Enabling Circular Value Chains via Production Digitization and Human Empowerment

ENCIRCLE: Empowering the Circular Shift via Digital Twins and AI

Presenter

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Presentation Outline

- ❑Overview
- ❑ENCIRCLE’s Vision
- ❑Use Cases
- ❑Conclusions

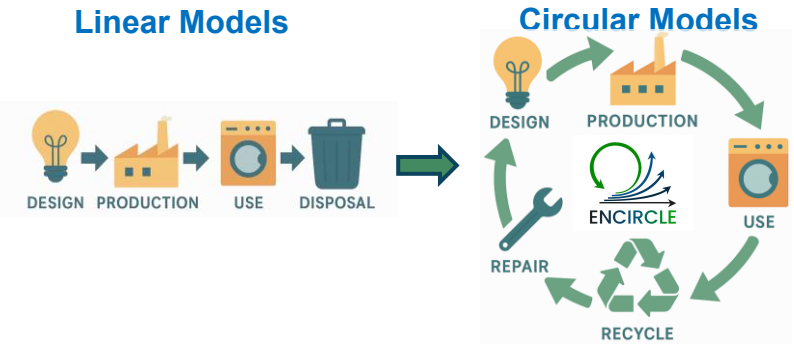
ENCIRCLE: A quick glance

- **15 partners** from **7 EC** member states and **4 international** partners
- **36 months (2024-2027) Research Innovation Action**
- HORIZON-CL4-2024-TWIN-TRANSITION-01
- GA: 101178230

ENCIRCLE: Transition to Circular Business Models

Aluminum Recycling (Alumil):

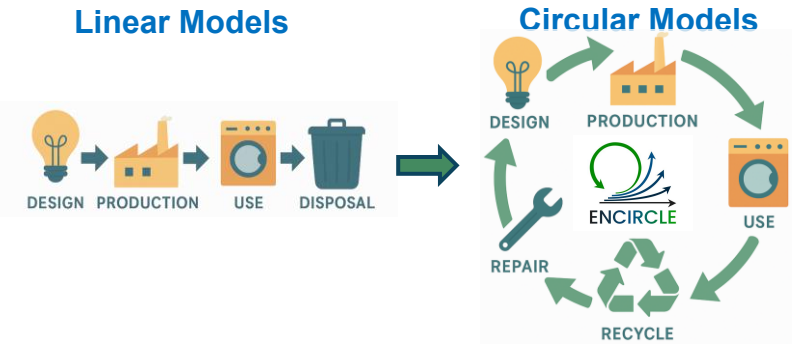
- **Closed-loop aluminum recycling** via Virtual Production Line.
- **DTs and Soft Sensors** for monitoring and dross reduction.
- **Simulation-driven optimization** to reduce energy use and emissions.
- Reduction in **emissions, energy, dross** and **raw material** waste.



ENCIRCLE: Transition to Circular Business Models

Galvanization Industry (ZINQ):

- **HDG[1] steel traceability** through the **DCPP[2]** enriched with **Soft Sensors** and **IIoT**.
- **AI inspection** and **RL production optimization**
- **DPP wallet** for end-to-end **traceability** and customer confidence.
- **Marketplace** for consumer registration and engagement in circular actions.

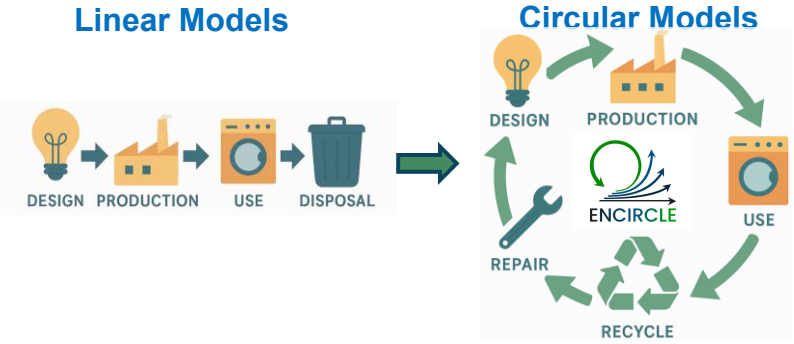


[1]HDG: Hot-Dip Galvanizing
[2]DCPP: ZINQ's Digital Circular Product Passport

ENCIRCLE: Transition to Circular Business Models

Home Appliances (Arcelik):

- **Circular use** and **reintegration** of end-of-life home appliances.
- **Audio-Visual DT** for **fault diagnosis** and **self-repair** guidance.
- **DPP wallet** and **marketplace** for maintenance, refurbishment, and recycling.
- **Recommender** and **DSS** modules deliver targeted **offers** and **reward sustainable behavior**.

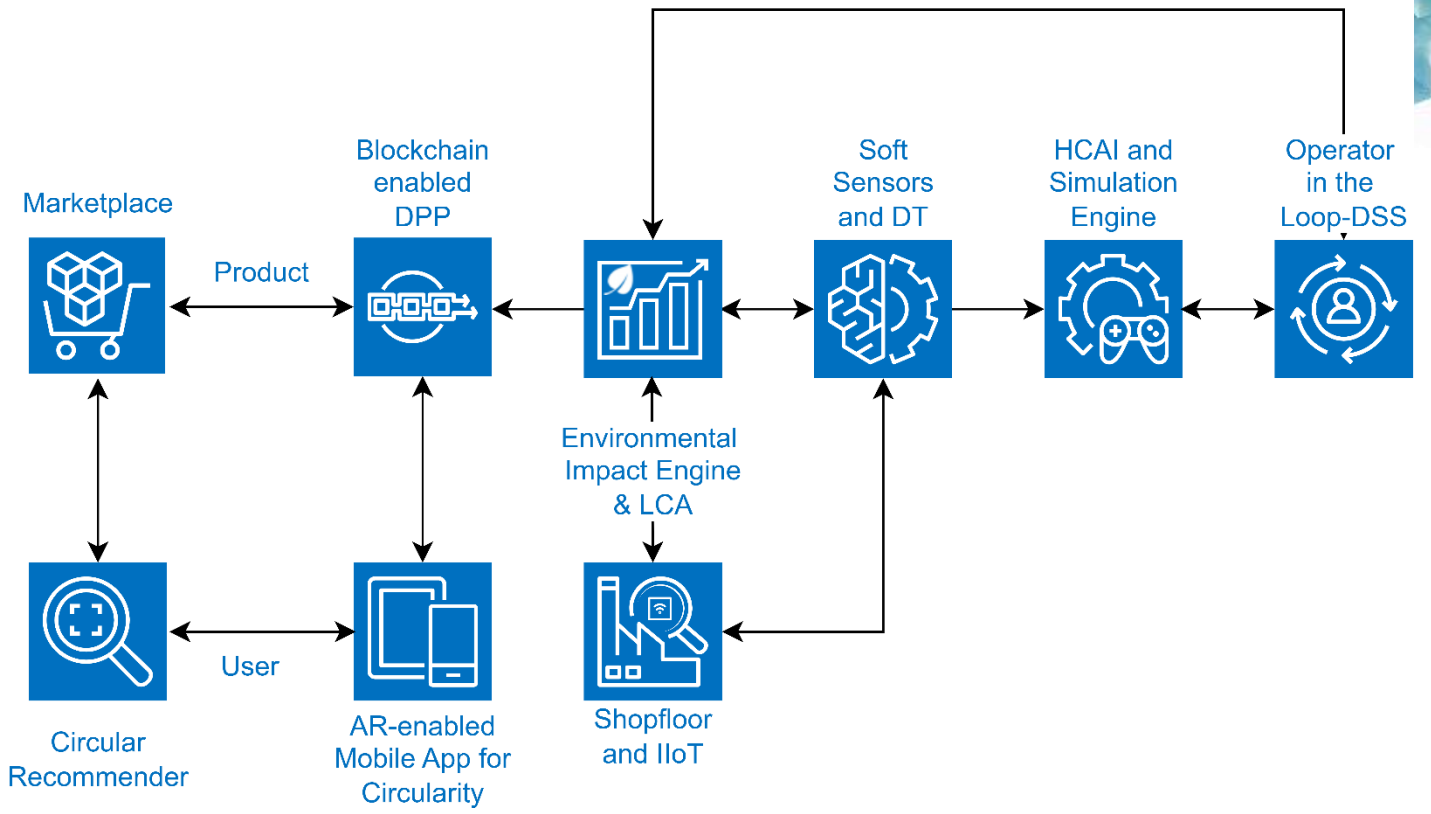


ENCIRCLE: Transition to Circular Business Models

- Make **circular business models** viable and data-driven.
- **DPP** and **Blockchain** enable traceable, **trusted circular trade**.
- **DTs and simulations** optimize production**.**
- **Circular incentives** drive repair, upgrade, and responsible return.
- New revenue from **longer lifecycles** and **green promotions**.

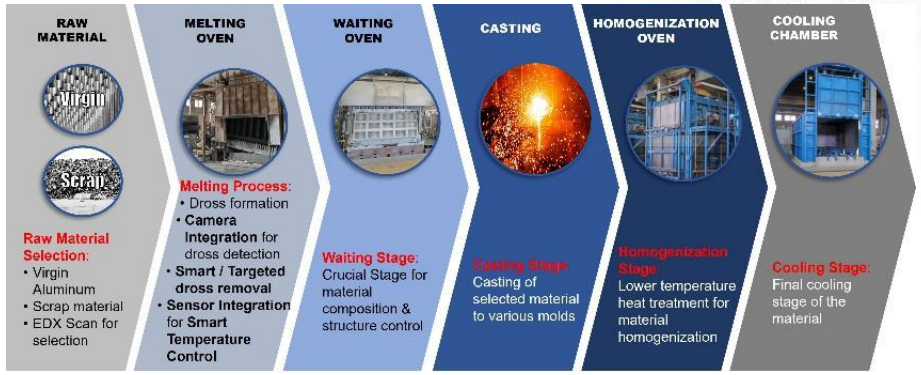
ENCIRCLE: Main Objectives

- **IIoT ecosystem for circular manufacturing**.
- **Digital Twin framework** for simulation.
- **AI and human feedback in simulation environments** to optimize production.
- **Blockchain-based DPP wallet** for circularity.
- **Train the workforce with AR** for circular manufacturing.
- **Digital marketplace** for circular business models.

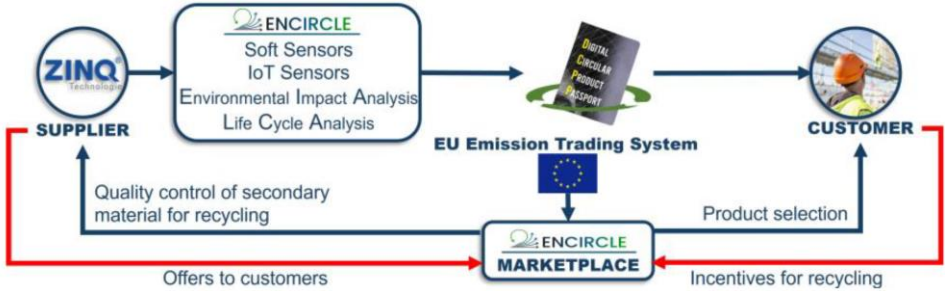


ENCIRCLE: Use Cases

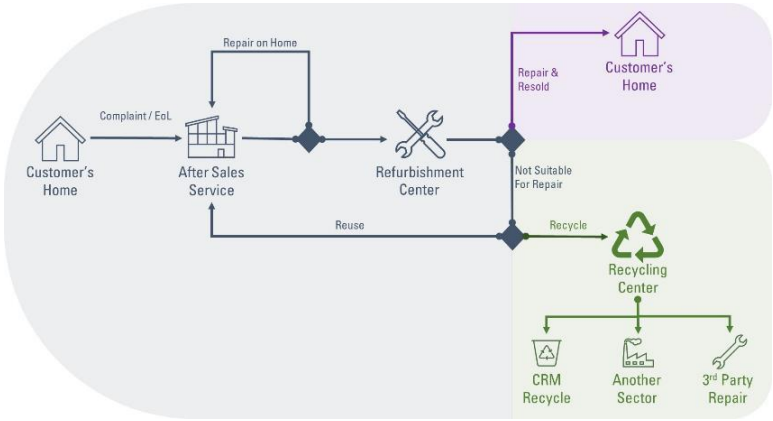
- **ENCIRCLE for a Green and Virtual Production Line:**
  - *ALUM use case* applies IIoT, Digital Twins, and XAI to optimize production and energy efficiency, decrease emissions and reduce waste.



- **Enabling the DPP for the Circular Transition of Surface Technology:**
  - *ZINQ use case* integrates real-time data and Digital Product Passports to enhance traceability, and circularity in galvanized steel industry.



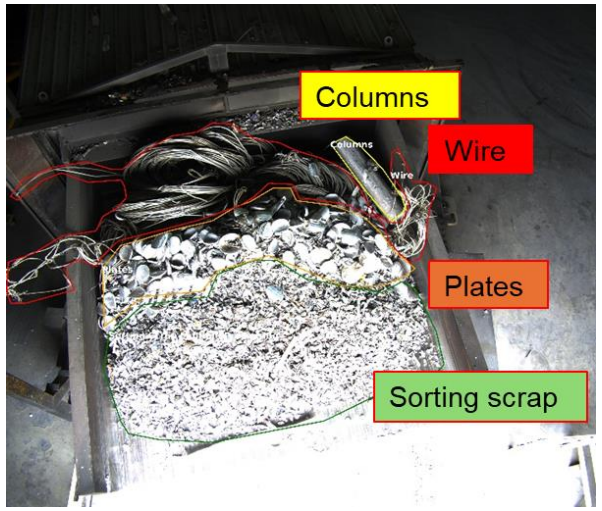
- **ENCIRCLE for Recycling, Refurbishing and Repairing Household Appliances:**
  - *ARCEL use case* leverages ENCIRCLE's Digital Marketplace, DPP Wallet, and C2RM (Circular Customer Relationship Management) tools to turn end-of-life appliances into refurbished and reusable products.



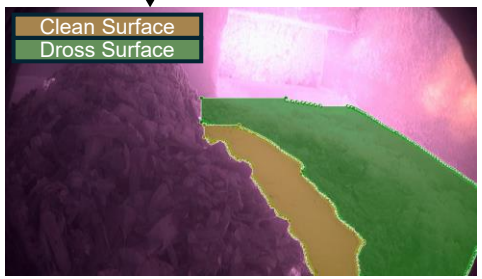
Soft Sensors and DTs - Alumil UC

- **Data registration** and **monitoring** via **Cameras and sensors**.
- **Soft Sensors** to predict **production parameters.**
- **Digital Twin** to simulate production (load plans, furnace states).
- **Operator-in-the-Loop** receives DSS recommendations on scrap mix.
- **<u>Goal:</u>** Run simulation scenarios based on DT predictions.

Scrap Category Detection



*YOLO v11**



Dross surface estimation

*Shen, P., Mei, K., Cao, H., Zhao, Y., & Zhang, G. (2025). LDDFSF-YOLO11: A Lightweight Insulator Defect Detection Method Focusing on Small-Sized Features. IEEE Access, 13, 90273–90292

NeRF Digitization- Alumil UC

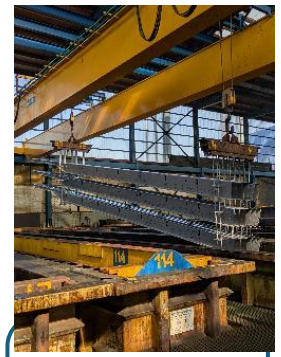
- **4D reconstruction of** furnace's geometry and dynamics from mobile video.
- Interactive DT driven by **Soft Sensor** predictions.
- Accurate furnace's **state estimation** and **predictive simulations**.
- **"What-if" scenario** analysis for process optimization.

Video of furnace (left) and 4D reconstruction snapshots (right)

*Wu, Guanjun, et al., Wang. "4D Gaussian Splatting for Real-Time Dynamic Scene Rendering." . In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR) 2024.

Soft Sensors and AI Predictions- ZINQ UC

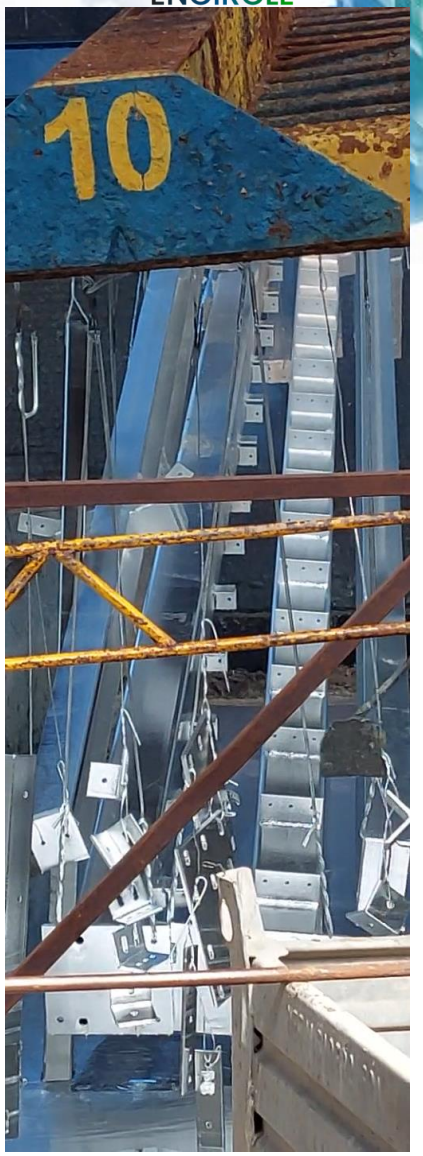
- **Machine Vision and Soft Sensors** monitor production.
- **Reinforcement Learning** optimizes bath sequences and energy consumption.
- **Human-in-the-Loop DSS** provides recommendations to operators.
- **DPP Integrates** IIoT and AI production results.
- **<u>Goal:</u>** To optimize production, improve product's quality and encourage circular incentives.



Pre-Treatment

Hot-Dip Galvanizing

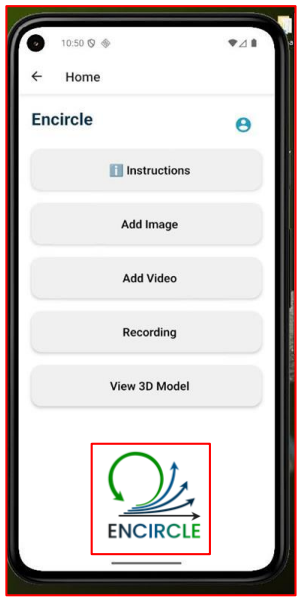
Post-Treatment

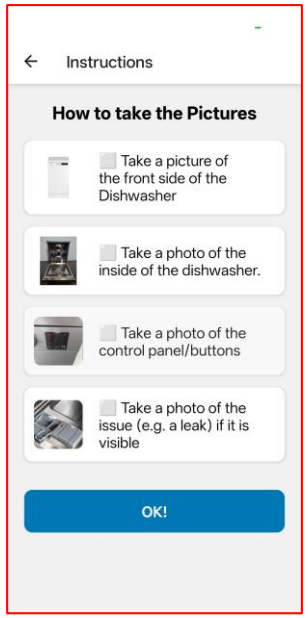


Mobile app for Circularity - Arcelik UC

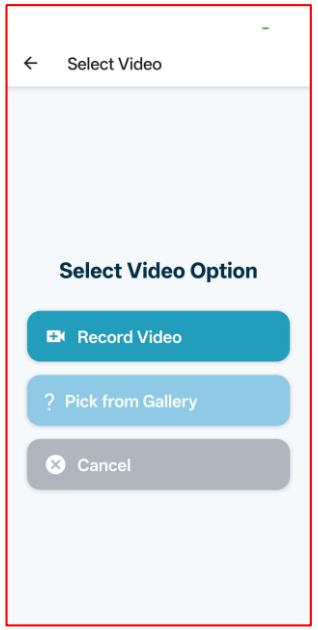
⇒Circular recycling of appliances via **Digital Marketplace** offers (repair, refurbish, recycle).

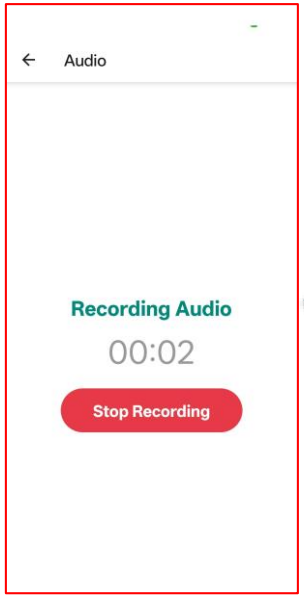
- **Consumer DPP Wallet App** for registration & retrieval of DPPs.
- User uploads videos and audio for **DT creation**.
- The **Mobile app** guides user for self-diagnostics
- **<u>Goal:</u>** Empower users **for service requests, discounts or extended warranties.**





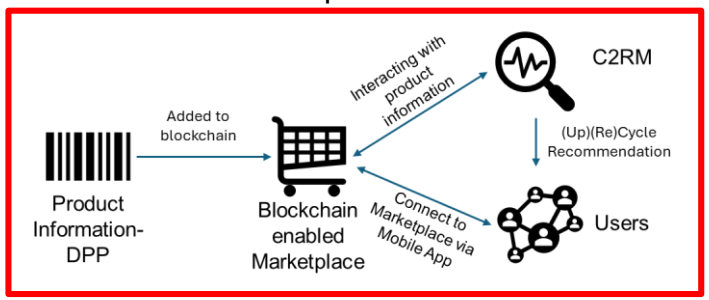
User receives self-diagnostics instructions





Audio/Visual Uploading for Fault Diagnosis

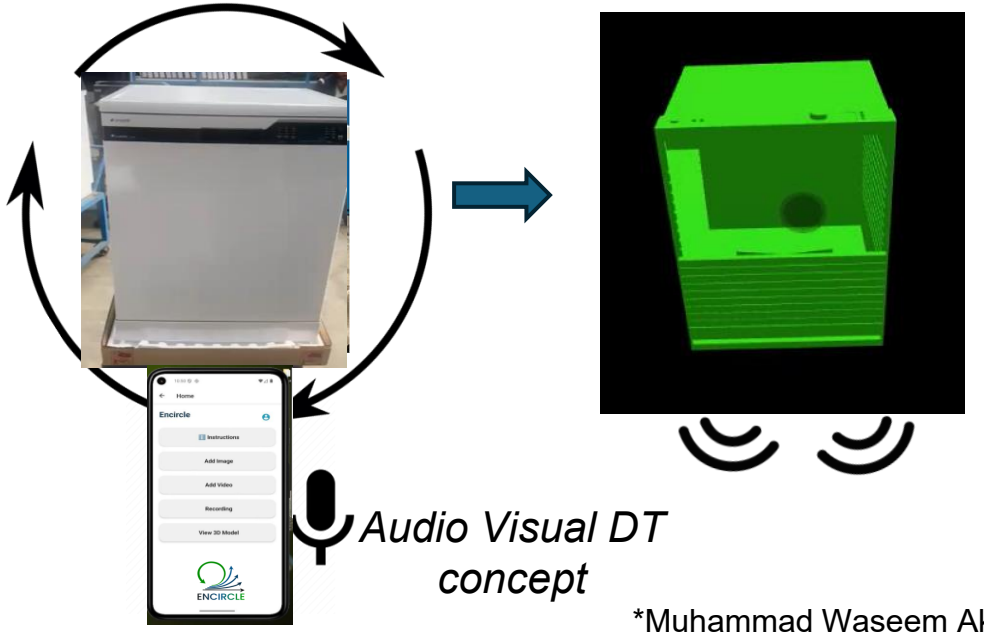
Connection to Marketplace for circular offers



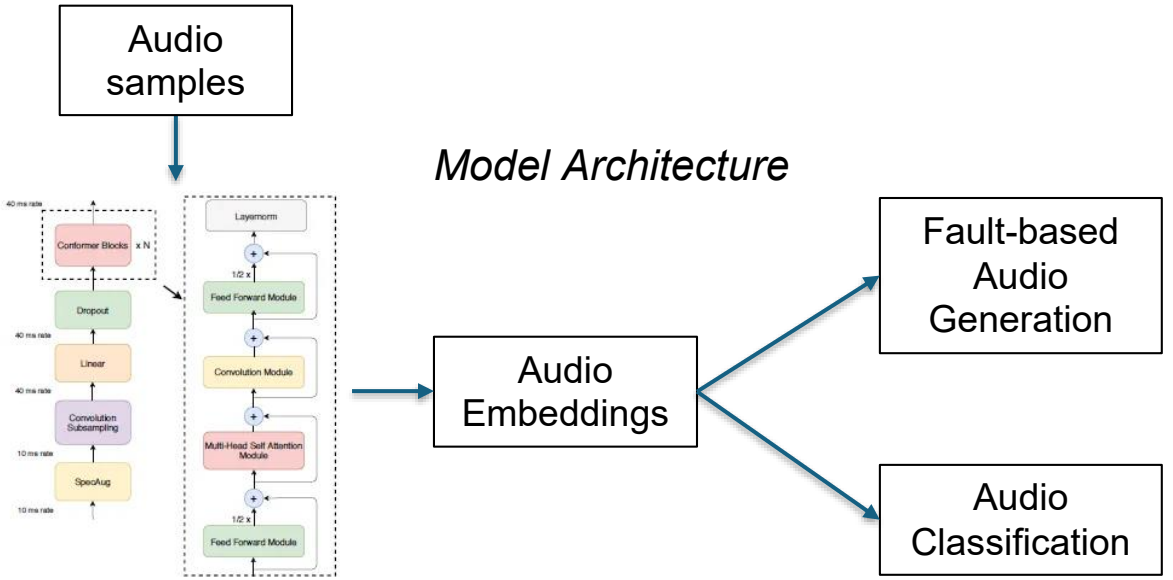
Self-Diagnostics / repair guides

DT & NeRF Digitization- Arcelik UC

- **3D reconstruction** helps users **locate faults** and capture visual/audio evidence.
- **Audio-Visual DT** using Con-former for **audio analysis and fault detection.**
- DT predictions inform **circular options** (repair, refurbish, up-/re-cycle)
- All transactions and updates are securely logged on the **blockchain**.



Audio Visual DT concept



Conformer Encoder

*Muhammad Waseem Akram., et al, "ChordFormer: A Conformer-Based Architecture for Large-Vocabulary Audio Chord Recognition," 2025.

Conclusions

⇒ ENCIRCLE enables both producers and consumers to benefit from circular practices.

- **Digitization** and **circularity** across the entire manufacturing value chain.
- **Empowers industry** and **consumers** through data-driven ecosystems.
- **Transparent** and **informed** circular decisions using the **DPP**.
- **Digital Twins, AI**, and **Soft Sensors** for sustainable, efficient and digitized production.
- Circular business models via the **Marketplace**, **DPP Wallet App** and **C2RM**.

Questions - Discussion

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