Sustainability in AM

Contents

- ❑ Introduction
- ❑ Environmental footprints of additive manufacturing
- ❑ Developing a suitable life cycle assessment(LCA) database
- ❑ Predicting environmental impact before printing
- ❑ How to reduce the environmental footprint of additive manufacturing
- ❑ Social impacts of AM
- ❑ Life cycle costing
- ❑ Eco-design methodology
- ❑ Sustainable materials science paradigm
- ❑ Summary

Introduction

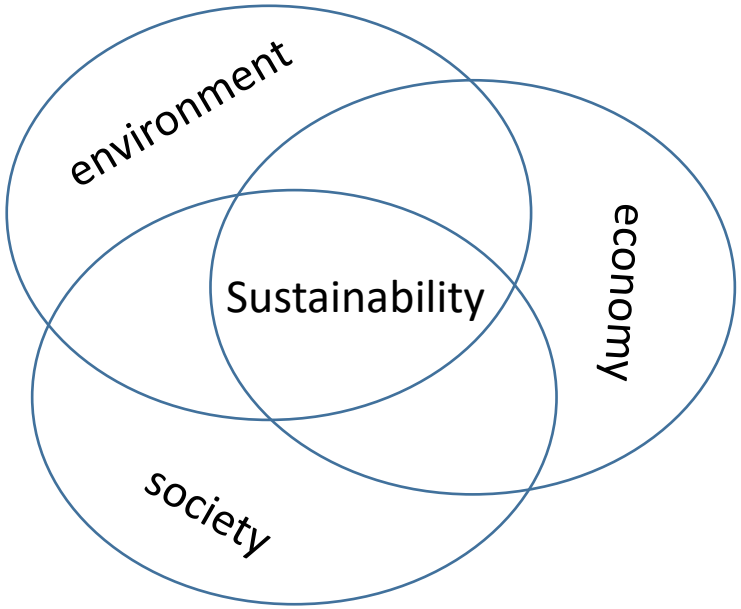


Fig. Sustainability dimensions

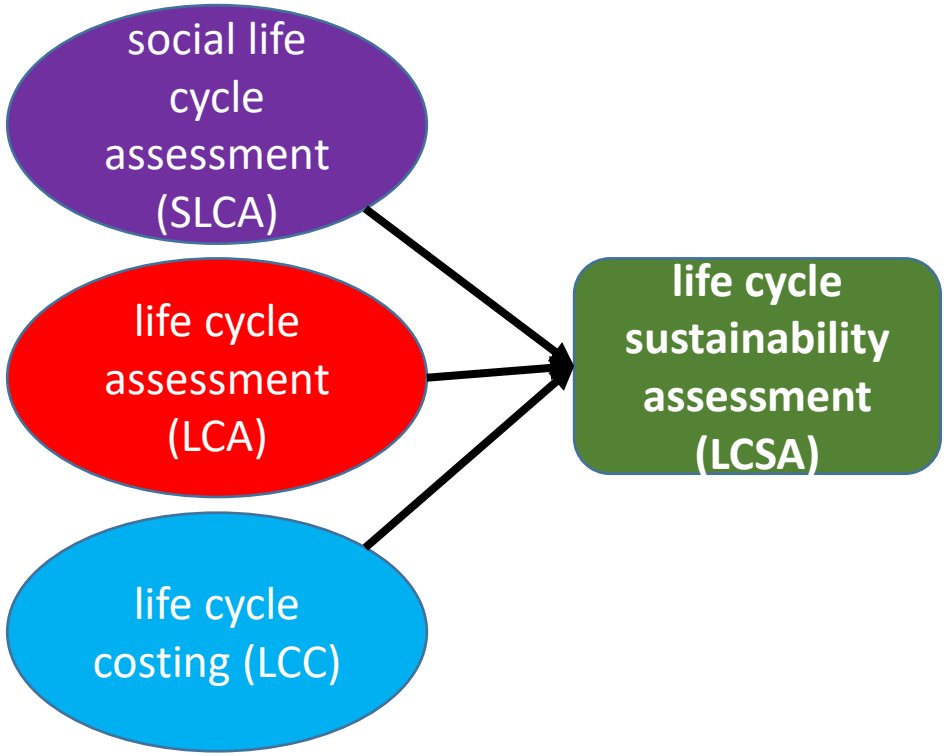


Fig. Life cycle sustainability assessment

The 6R concept:

reduce,
recover,
recycle,
reuse,
redesign, and
remanufacture

Actions to be considered

- ✓ More transparency to AM's environmental footprints
- ✓ Suitable lifecycle assessment database
- ✓ Predicting environmental impact before printing
- ✓ Performing actions to reduce the environmental footprint of AM.

Environmental footprints of additive manufacturing

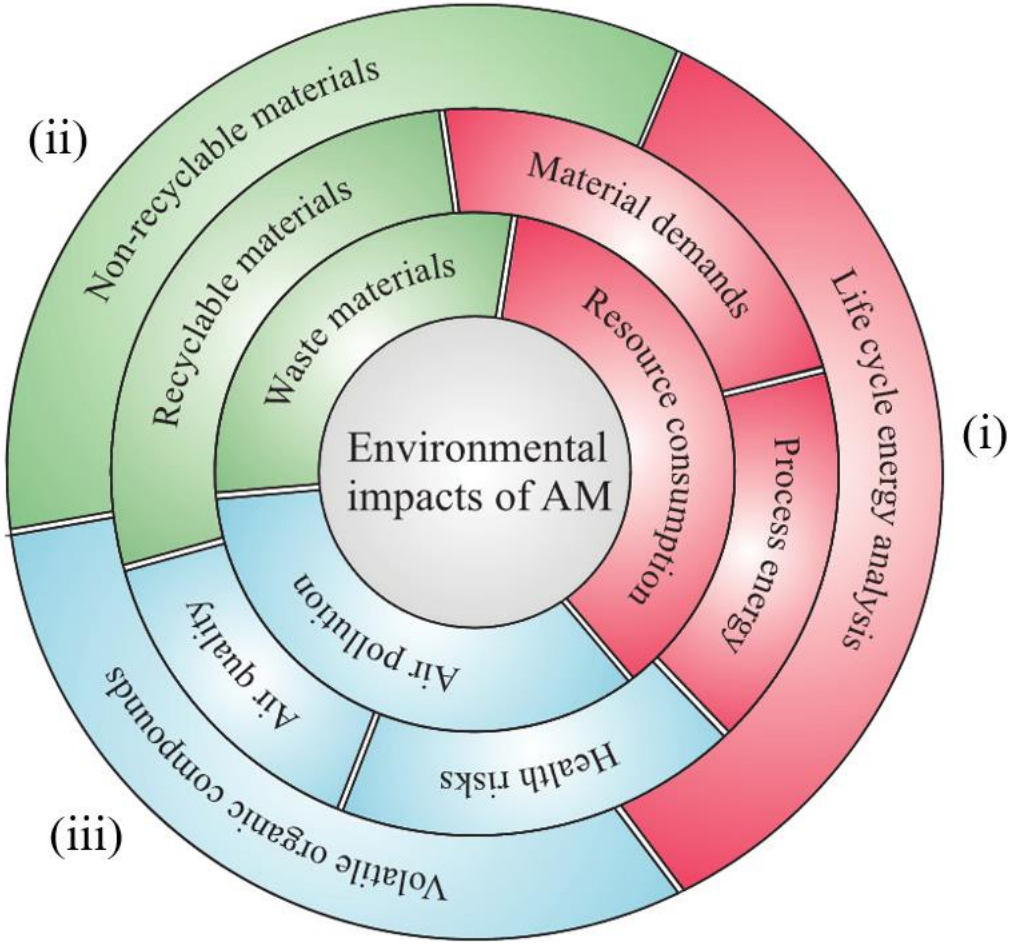


Fig. Factors showing how AM processes affect the environment. (i) Resources (red), (ii) waste (green), and (iii) pollution (blue)

Source: Khosravani and Reinicke 2020 [https://doi.org/10.1016/j.apmt.2020.100689]

Environmental footprints of additive manufacturing

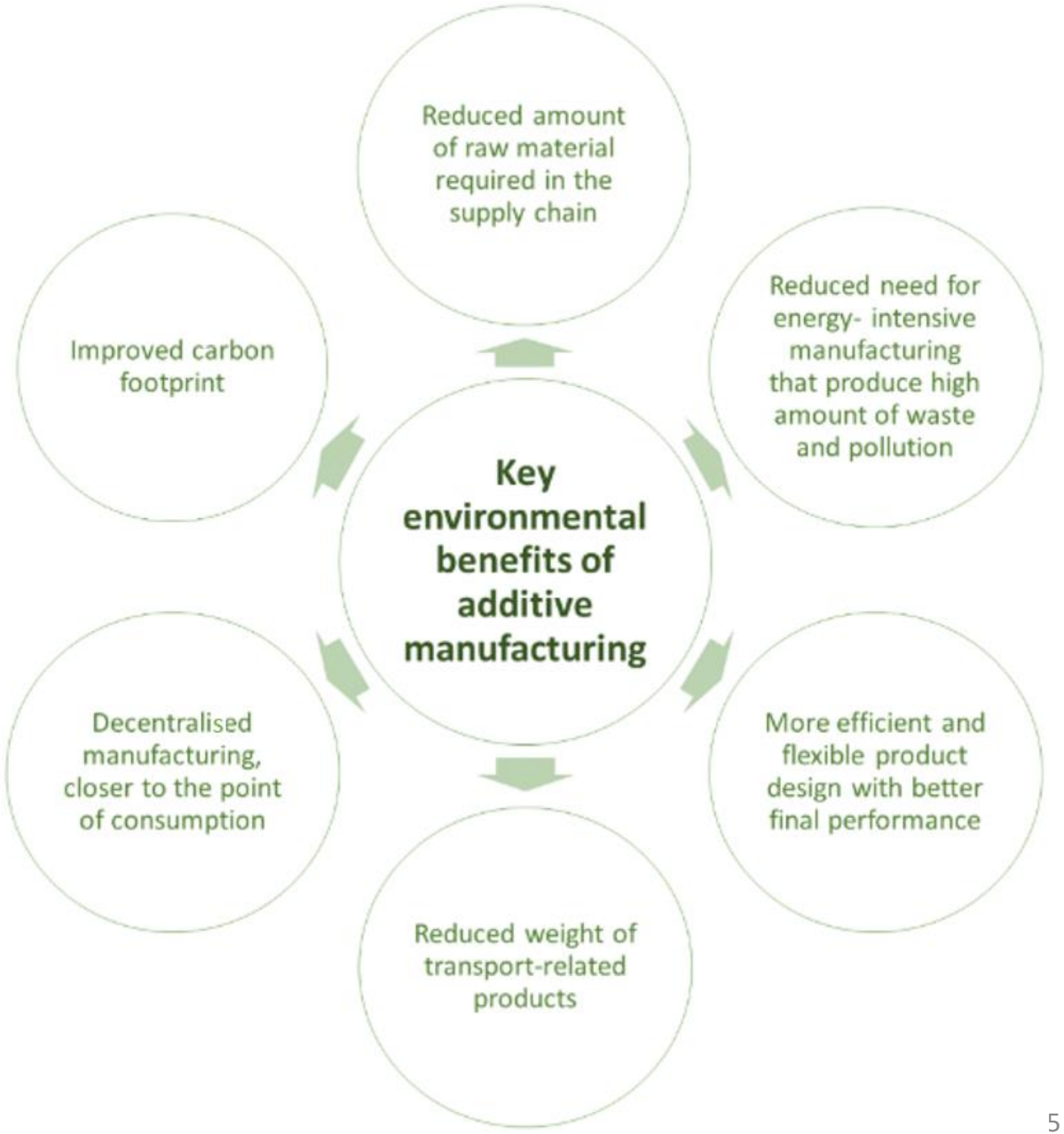


Fig. Environmental benefits of AM

Source: Jambrak et al. 2021 [https://doi.org/10.3390/app11020686]

Developing a suitable life cycle assessment(LCA) database

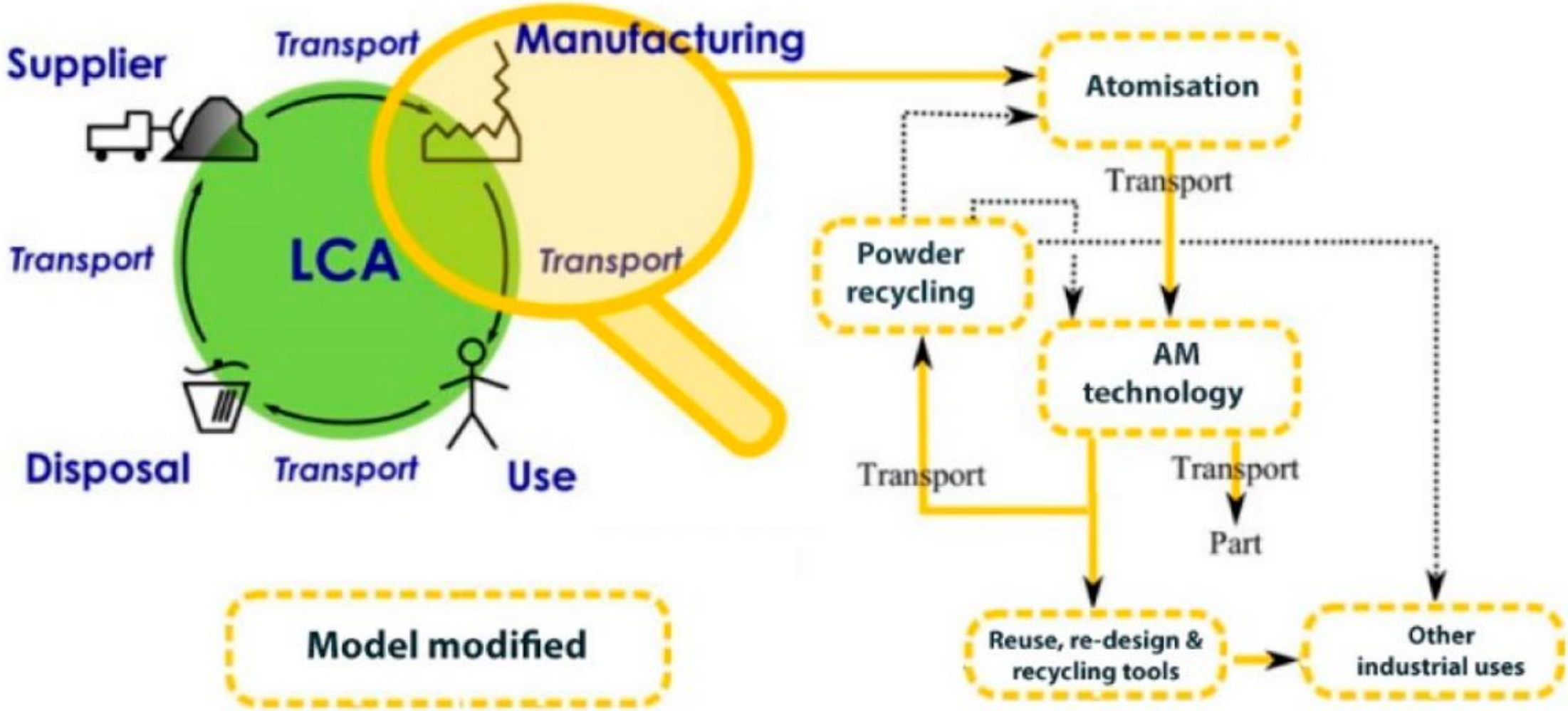


Fig. The modified AM LCA scheme

Source: Bourhis et al. 2014 [https://doi.org/10.1016/j.procir.2014.06.031]

Developing a suitable life cycle assessment(LCA) database

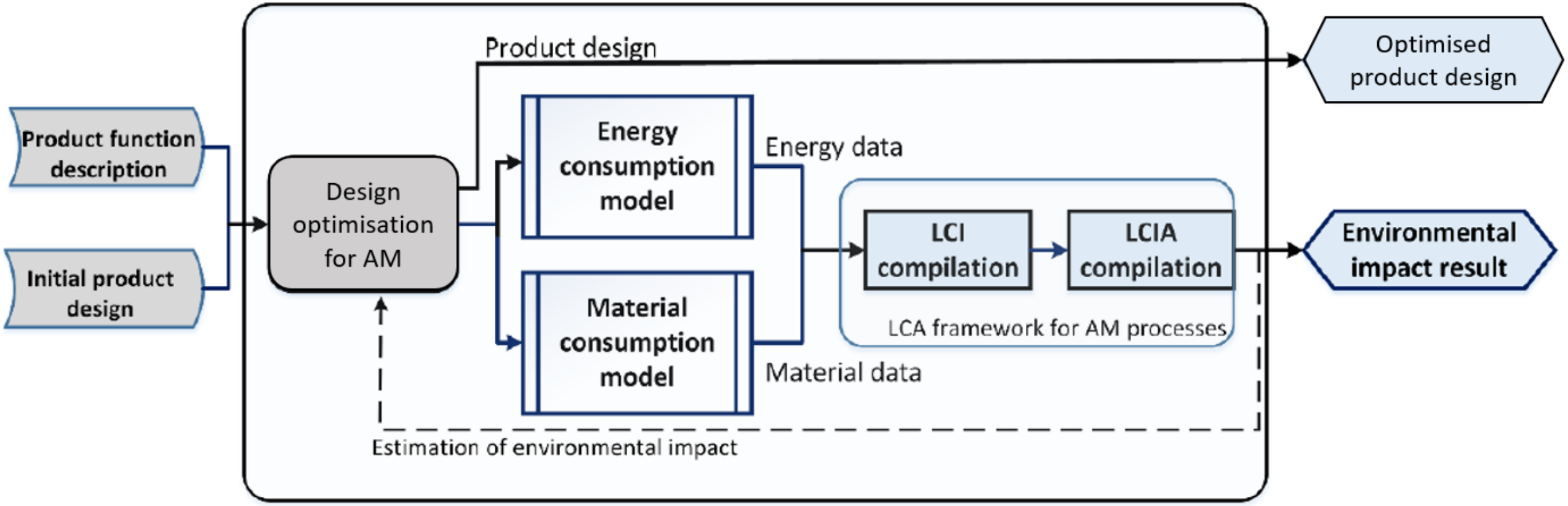


Fig. A general methodology for evaluating the environmental impact of AM processes

Source: Gebisa, and Lemu 2017 [https://doi.org/10.1016/j.promfg.2017.09.120]

Developing a suitable life cycle assessment(LCA) database

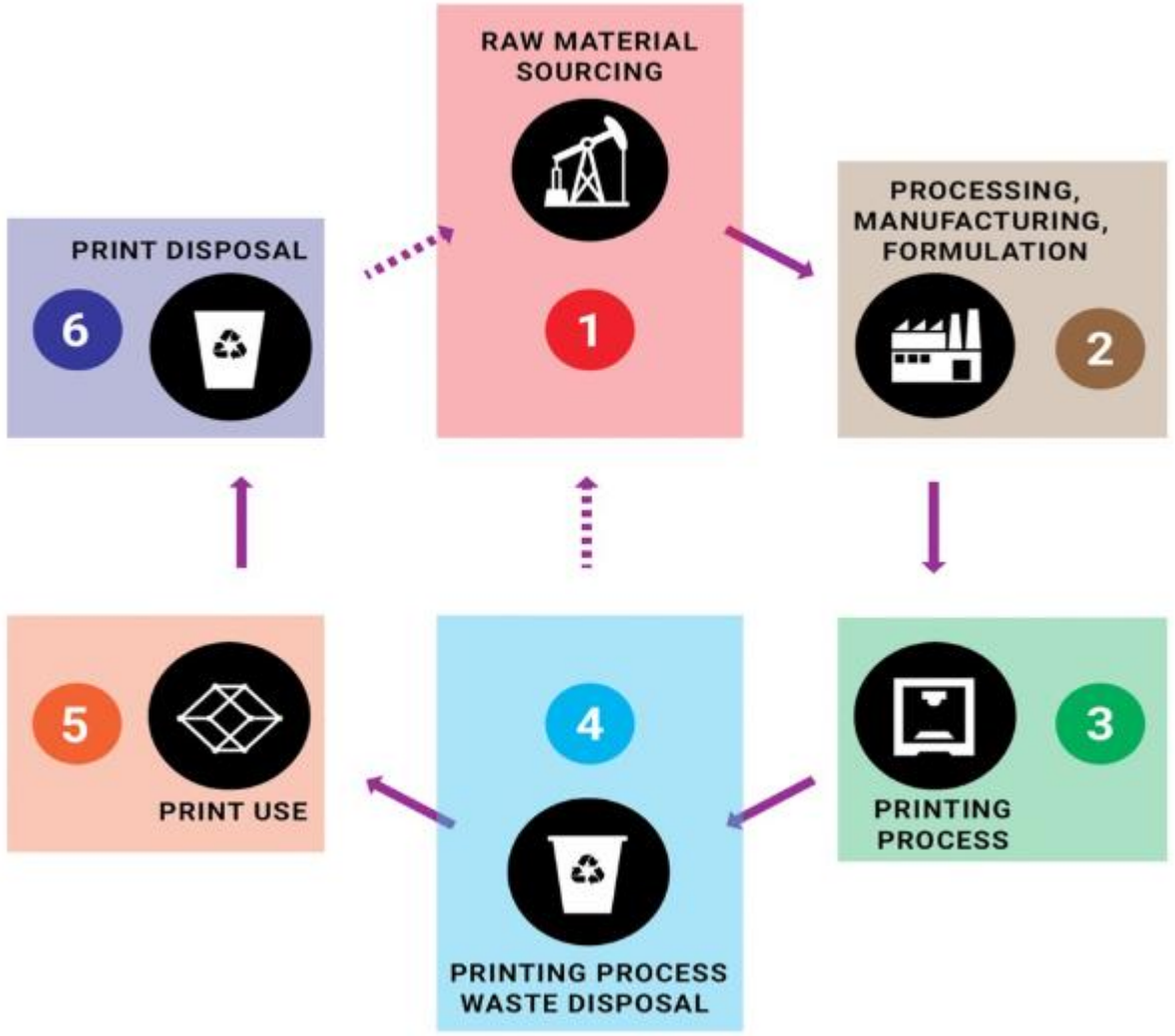


Fig. AM life cycle stages

Source:Bours et al. 2017 [https://doi.org/10.1111/jiec.12587]

Predicting environmental impact before printing

Approaches to examine the sustainability of AM

- predictive models,
- general methodologies,
- analytical methodologies,
- experimental methodologies,
- LCA-based approaches,
- road mapping frameworks, and
- design for environment methodologies

<u>Product Sustainability Index (PSI) criteria:</u>

1. environmental effects,
2. resource use and economy,
3. manufacturability,
4. functionality,
5. societal impact, and
6. recyclability/remanufacturability

How to reduce the environmental footprint of additive manufacturing

Powder production and reuse

- Replace the fossil fuel energy inputs in their processes with renewable alternatives
- energy-saving measures
- AM materials generated from chemical processes that produce less pollution
- Powder recycling
- Support structure optimizing

Printing

- Printing procedure:
  - Preheating the powder bed and generating an inert gas atmosphere,
  - exposing the energy source,
  - cooling the component, and
  - recovering unused powder
- Laser Unit: laser scanning consumes the most share of energy; modifications in processing parameters can result in improvement in AM sustainability.
- The management system and power generating fan
- Process heaters and pumps for the vacuum and gas circulation

Appraising environmental impact

- ❑ Resource consumption
- ❑ Waste management
- ❑ Pollution control

Social impacts of AM

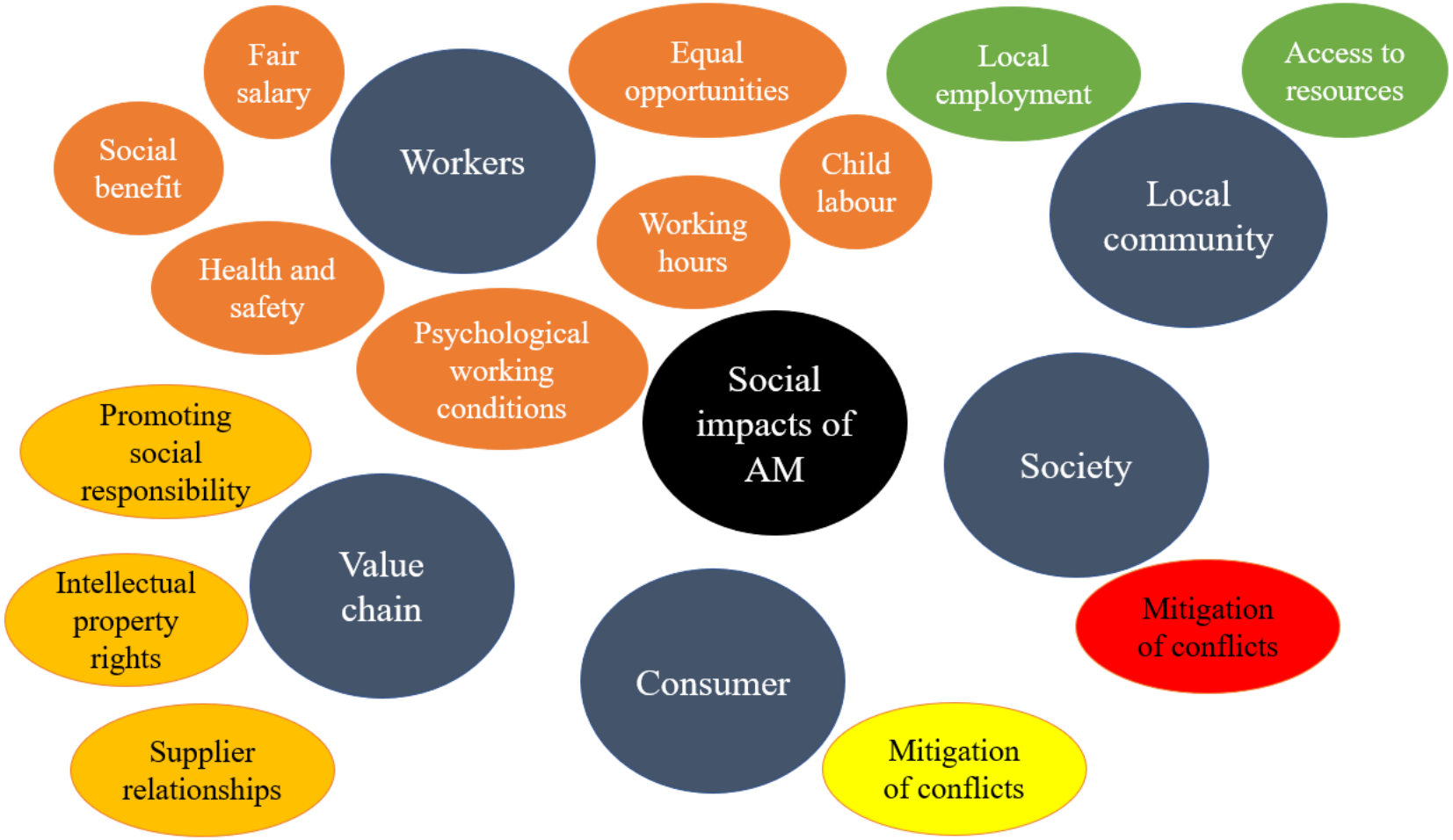


Fig. Social impacts of AM

Source: Naghshineh et al. 2021 [https://doi.org/10.1016/j.techfore.2020.120368]

Life cycle costing

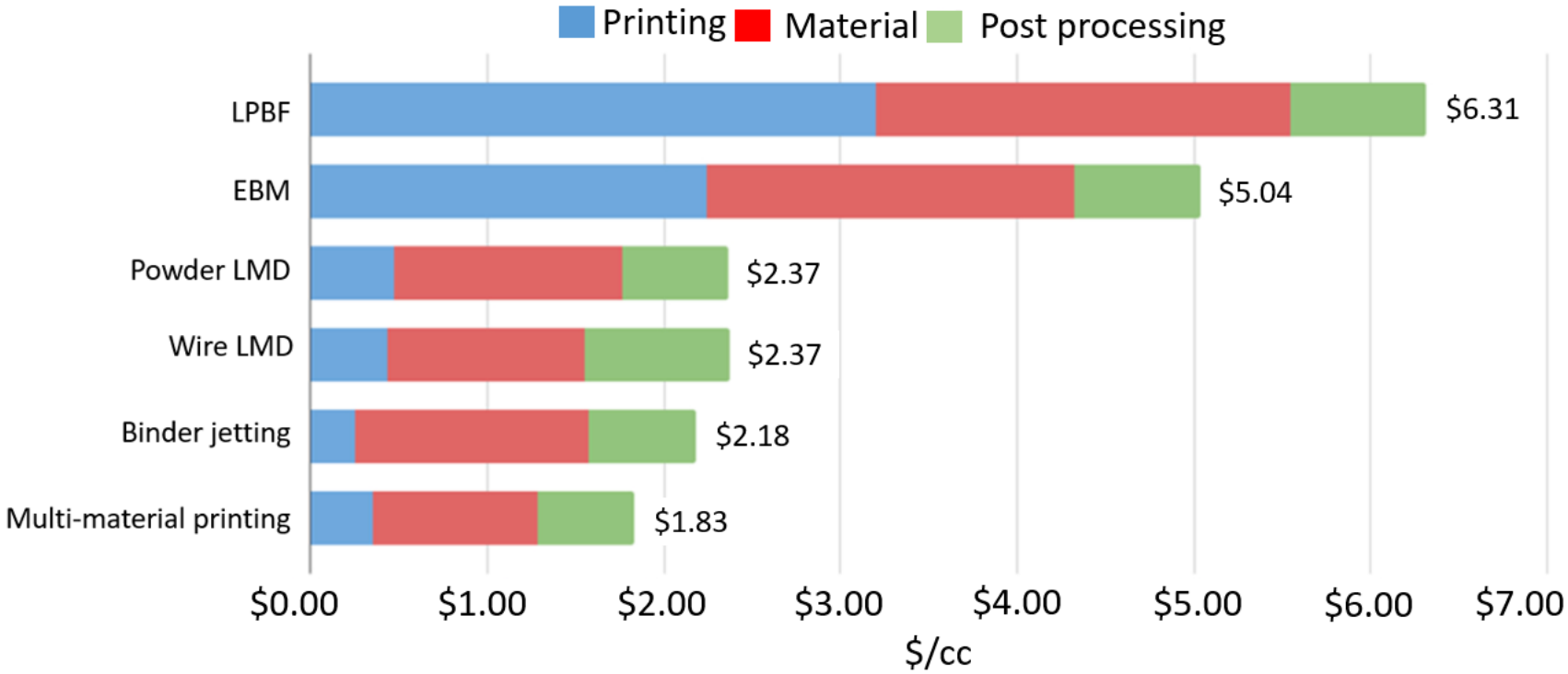
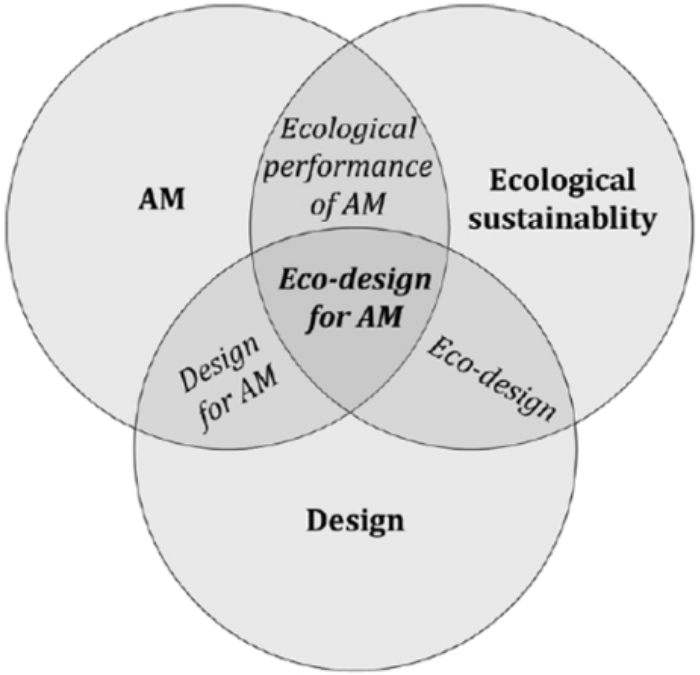


Fig. Cost of AM of a titanium component via various techniques

Source: Gao et al. 2021 [https://doi.org/10.1016/j.jmsy.2021.06.011]

Eco-design methodology



Three dimensions of eco-design for AM

$$\text{Eco-design for AM} \propto \frac{\text{Maximisation of design benefits with AM}}{\text{Minimisation of environmental impacts with AM}}$$

$\propto$:Indicates a propotional relationship

Aim of eco-design for AM

Fig. Three dimensions and objectives of eco-design for AM

Source: Gao et al. 2021 [https://doi.org/10.1016/j.jmsy.2021.06.011]

Sustainable materials science paradigm

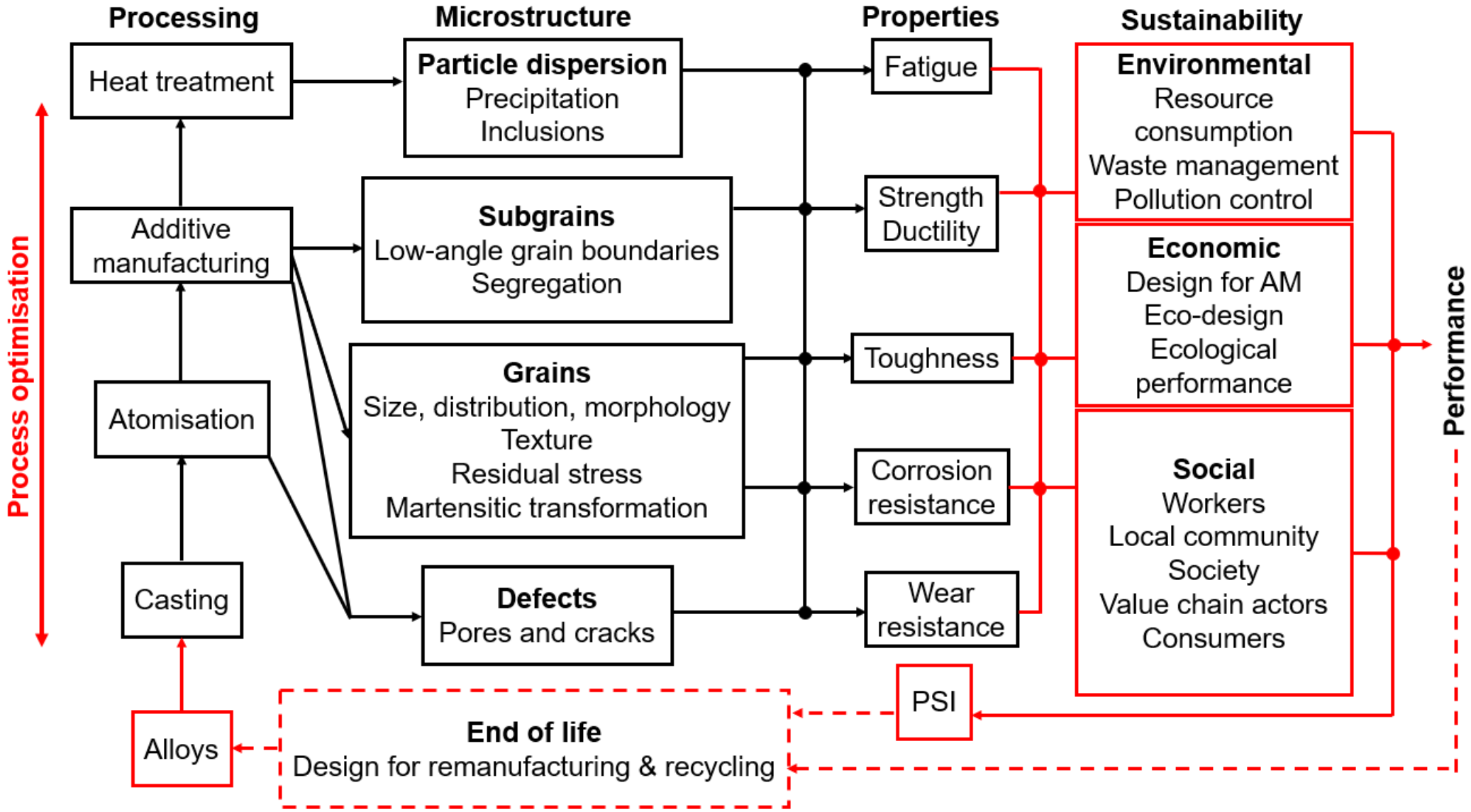


Fig. Processing-microstructure-properties-sustainability-performance analysis for AMed alloys (Red indicates activities related to sustainability)

Summary

- For AM, resource usage is the most crucial environmental factor

AM has the ability:

  - To minimise the amount of raw materials needed in the supply chain,
  - To eliminate the need for costly, energy-intensive, and environmentally damaging manufacturing methods,
  - To enable more effective and adaptable product design

- it is often impossible to gather complete data for LCA.
- There should be general models created for each type of AM technique

Four-step approach

1. increase material and process impact
2. create a suitable database for LCA
3. Predicting the environmental impact of an AM product before manufacturing
4. energy consumption of various AM methods