Digital Twins and Circular Economy challenges and an up-coming Project

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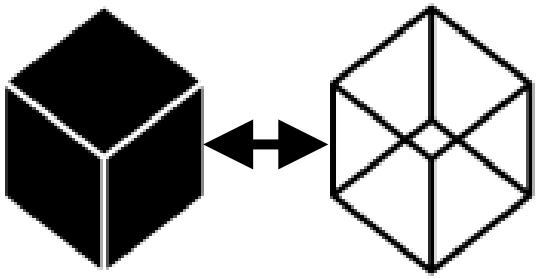
Framework

The transition towards a circular economy is estimated to represent a $4.5 trillion global growth opportunity by 2030 [Accenture Strategy, 2015, Waste to Wealth]

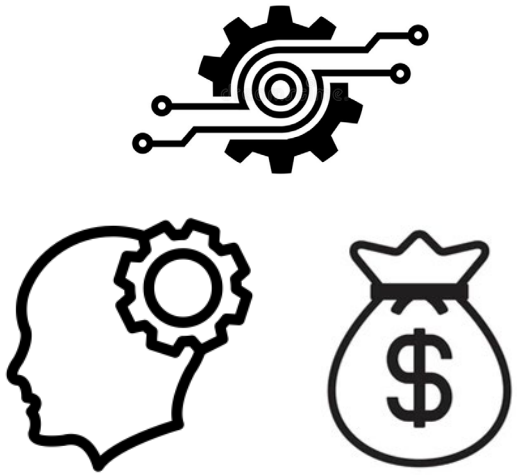


A fully-circular, value-chain-wide **digital twin** is largely recognized as an accelerator and an enabler of CE in business and in production [Lacy, 2015. Using digital tech to spin the circular economy. Accenture Outlook] [Antikainen et alt., 2018. Digitalisation as an Enabler of Circular Economy. Procedia CIRP, 73, 45-49.]

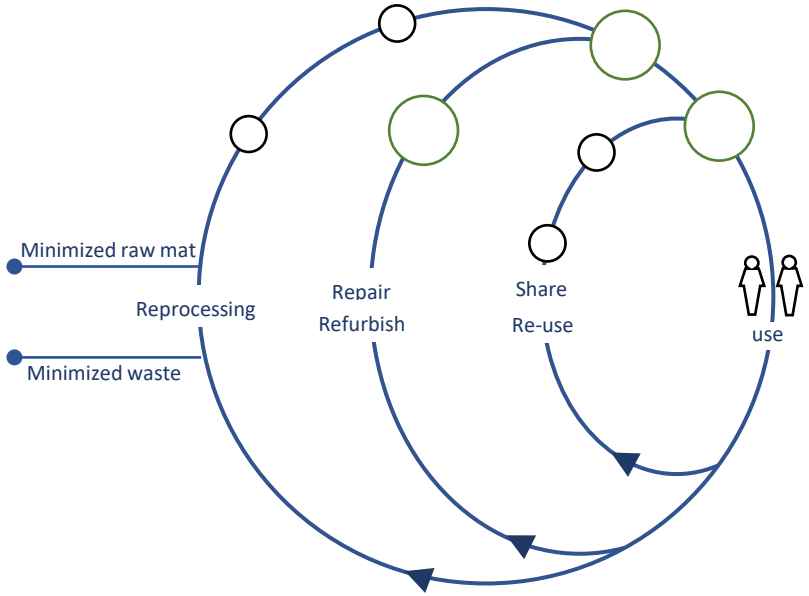
The digital twin market was valued at $3.8 billion in 2019, $7.5 billion in 20205, and is estimated to reach a value of $46.08 billion by 2026

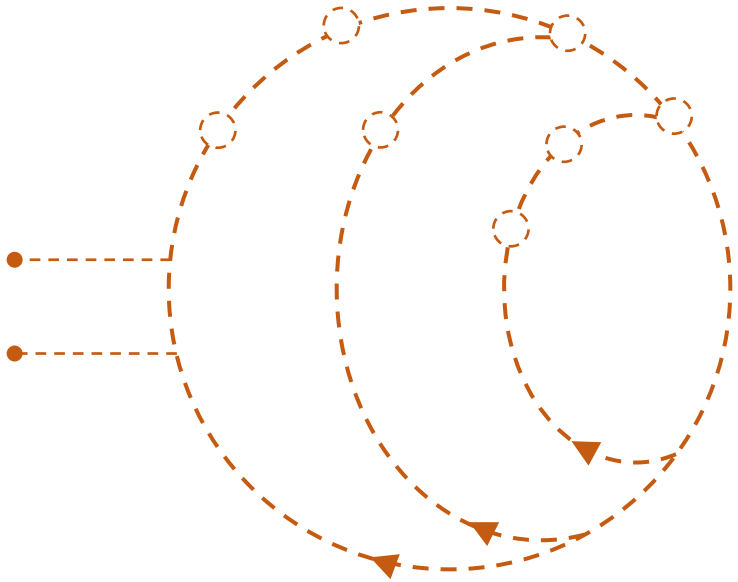
[Mordor Intelligence 2022, Digital Twin Market, Growth, Trends, and Forecasts]

Framework



The ***pivotal role of DT raises significant questions*** related to its development within the present ***technological framework***, ***needed skill sets***, and ***implementation costs***


Minimized raw mat
Reprocessing
Minimized waste
Repair
Refurbish
Share
Re-use
use



Challenge 1 - Creation and update of DT still requires high level of skills

Challenge 2 – The silo effect has not been actually relieved, and interfaces are only partially developed

Challenge 3 – Too many overlapping standards and vendor-specific platforms make interconnections laborious

Challenge 4 – Lack of secure exchange of data and clear data ownership

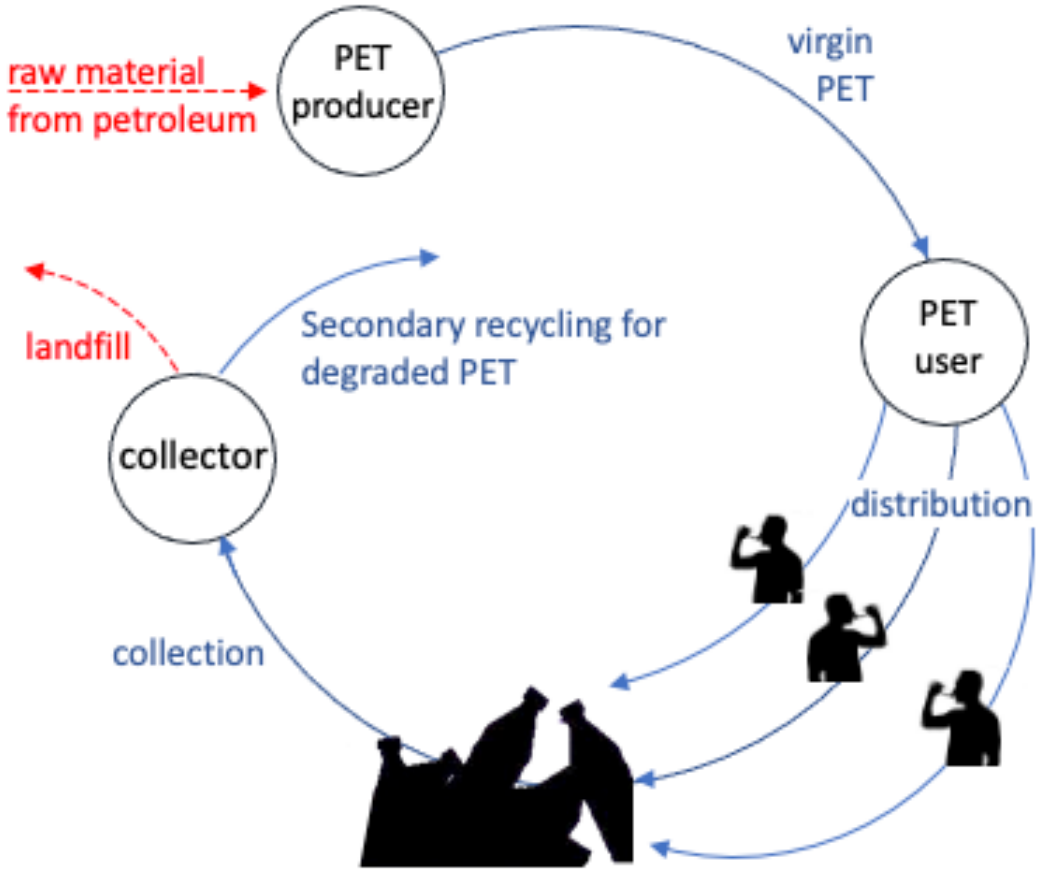
Challenge 5 - No effective and reliable LCA data sources

Challenge 6 - Poor use and exploitation of IoT-enabled data streams

Challenge 7 - implementation costs constitute a significant barrier

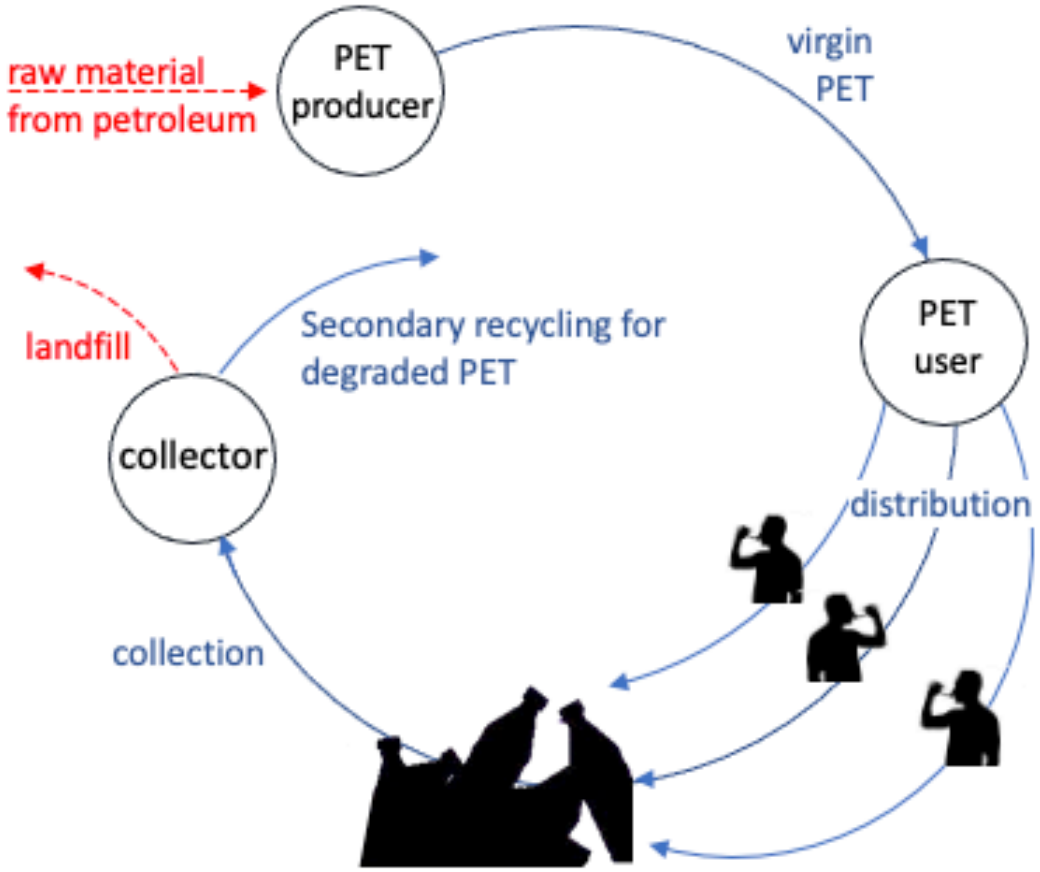
Challenges and Founding Pillars for a Manufacturing Platform to Support Value Networks Operating in a Circular Economy Framework
Pedrazzoli, Sorlini, Rovere, Lazaro, Malò, Fiorello, - Applied Sciences 2022

AS IS

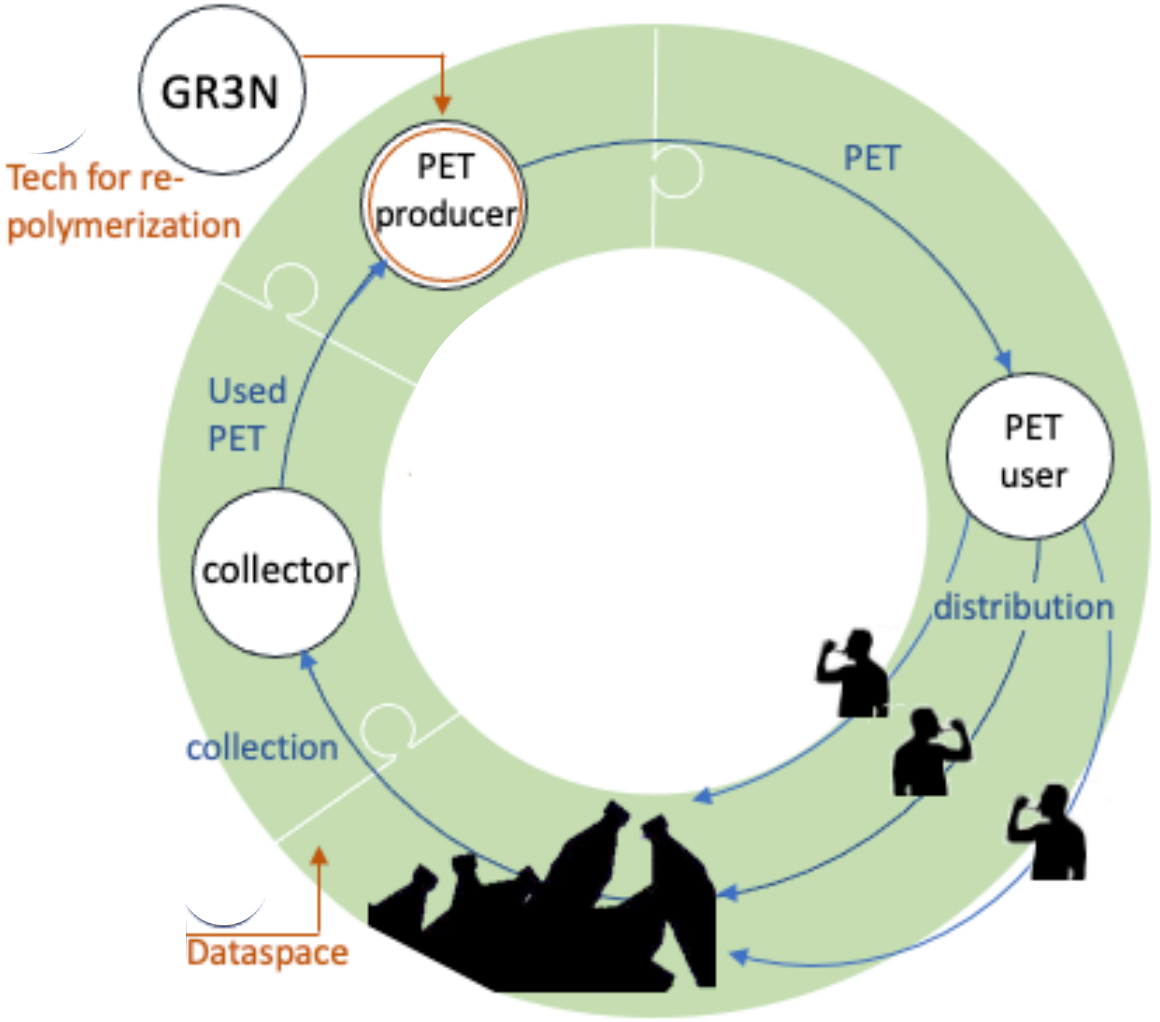


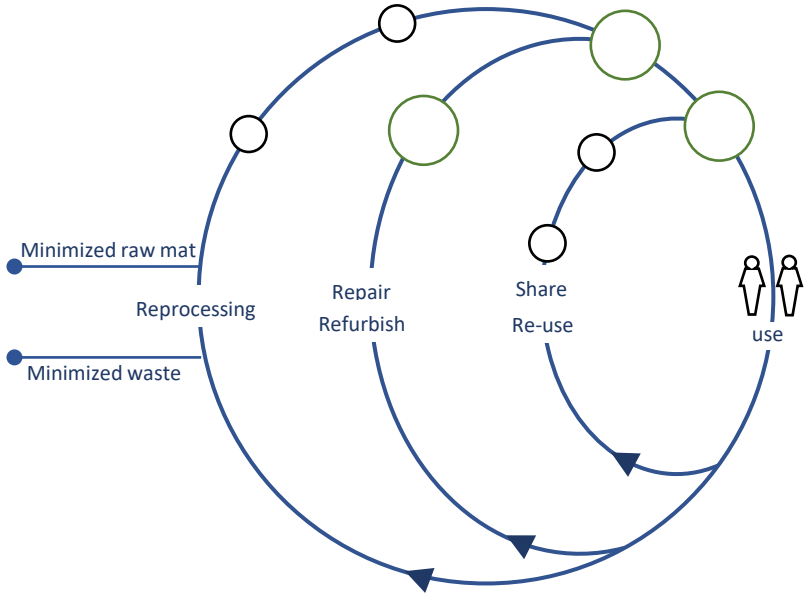
AN EXAMPLE!

AS IS

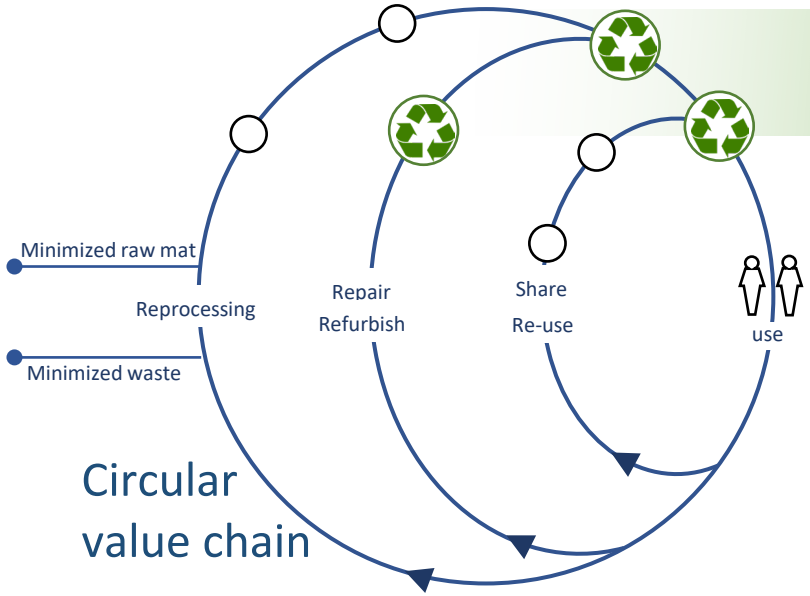

raw material
from petroleum
PET
producer
virgin
PET
PET
user
landfill
Secondary recycling for
degraded PET
collector
distribution
collection

TO BE


GR3N
Tech for re-
polymerization
PET
producer
PET
Used
PET
PET
user
collector
distribution
collection
Dataspace

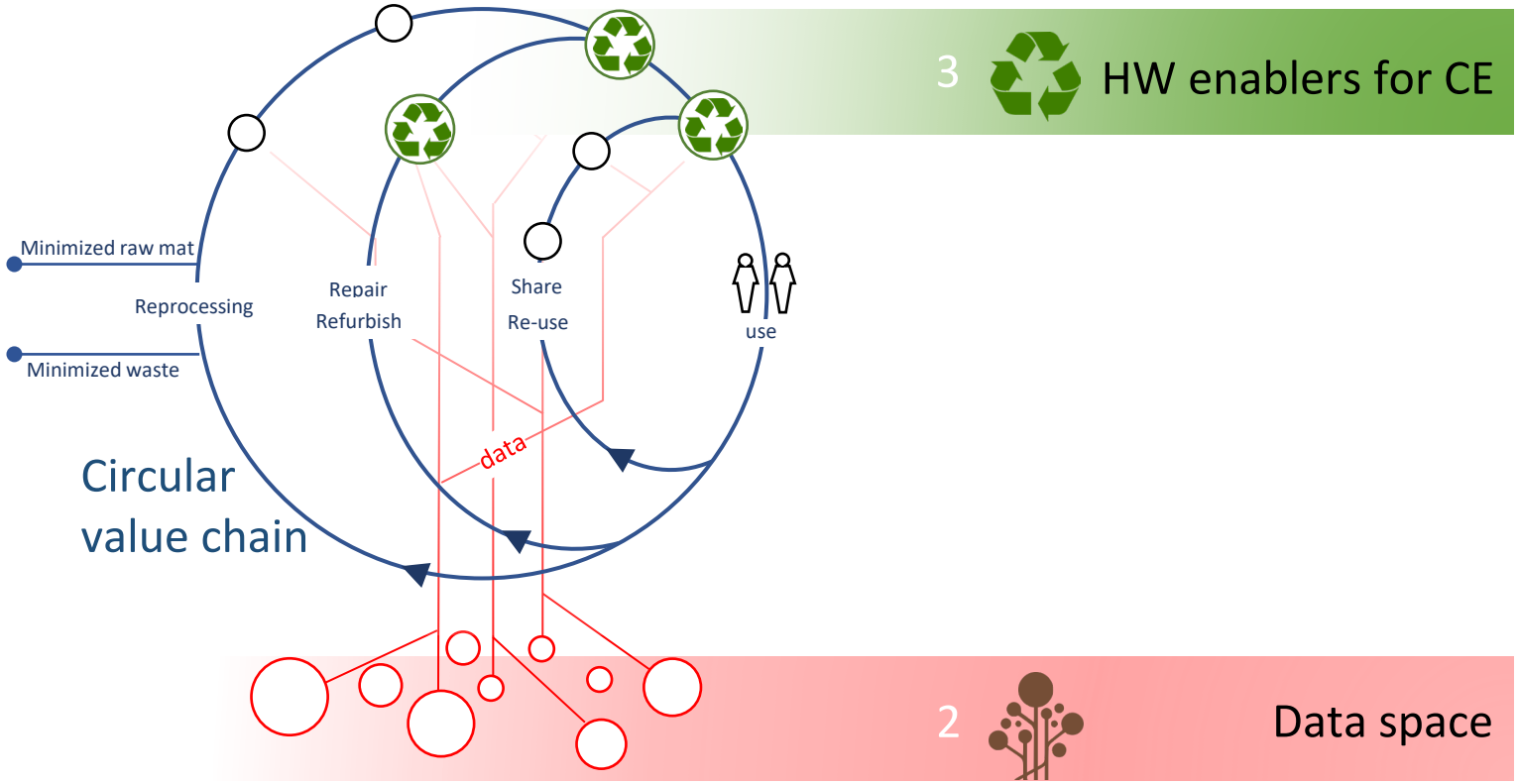

Minimized raw mat
Reprocessing
Minimized waste
Repair
Refurbish
Share
Re-use
use

3 HW enablers for CE



To integrate novel hardware technologies into the digital thread, to unleash their full potential for actual Circular Economy and reduced dependency from raw materials.

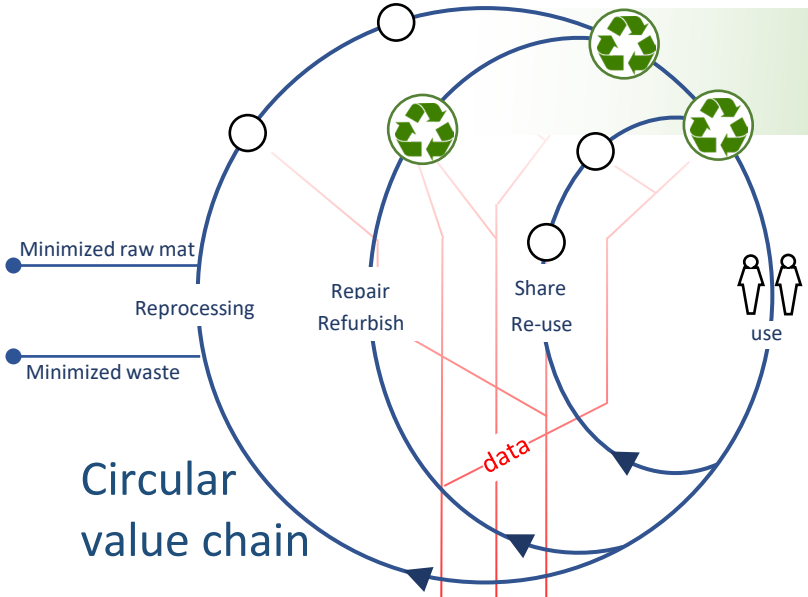
To set up an adequate sensors layer, where data, collected on the shop floor along the supply chain, are gathered and managed. The need of a common data space arises, to promote and facilitate the secure and seamless exchange of manufacturing / product / business data within value-networks in a circular-economy ecosystem



3 HW enablers for CE

2 Data space

The data across the value network needs to be exploited by data-driven methods for the generation and adaptation of multi-fidelity digital twins



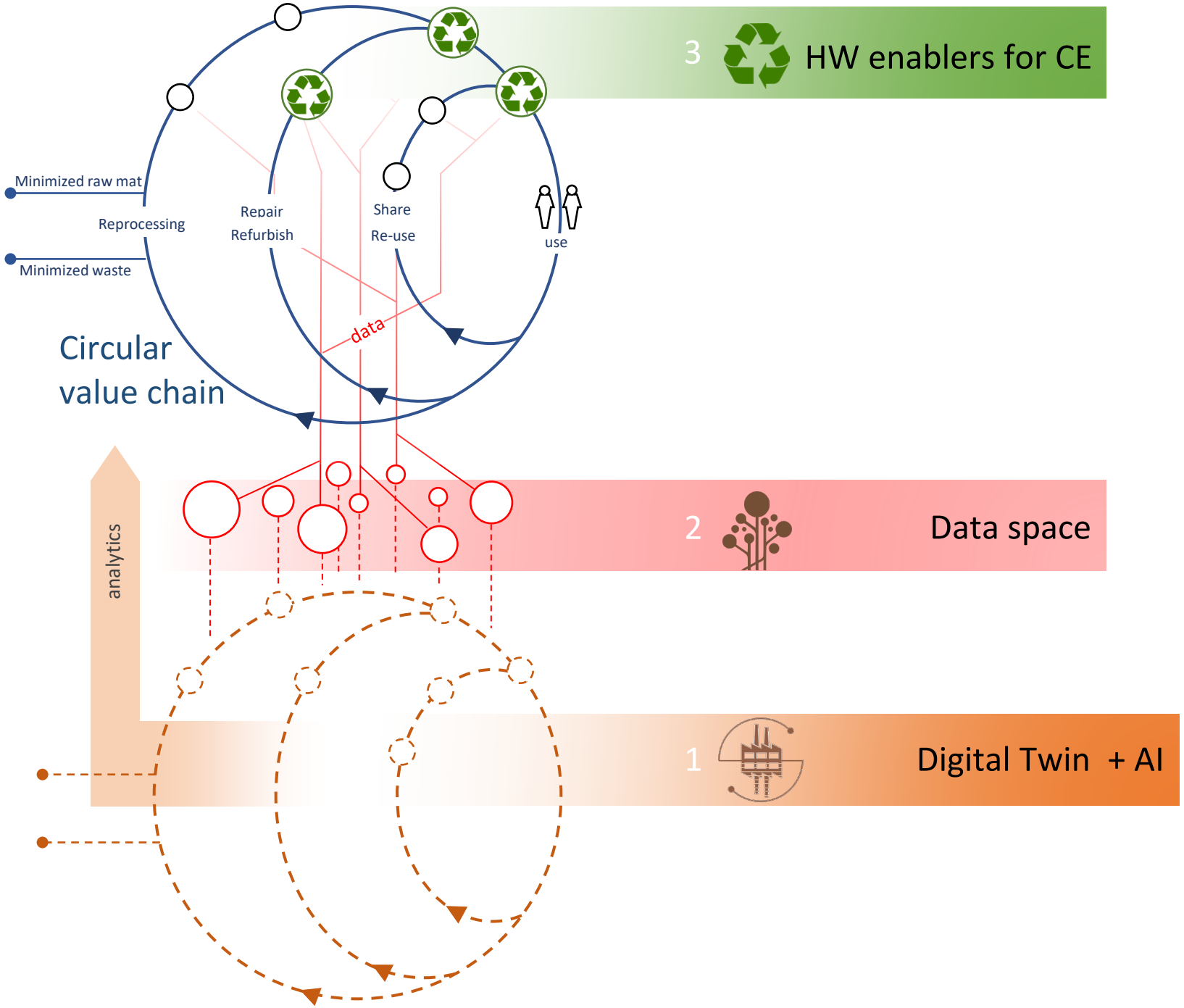
Circular value chain

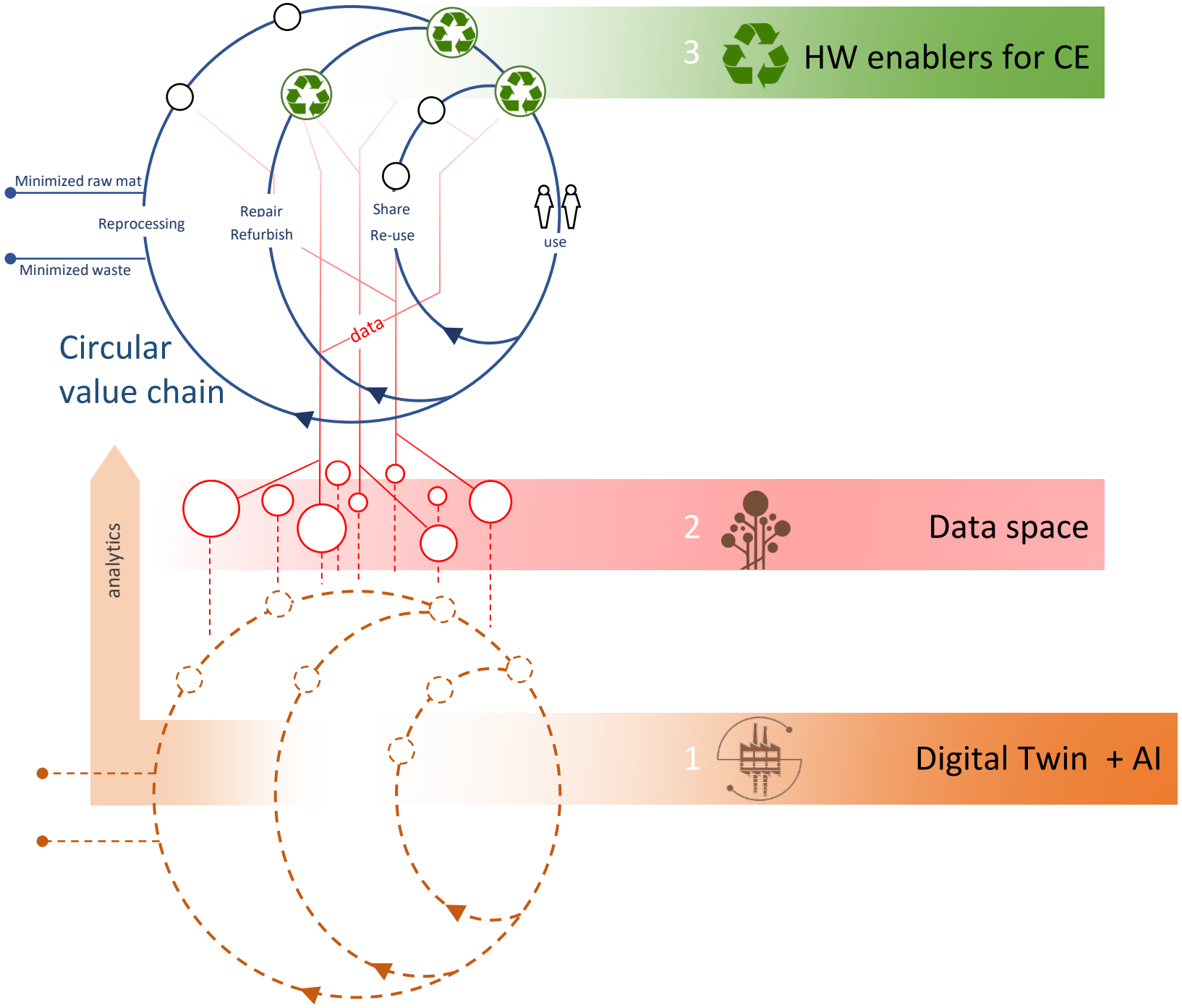
3 HW enablers for CE

2 Data space

1 Digital Twin

The digital twin emerges from the data collected


3
HW enablers for CE
Minimized raw mat
Reprocessing
Minimized waste
Repair
Refurbish
Share
Re-use
use
data
Circular
value chain
analytics
2
Data space
1
Digital Twin + AI



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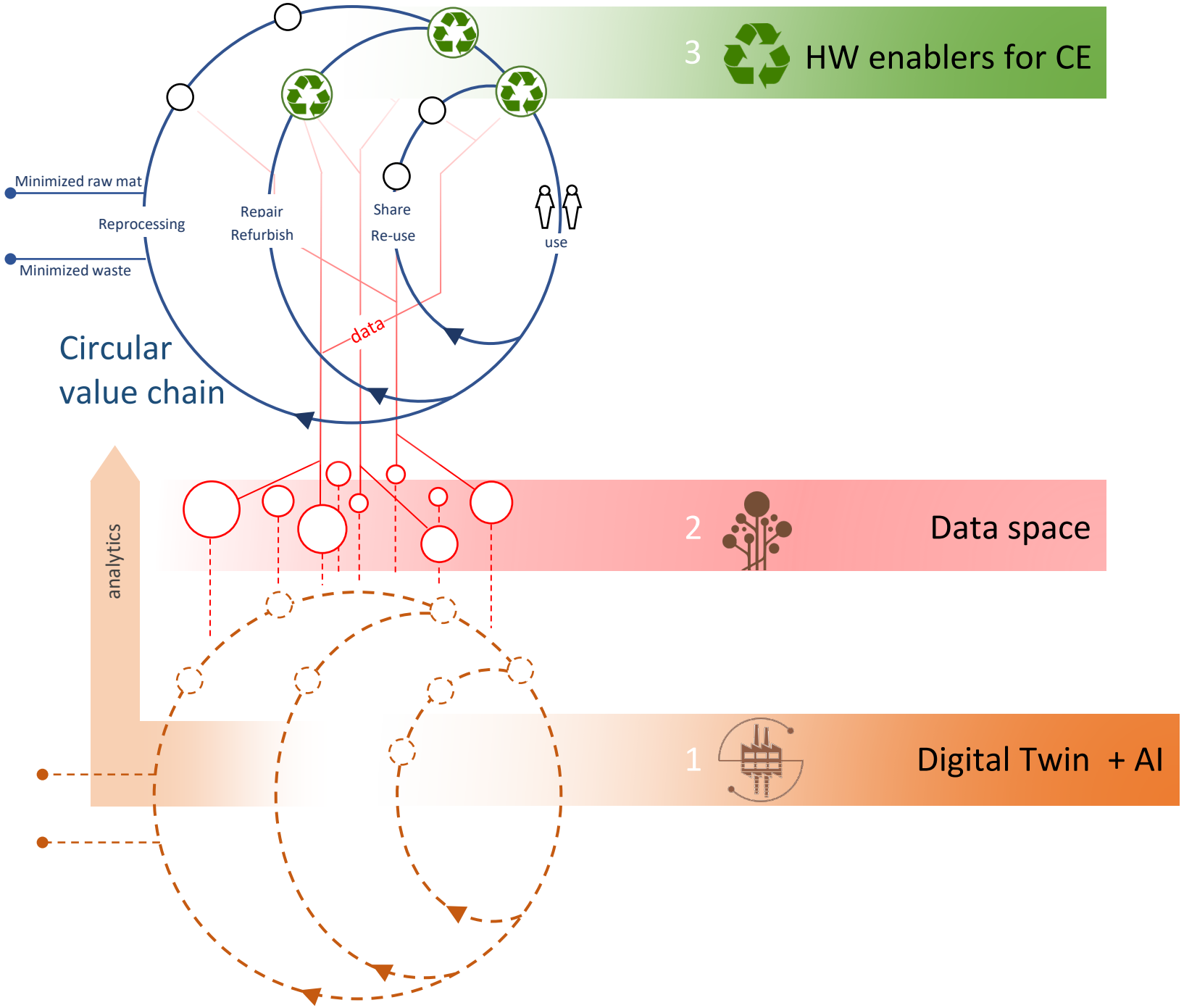


Do we really need the AI?

AN EXAMPLE!

GWP [kg eq. CO_2/kg]

$GWP_{Ext} + GWP_{M.P.} + GWP_{Manuf.} + GWP_{Ass.} + GWP_{Use} + GWP_{Repair} + GWP_{EoL} + GWP_{T}$

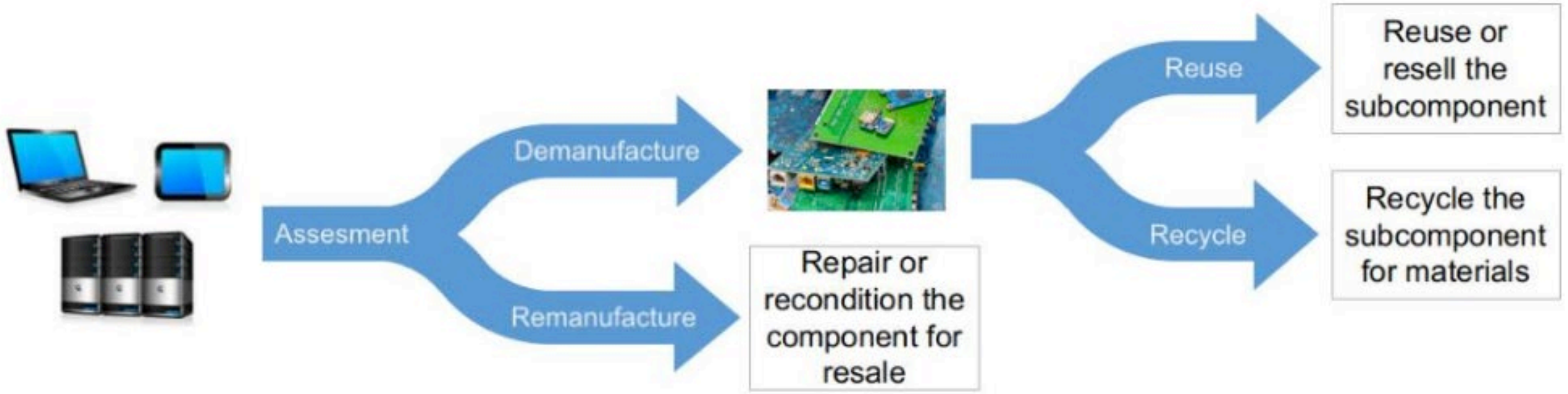
GWP [kg eq. CO_2/kg]

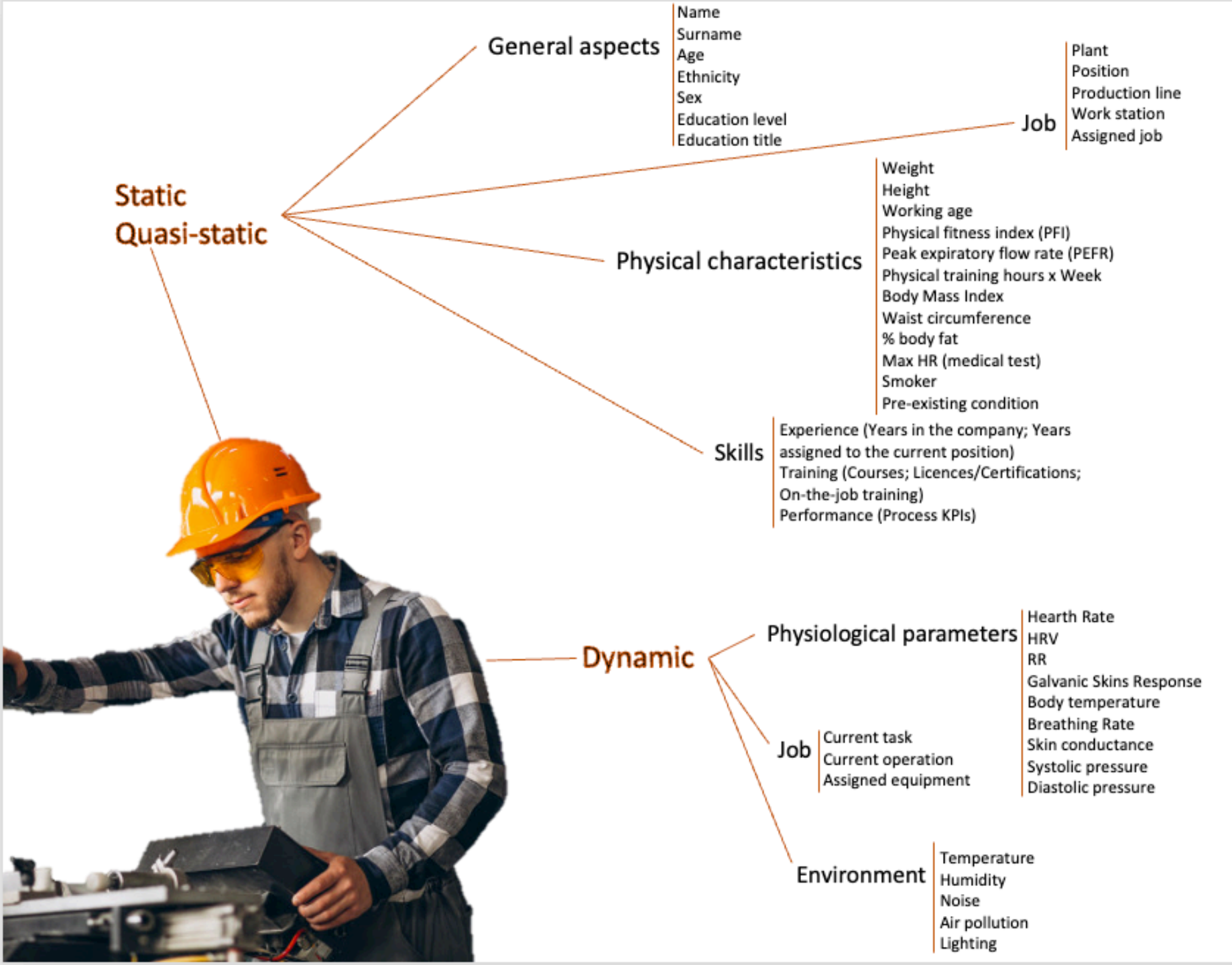
$$GWP_{Ext} + GWP_{M.P.} + GWP_{Manuf.} + GWP_{Ass.} + GWP_{Use} + GWP_{Repair} + GWP_{EoL} + GWP_{T}$$

$$
\begin{aligned}
&(1+SRC) * (\textstyle\sum_m f_m * CS_m * GWP_{man\ m}) + \\
&+ SRC * (\textstyle\sum_i \sum_j f_i * V_{i,j} * \rho_j * GWP_{ext\ j} + \\
&+ \textstyle\sum_i \sum_j \sum_p f_i * \chi_{p,i,j} * V_{i,j} * \rho_j * GWP_{mp\ p,j} + \\
&+ \textstyle\sum_i \sum_j \sum_l f_i * f_{SRC\ i,j,l} * V_{i,j} * \rho_j * GWP_{EOL\ j,l} + \\
&+ \textstyle\sum_i \sum_j \sum_q \sum_z f_i * V_{i,j} * \rho_j * f_{i,j,q} * d_{i,j,q,z} * GWP_{tra\ z} + \\
&+ \textstyle\sum_i \sum_j \sum_r \sum_z f_i * V_{i,j} * \rho_j * f_{SRC\ i,j,r} * d_{EOL\ r,z} * GWP_{tra\ z}) + \\
&+ (1+SRC) * (\textstyle\sum_m \sum_w f_m * Q_{aux\ w,m} * GWP_{ext\ w} + \\
&+ \textstyle\sum_m \sum_w \sum_p f_m * \chi_{p,w} * Q_{aux\ w,m} * GWP_{mp\ p,w} + \\
&+ \textstyle\sum_m \sum_w \sum_l f_m * f_{w,l} * Q_{aux\ w,m} * GWP_{EOL\ w,l} + \\
&+ \textstyle\sum_m \sum_w \sum_q \sum_z f_m * f_{w,q} * Q_{aux\ w,m} * d_{w,q,z} * GWP_{tra\ z} + \\
&+ \textstyle\sum_m \sum_w \sum_r \sum_z f_m * f_{w,r} * Q_{aux\ w,m} * d_{EOL\ r,z} * GWP_{tra\ z}) + \\
&+ (1+SRC) * (\textstyle\sum_m \sum_j f_m * Q_{wm\ j,m} * GWP_{ext\ j} + \\
&+ \textstyle\sum_m \sum_j \sum_p f_m * \chi_{p,j} * Q_{wm\ j,m} * GWP_{mp\ p,j} + \\
&+ \textstyle\sum_m \sum_j \sum_l f_m * f_{j,l} * Q_{wm\ j,m} * GWP_{EOL\ j,l} + \\
&+ \textstyle\sum_m \sum_j \sum_q \sum_z f_{m\ *} f_{j,q} * Q_{wm\ j,m} * d_{j,q,z} * GWP_{tra\ z} + \\
&+ \textstyle\sum_m \sum_j \sum_r \sum_z f_m * f_{j,r} * Q_{wm\ j,m} * d_{EOL\ r,z} * GWP_{tra\ z})
\end{aligned}
$$

WEEE

AN EXAMPLE!



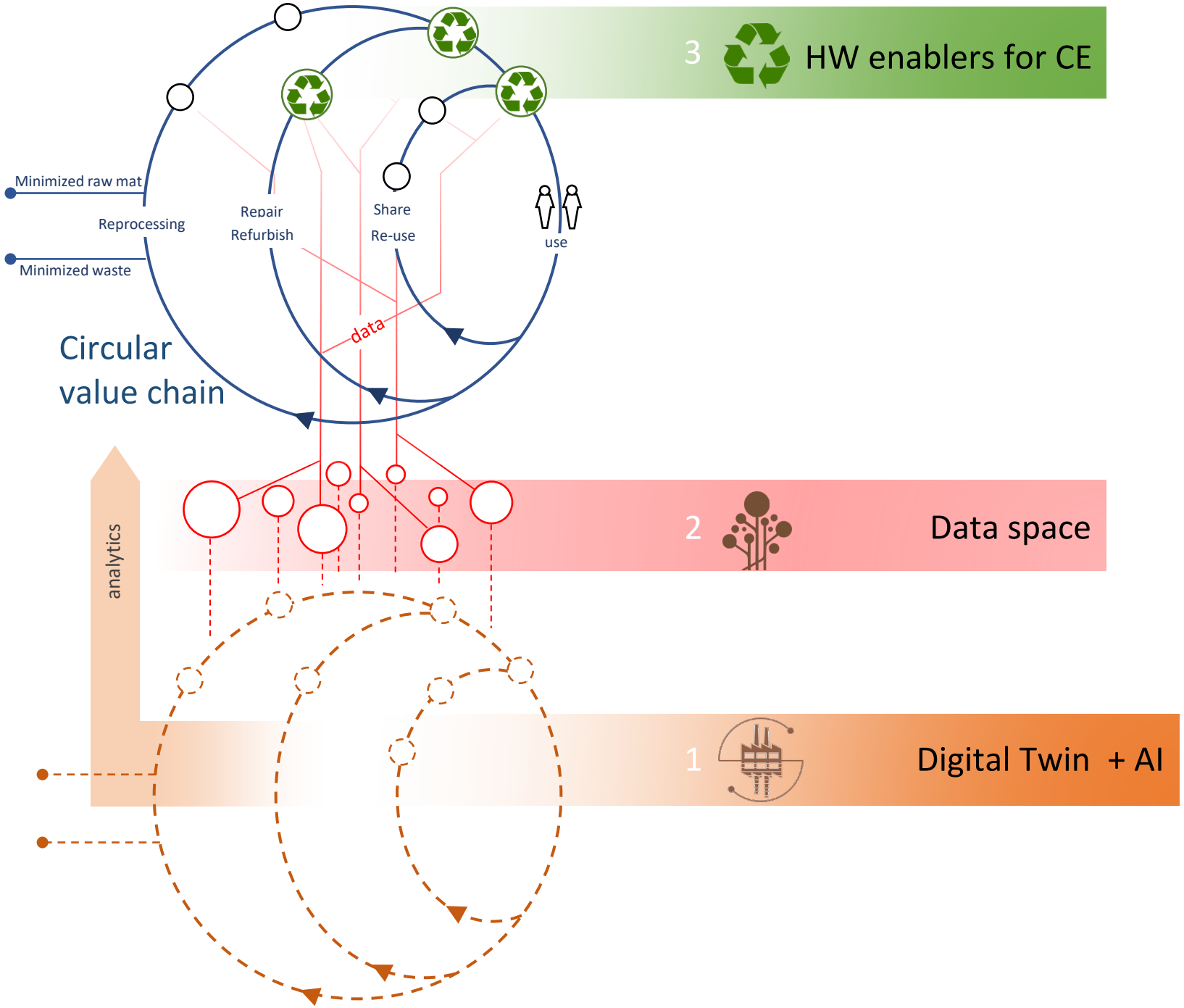


Static
Quasi-static

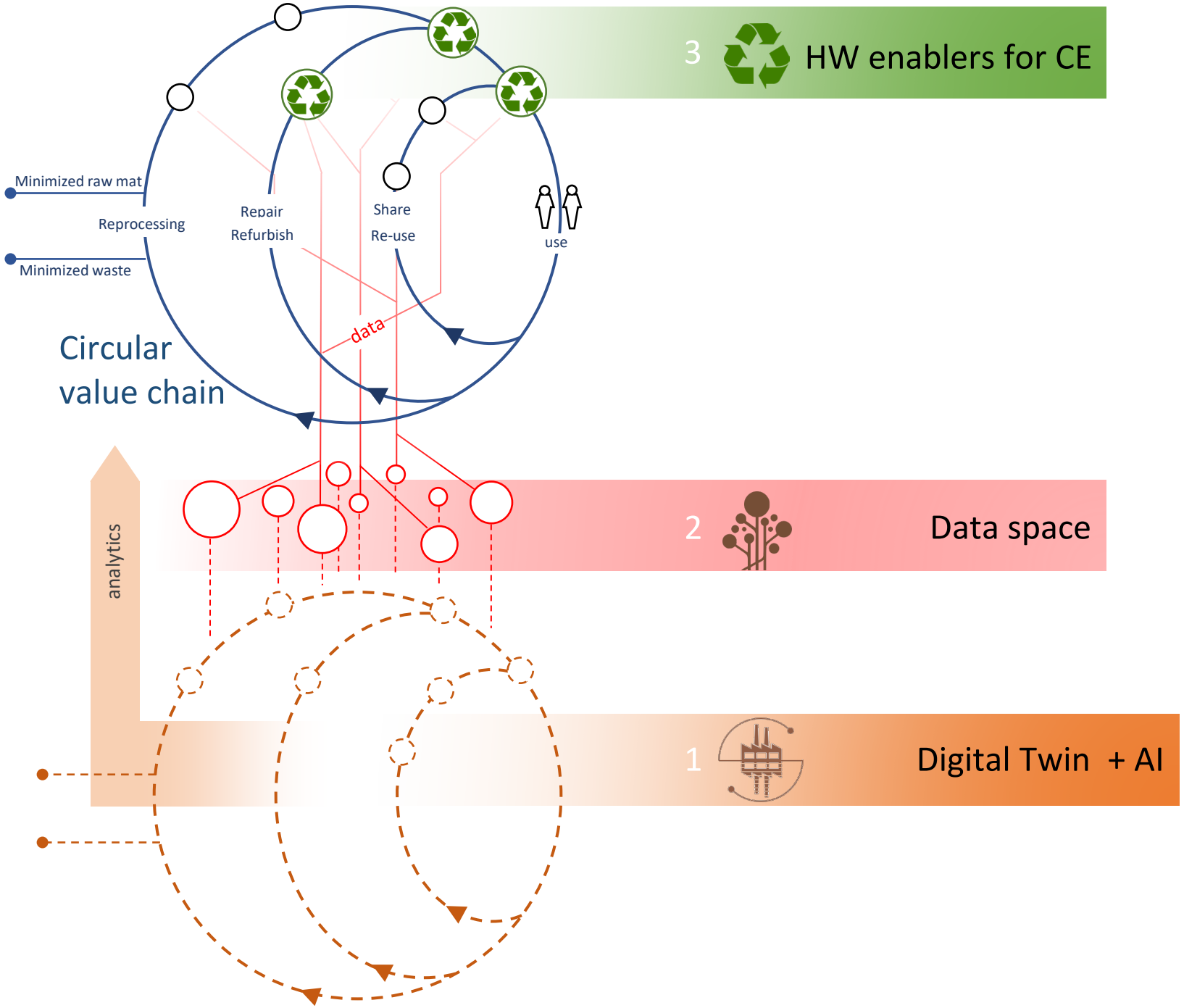
- **General aspects**
  - Name
  - Surname
  - Age
  - Ethnicity
  - Sex
  - Education level
  - Education title
- **Job**
  - Plant
  - Position
  - Production line
  - Work station
  - Assigned job
- **Physical characteristics**
  - Weight
  - Height
  - Working age
  - Physical fitness index (PFI)
  - Peak expiratory flow rate (PEFR)
  - Physical training hours x Week
  - Body Mass Index
  - Waist circumference
  - % body fat
  - Max HR (medical test)
  - Smoker
  - Pre-existing condition
- **Skills**
  - Experience (Years in the company; Years assigned to the current position)
  - Training (Courses; Licences/Certifications; On-the-job training)
  - Performance (Process KPIs)

Dynamic

- **Physiological parameters**
  - Hearth Rate
  - HRV
  - RR
  - Galvanic Skins Response
  - Body temperature
  - Breathing Rate
  - Skin conductance
  - Systolic pressure
  - Diastolic pressure
- **Job**
  - Current task
  - Current operation
  - Assigned equipment
- **Environment**
  - Temperature
  - Humidity
  - Noise
  - Air pollution
  - Lighting



Circular
TwAIn



Circular TwAIn

Circular TwAIn

CIRCVLAR TWAIN

Circular

Digital
Twin

Data
Spaces
Enabling the
whole endeavour

Circular
TwAIn