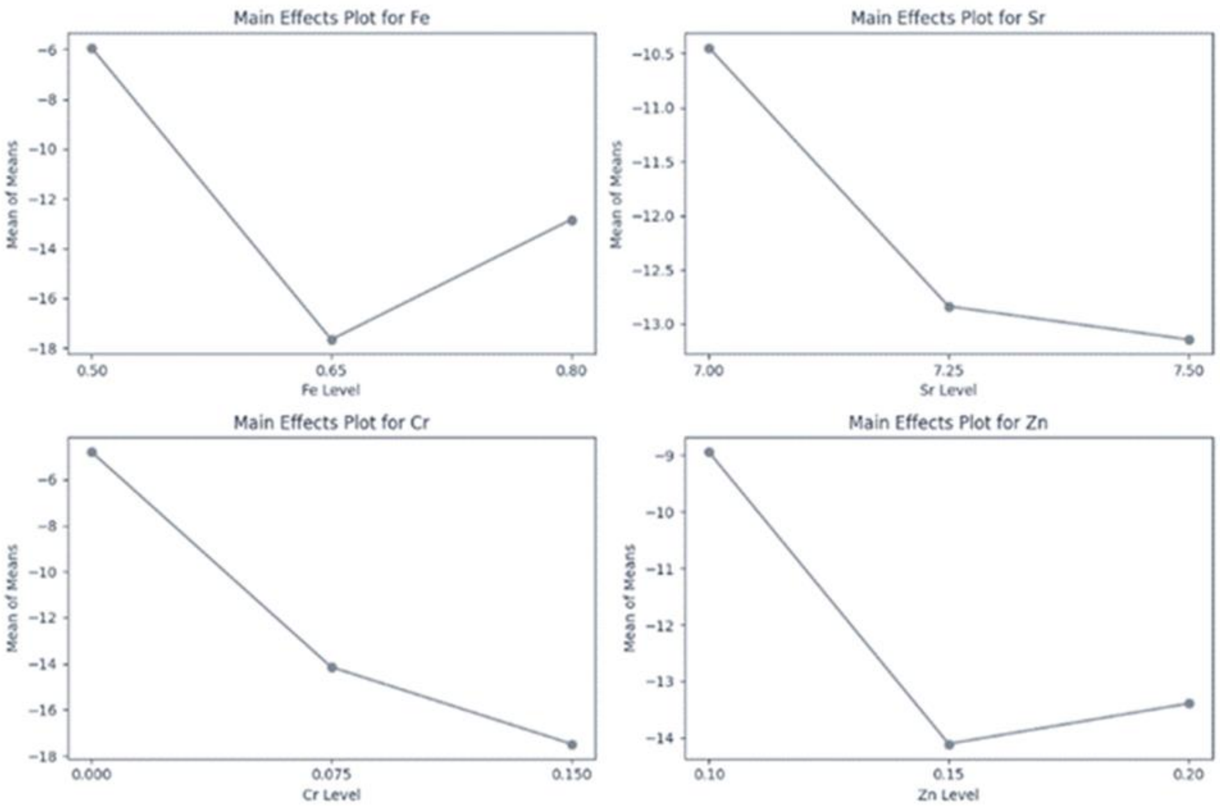
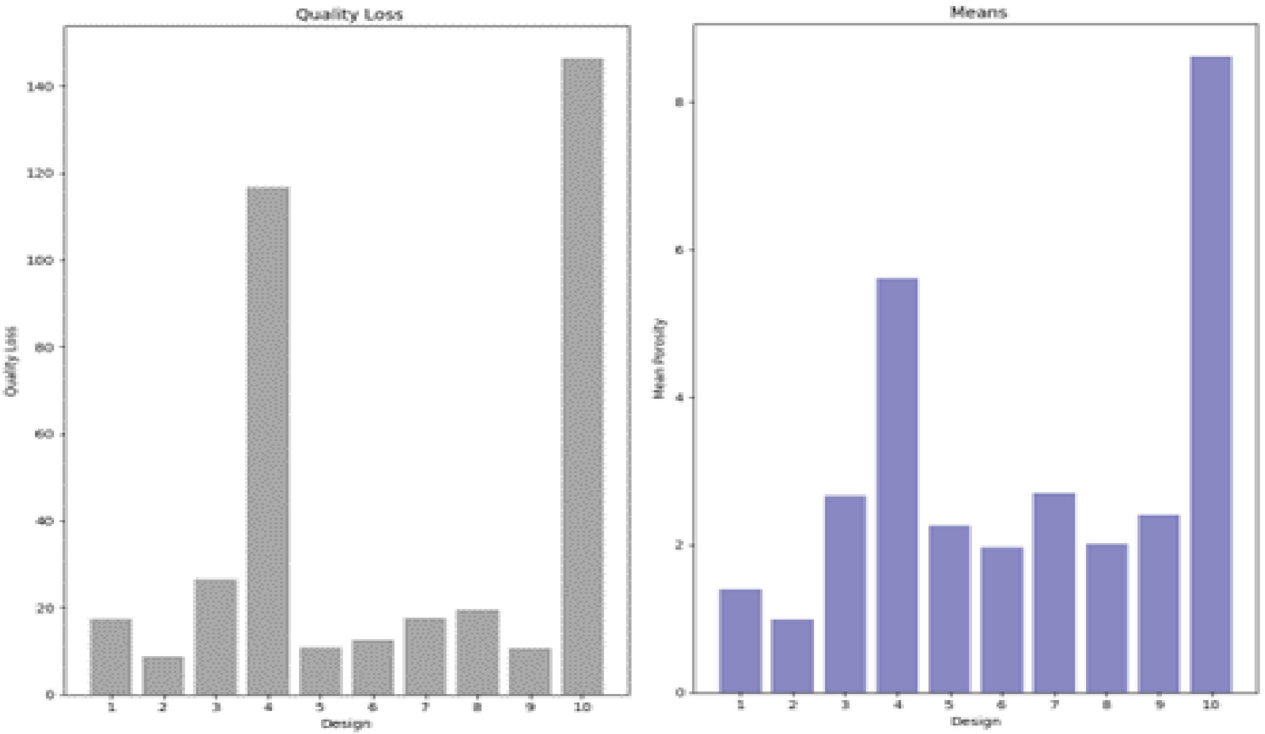
DOSE S/N and QL analysis



S/N ratio analysis for alloying compositions



Linear graph in QL function, (a) mean values; (b) QL function

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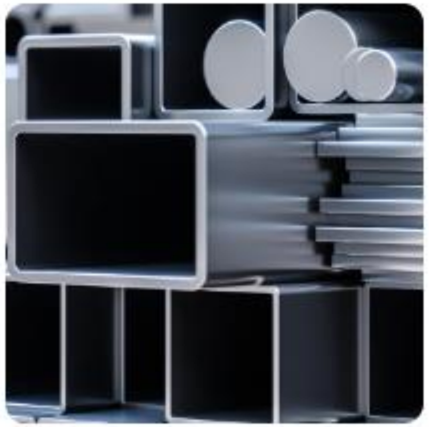
Conclusions

With RecAL:



Increased impurity tolerance in alloy design without compromising performance

Harmonising communication between all sectors of the aluminium industry

Creating recyclate streams with vastly enhanced impurities

Adapting production to unlock potential of secondary resources

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Thank you!

Alberto Vergnano
UniMoRe
WP Cluster D Leader

Hamed Rezvanpour
UniMoRe
CAT 13 Researcher

recal-project.eu
@RecAL_Project
linkedin.com/showcase/recal-eu

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