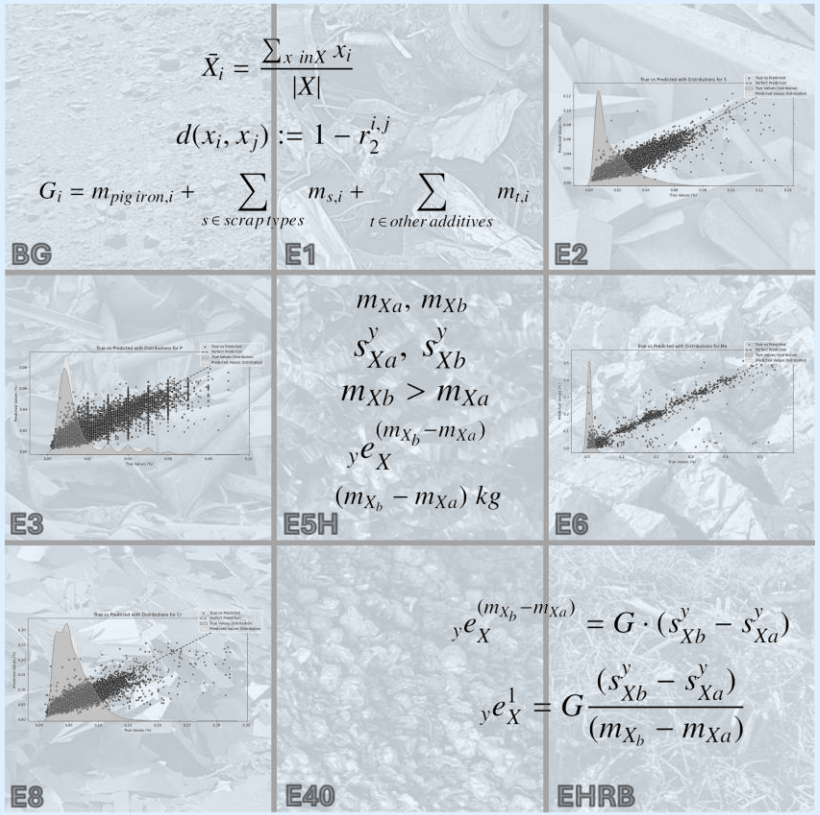
An AI-powered holistic system for optimizing the usage of steel scrap in steel production



Michael Schäfer

Introduction & Motivation | Today

Source: Saarstahl AG

The steel industry is responsible for around 5% of CO2 emissions in the EU and 7% globally

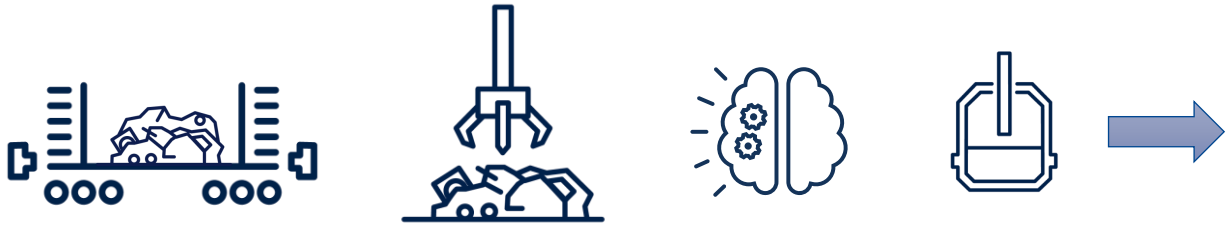
Steel scrap is often treated very poorly today

Manuel checks

Introduction & Motivation | Future

Source: https://www.pure-steel.com/power4steel/

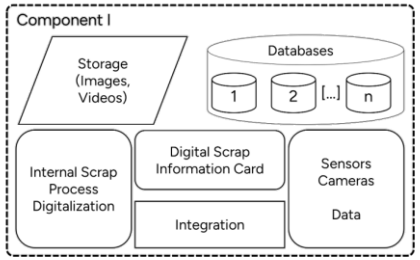
Source: https://www.pure-steel.com/power4steel/



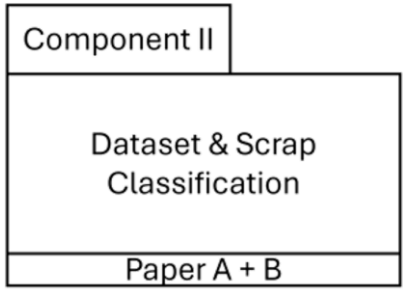
An AI-powered holistic system for optimizing the usage of steel scrap in steel production

Methodology

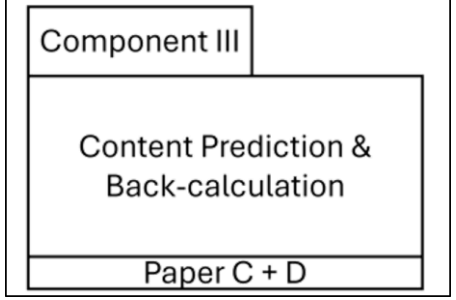
Component I



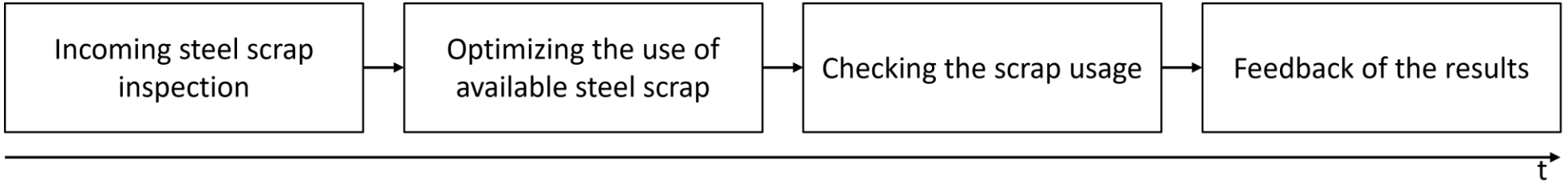
Component II

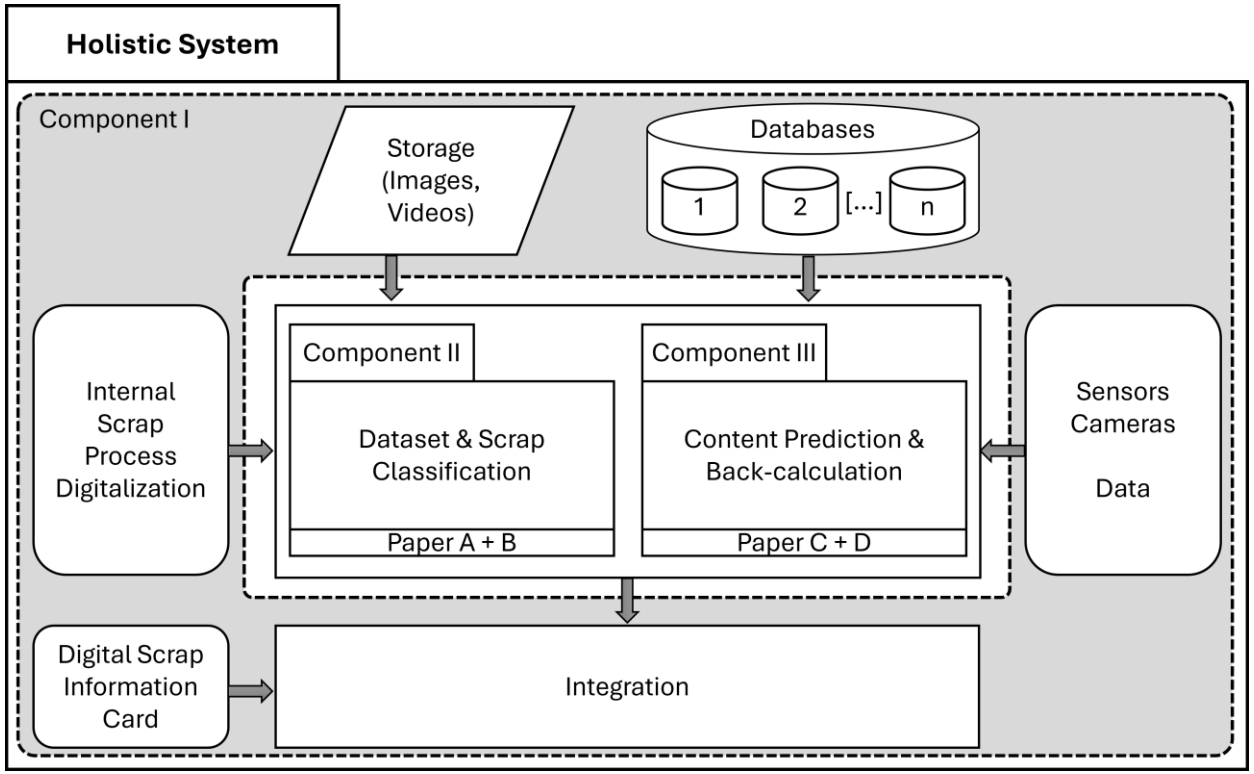


Component III



AI-powered process optimization from scrap input to the end of the converter process

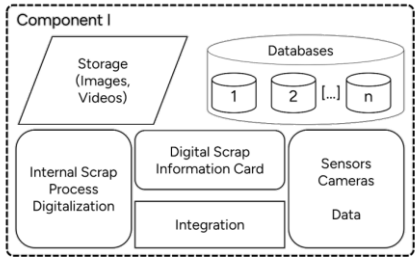




- Complete steel scrap process
- Three main components
- Heterogeneous infrastructure
- Dataset and classification
- Prediction of the chemical content of the heat
- Back-calculation

Methodology | Infrastructure

Component I



Component II

Component II

Dataset & Scrap Classification

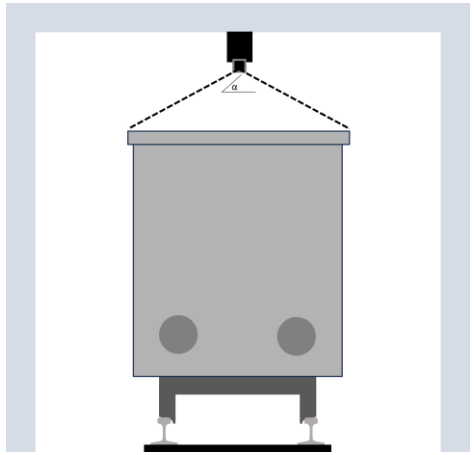
Paper A + B

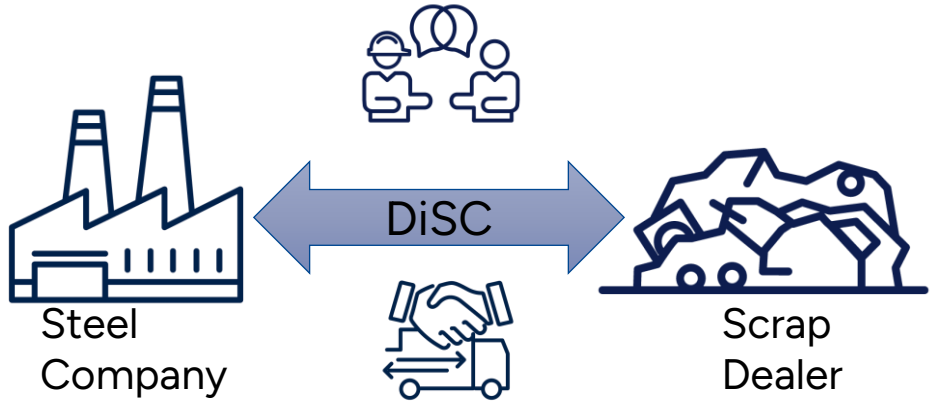
Component III

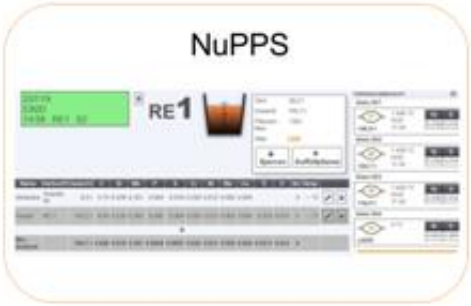
Component III

Content Prediction & Back-calculation

Paper C + D



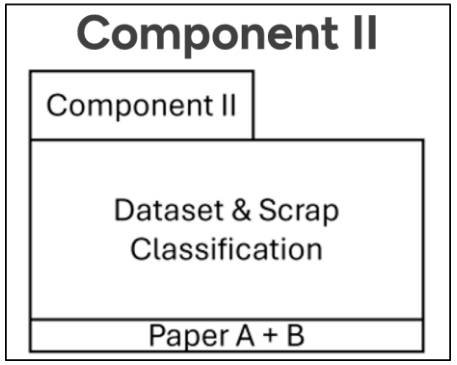




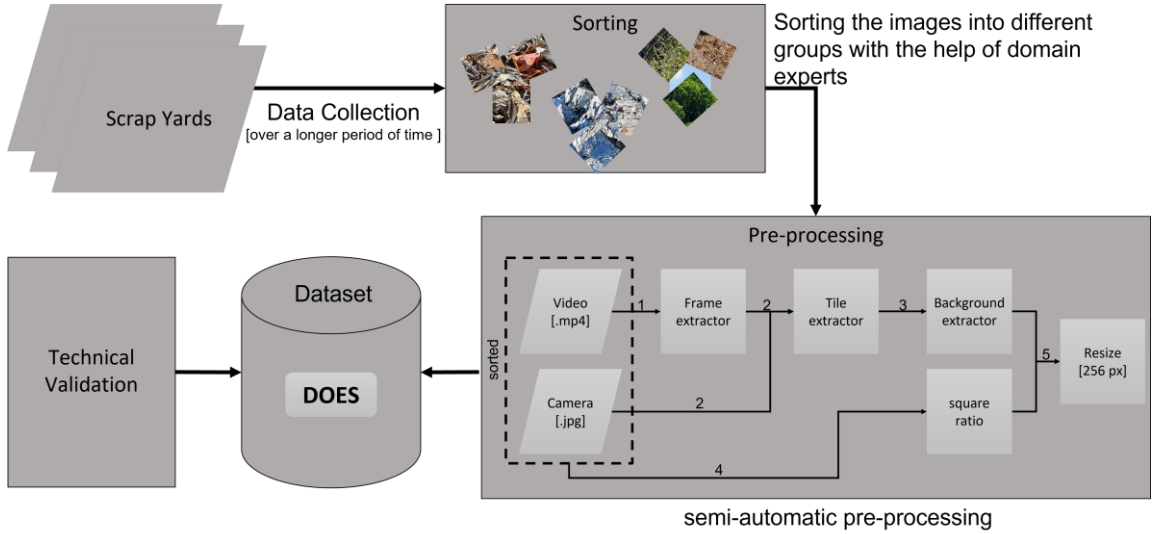
Listing 2.1: Get camera frame.

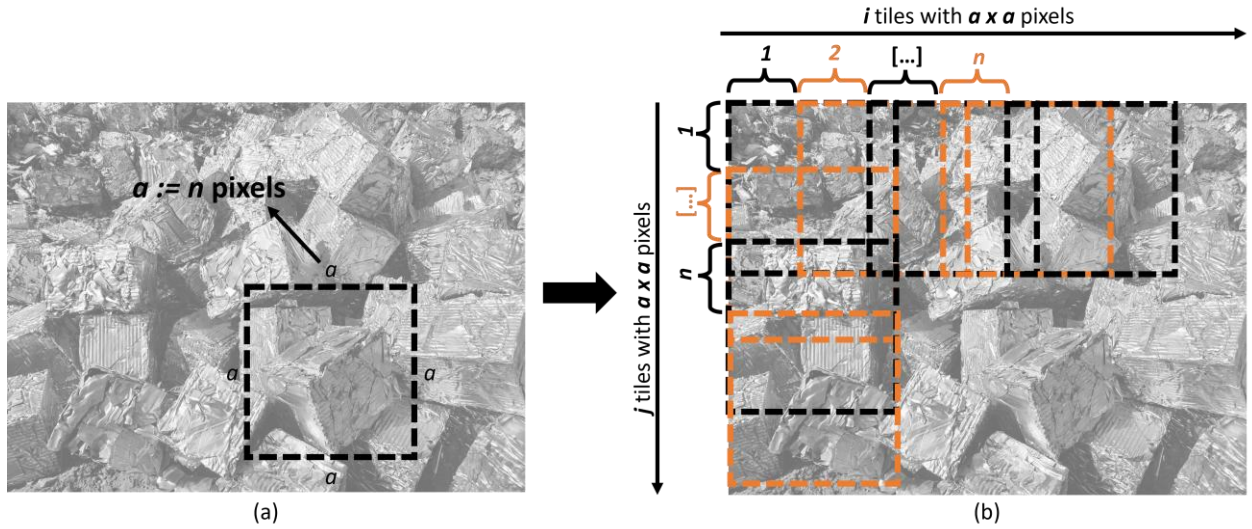
```
def get_camera_frame(camera_id):
    my_cam = get_camera_config(camera_id)
    user = my_cam["credentials"]["username"]
    pwd = my_cam["credentials"]["password"]
    adr = my_cam["credentials"]["address"]

    stream = cv2.VideoCapture(f"rtsp://{user}:{pwd}@{adr}\
----/profile2/media.smp",cv2.CAP_FFMPEG)
    stream.release()
    retval, frame = stream.read()
    if retval:
        frame = cv2.cvtColor(frame, cv2.COLOR_BGR2RGB)
        pil_frame = Image.fromarray(frame)
        return pil_frame
    else:
        logger.info("Did not receive a frame.")
        return None
```

Methodology | Dataset



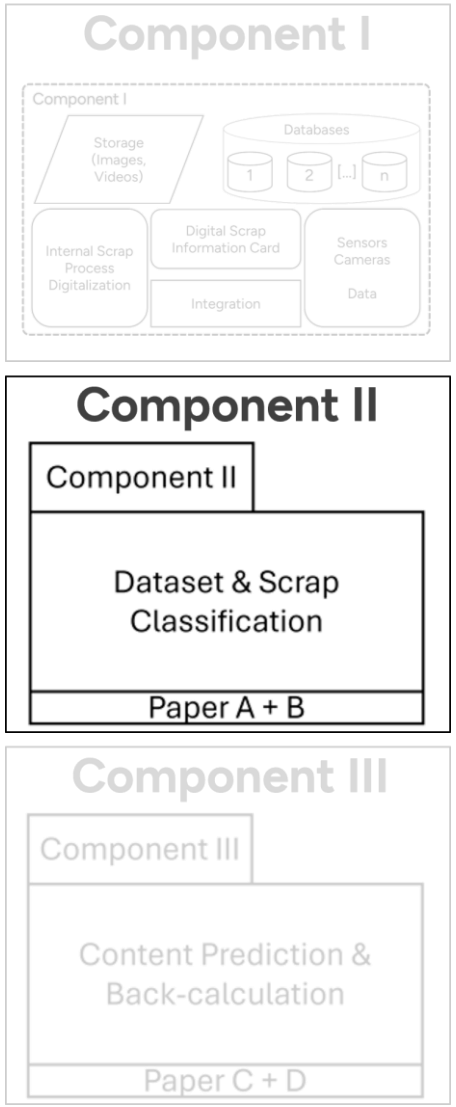
- Collect images (drone & camera)
- Sort into classes
- Pre-processing
- Packaging
- Technical Validation
  - Manual
  - Neural Network



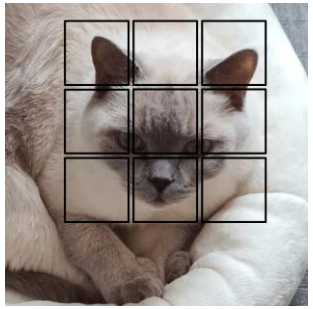
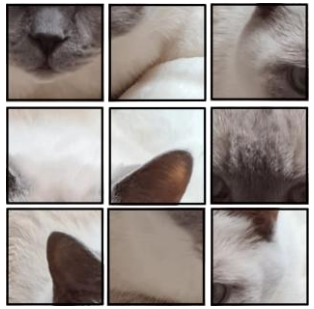
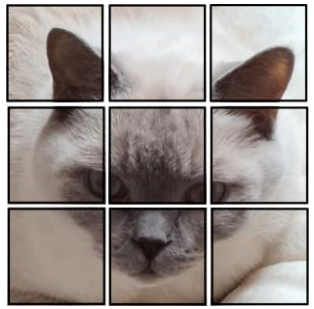


- Novel tiling approach
- One size fits all
- Semi-automatic labeling
- Turning one image into many

Methodology | SSL - Classification



Solving Jigsaw Puzzle

✓

Image Rotation



✓

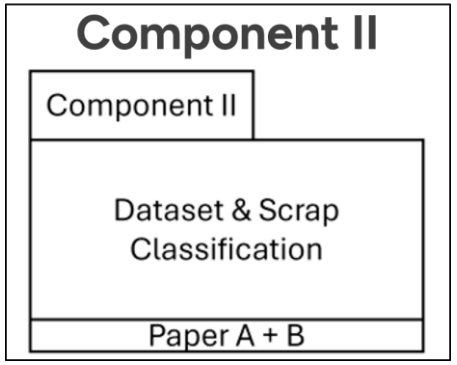
Steel Scrap



✗

Methodology | SSL - Classification

AI-powered Steel Production



Examples of augmentations used

Original

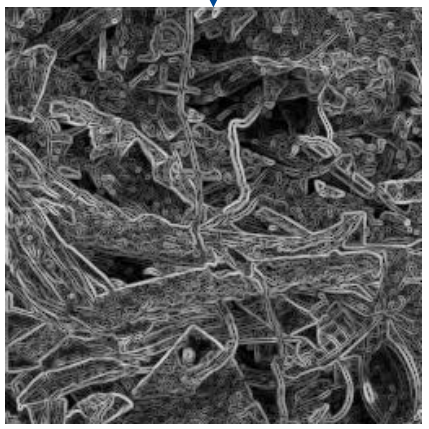
Color jitter

Grayscale

Resized crop

Horizontal flip

Gaussian blur



Sobel

Methodology | SSL - Classification

AI-powered Steel Production

Component I

Component I

Storage (Images, Videos)

Databases

1 2 [...] n

Internal Scrap Process Digitalization

Digital Scrap Information Card

Sensors Cameras

Integration

Data

Component II

Component II

Dataset & Scrap Classification

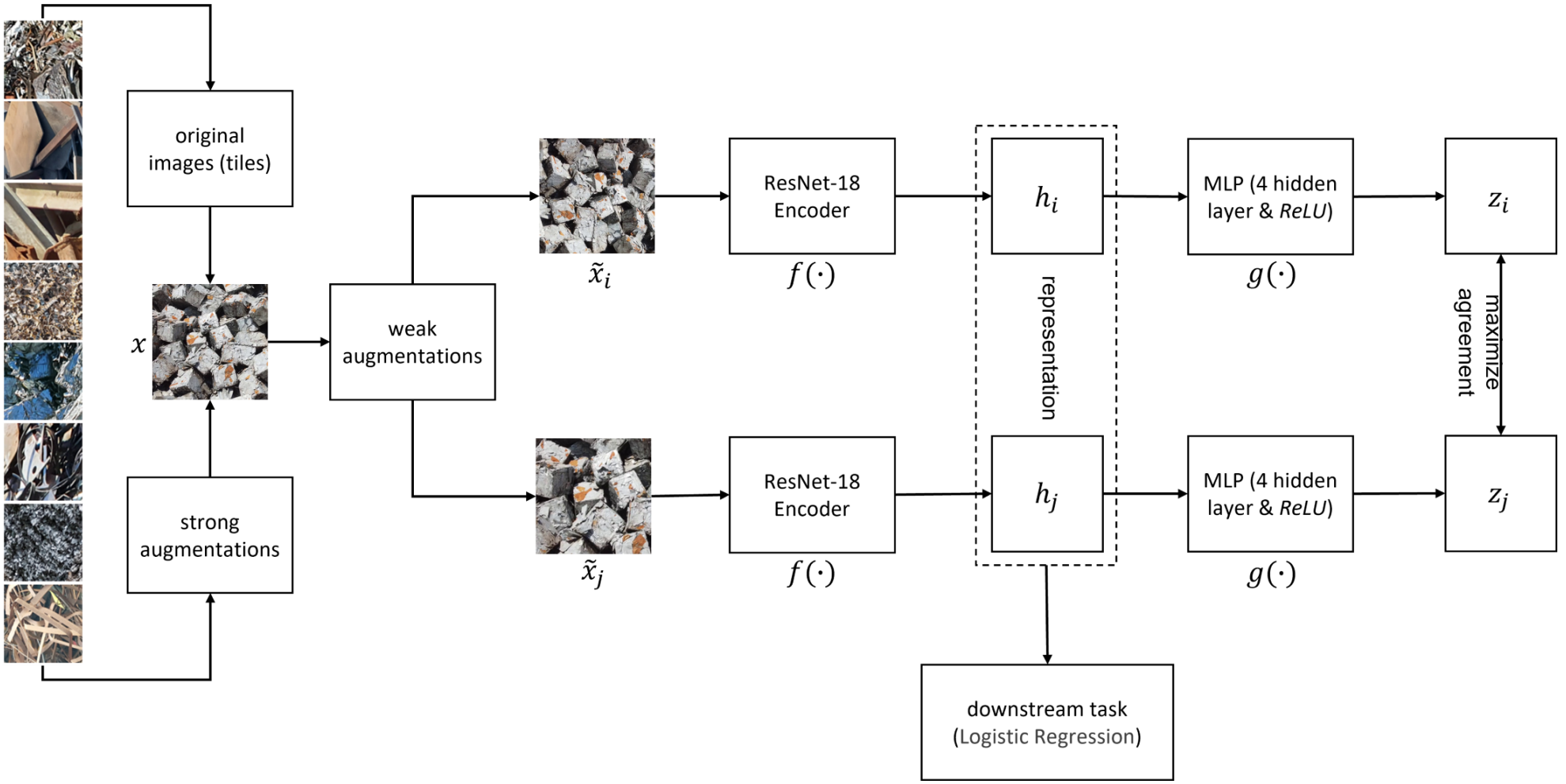
Paper A + B

Component III

Component III

Content Prediction & Back-calculation

Paper C + D



Methodology | Content Prediction

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Component I

Storage (Images, Videos)

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1 2 [...] n

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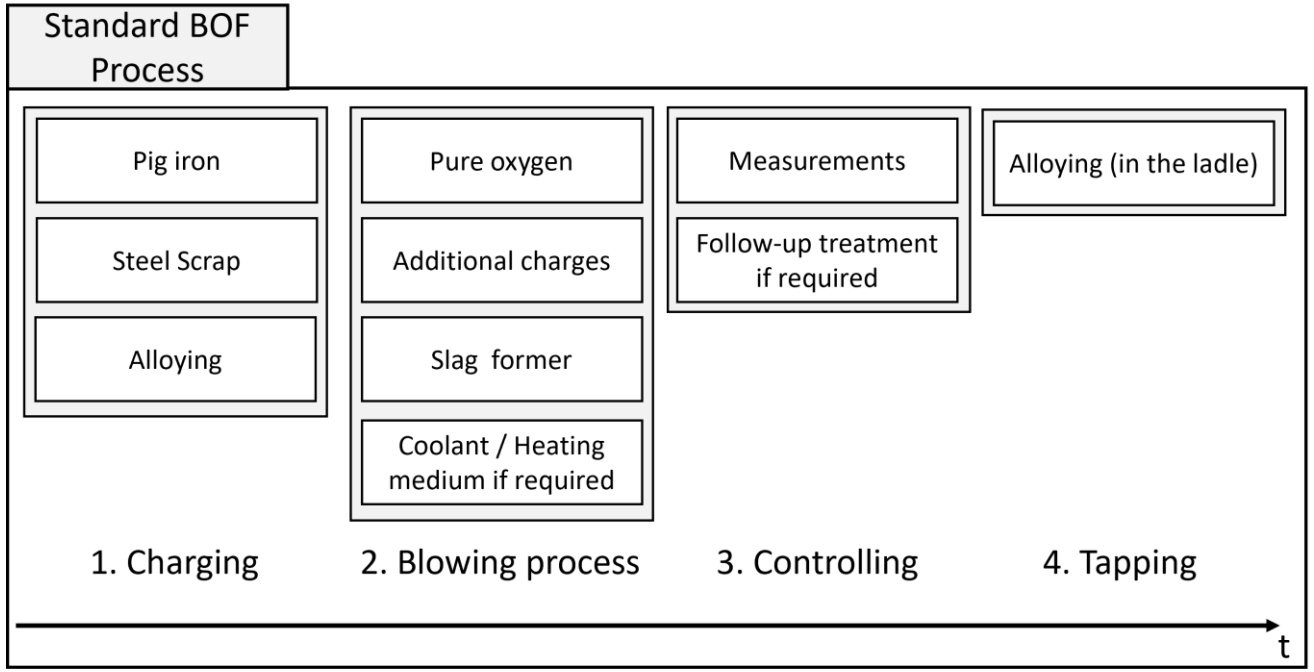
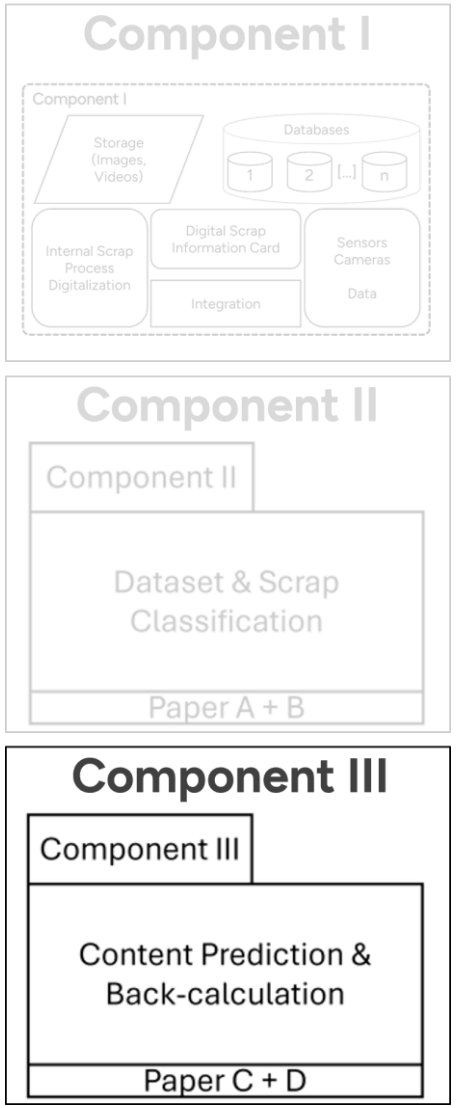
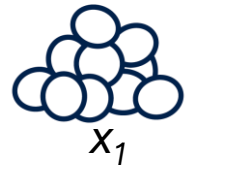


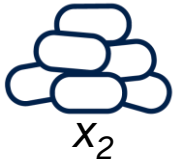
Feature Variables						Target Variables
Chemical Analyses Pig Iron [mass %]	Weight Pig Iron [kg]	Steel Scrap [kg]	Alloys [kg]	Other Additives [kg]	Chemical Analyses Slag [mass %]	Target Variables [mass %]

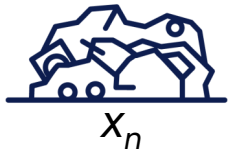
Methodology | Content Prediction

AI-powered Steel Production

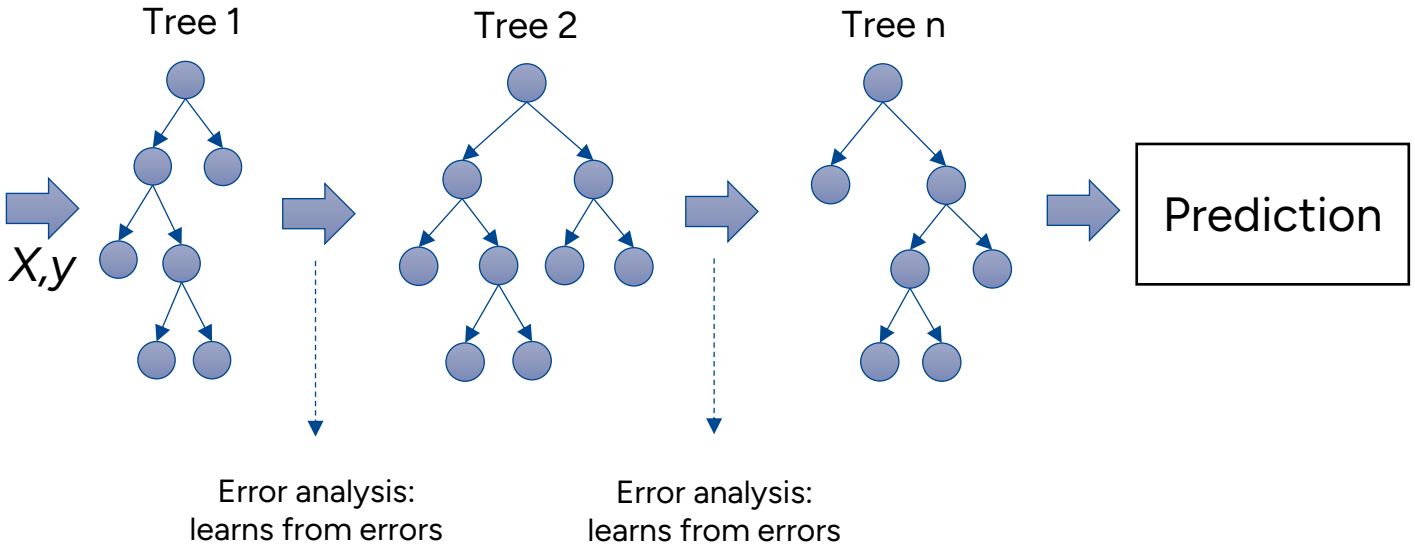








XGBoost Algorithm for each tramp element



Methodology | Back-Calculation

AI-powered Steel Production

Component I

Component I

Storage (Images, Videos)

Databases

1 2 [...] n

Internal Scrap Process Digitalization

Digital Scrap Information Card

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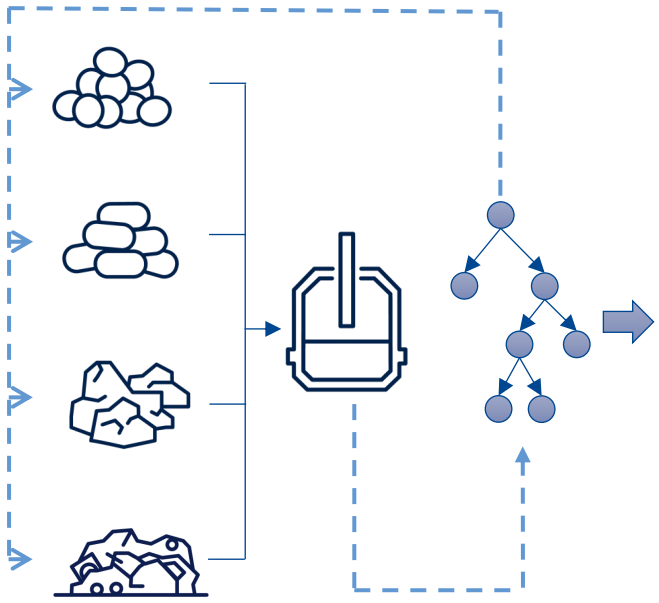
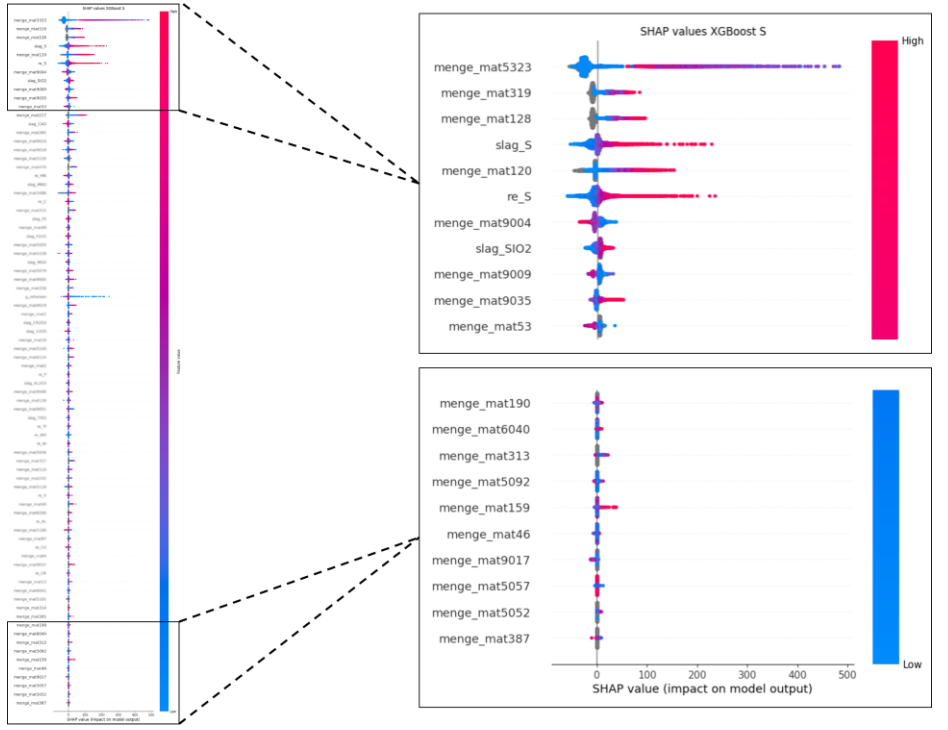
Component III

Content Prediction & Back-calculation

Paper C + D





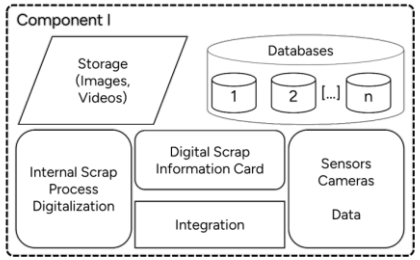
Estimate

SHAP values (Shapley Additive exPlanations): A game-theoretical approach to explain model results for ML models

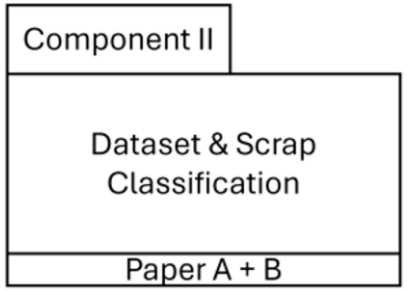
Results | Recap Holistic system

AI-powered Steel Production

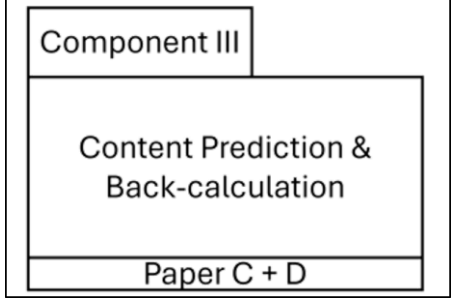
Component I

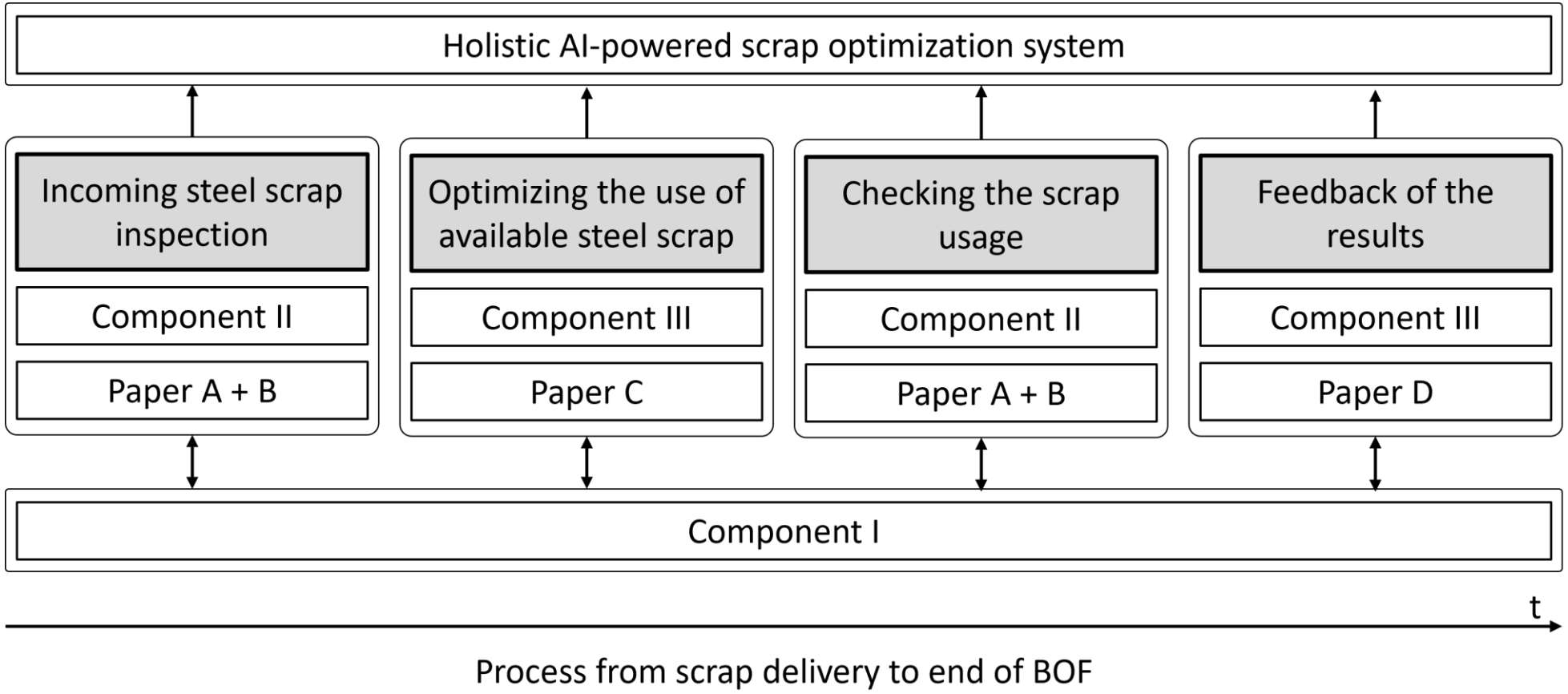


Component II



Component III

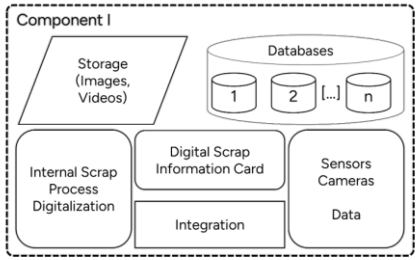




Results | Train Station

AI-powered Steel Production

Component I



Component II

Component II

Dataset & Scrap Classification

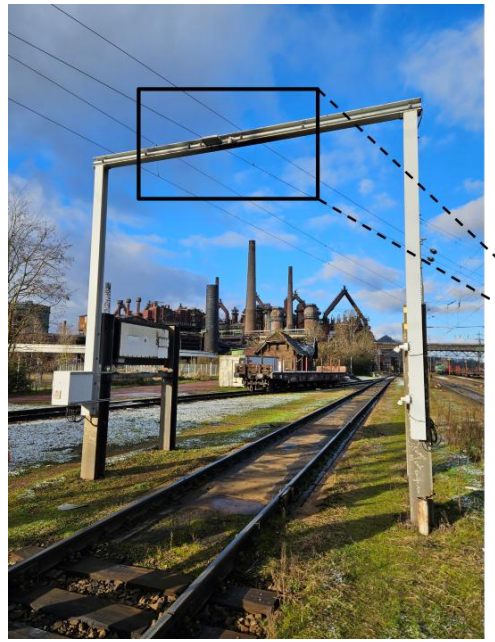
Paper A + B

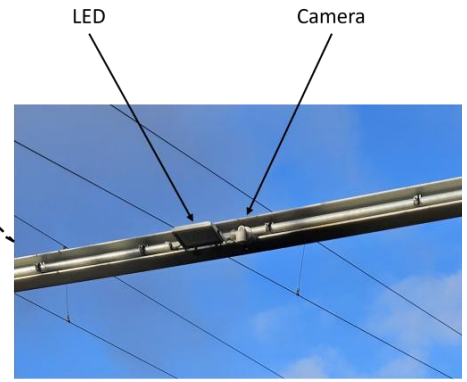
Component III

Component III

Content Prediction & Back-calculation

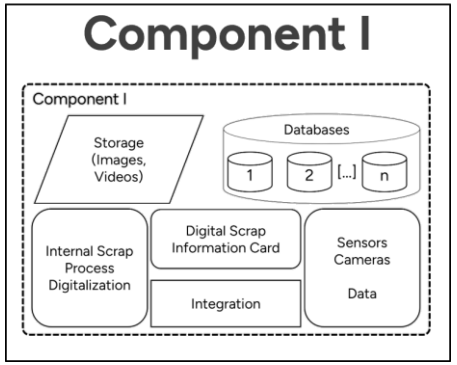
Paper C + D

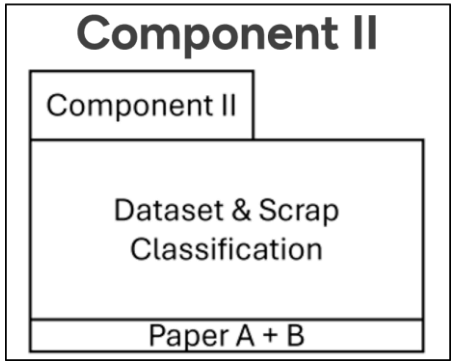


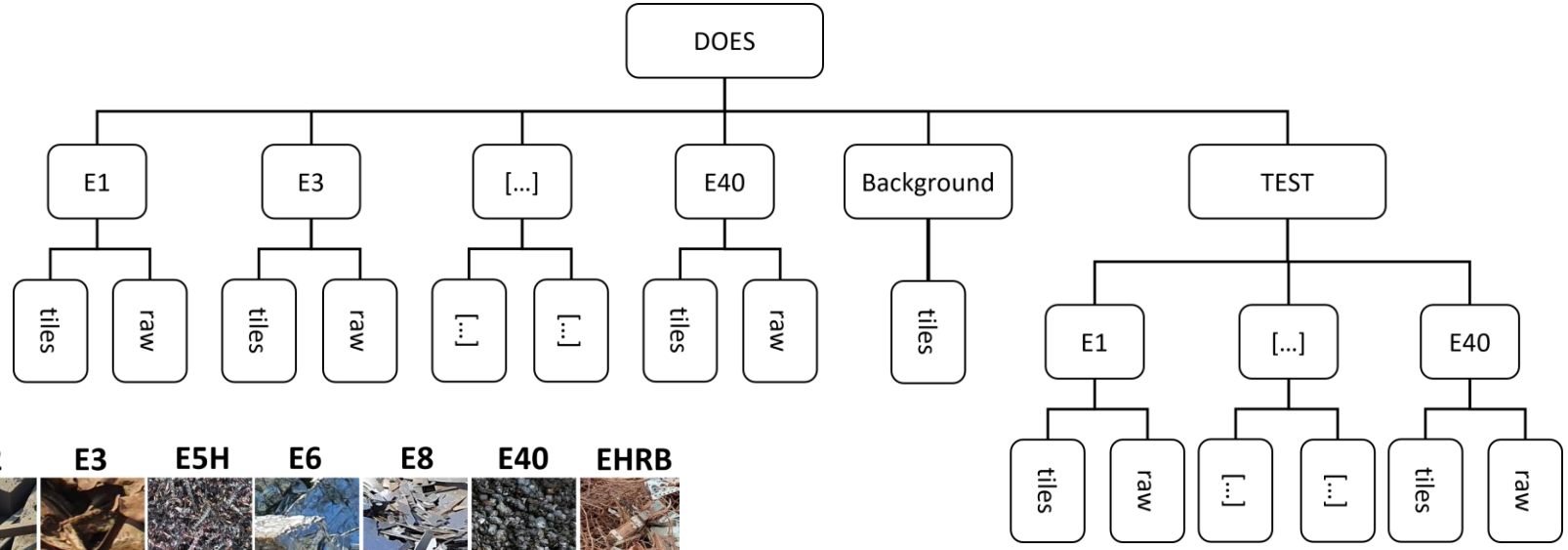


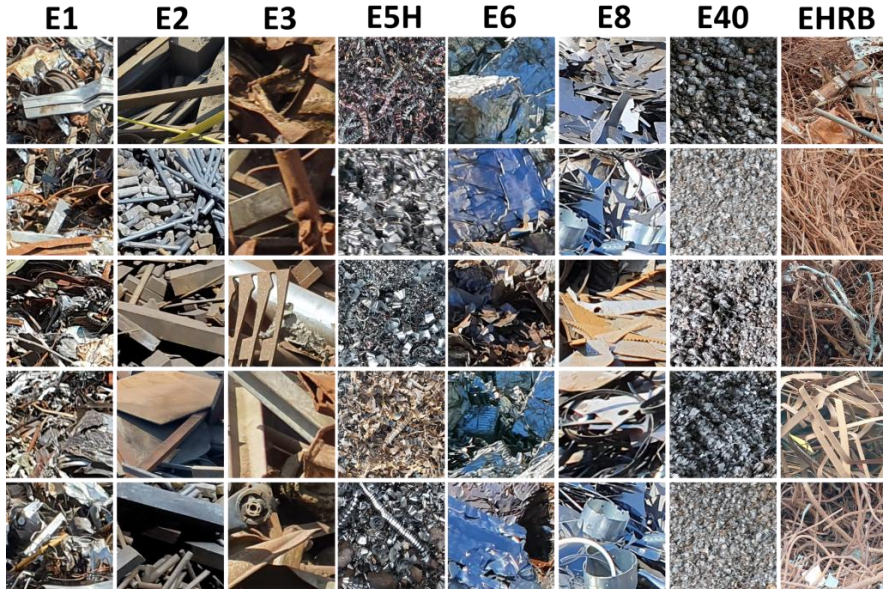
Results | Created Dataset

AI-powered Steel Production





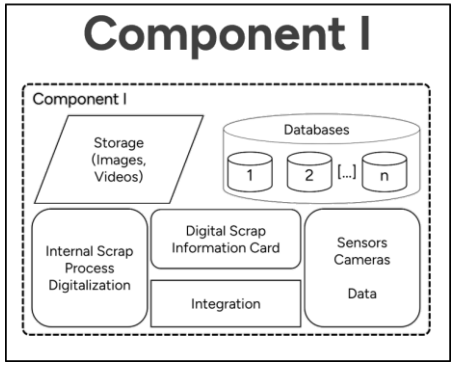


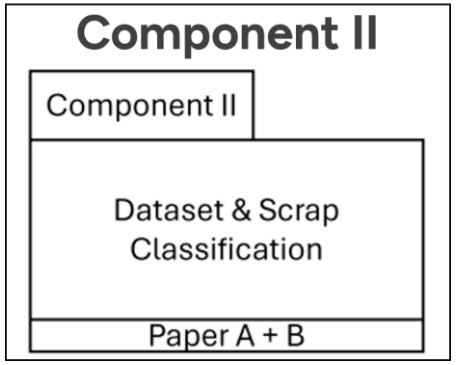


First freely available steel scrap dataset

Zenodo: https://doi.org/10.5281/ zenodo.8219163

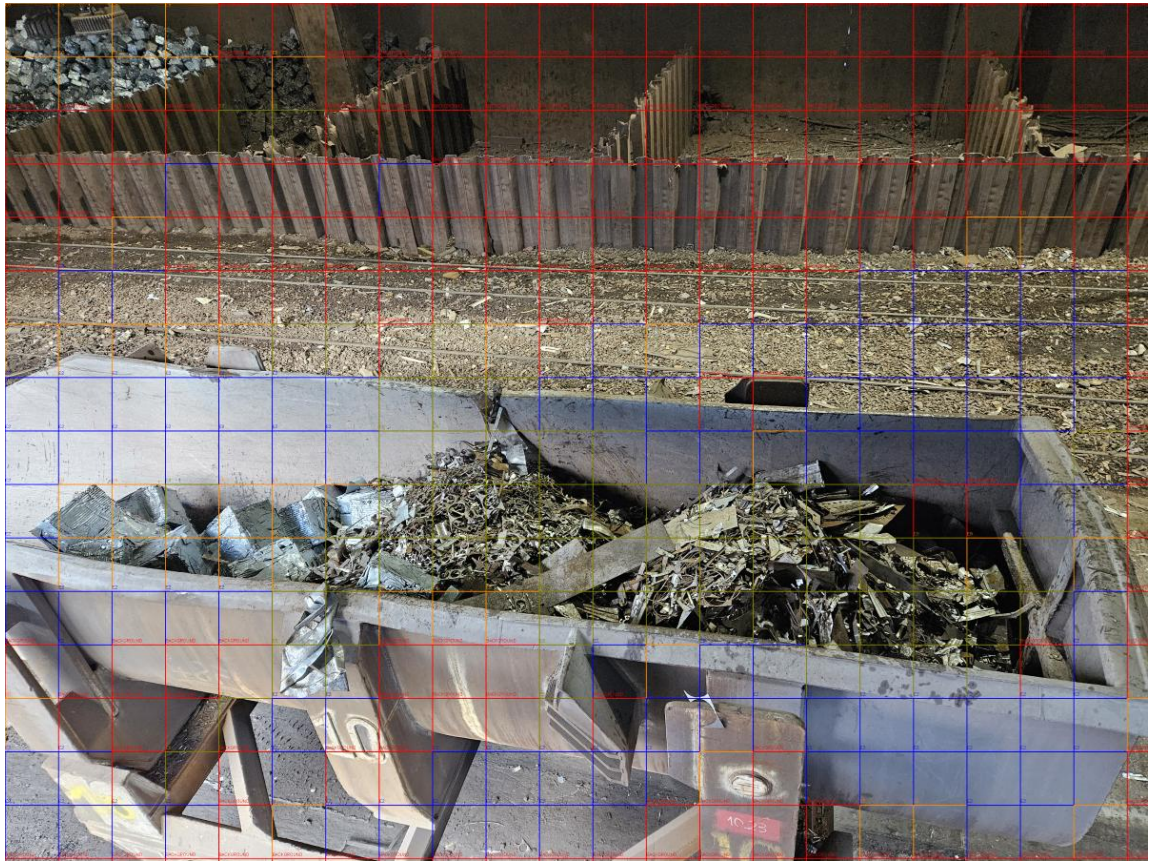
Results | Scrap Classification

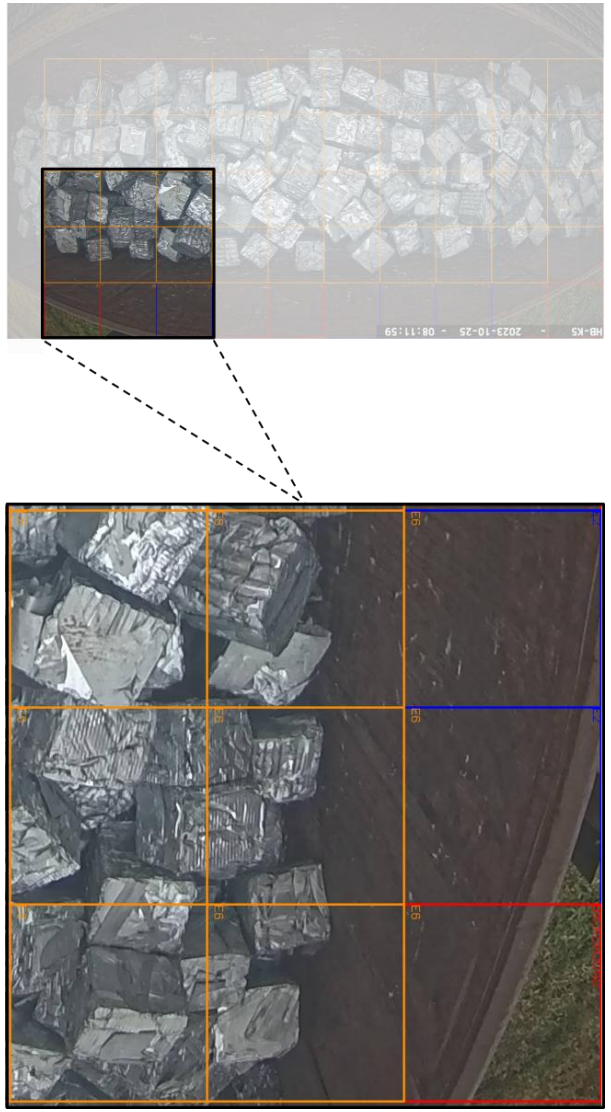




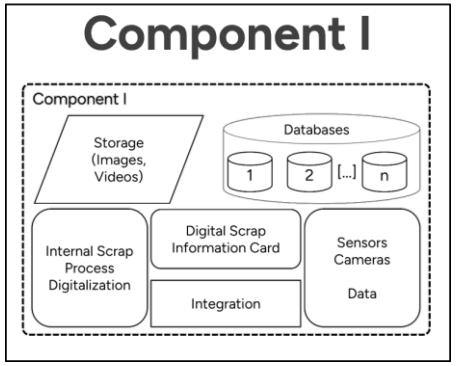
Overall classification accuracy of tiling approach:

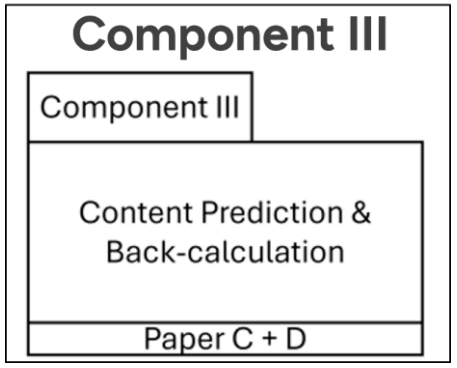
- **64.20 %** (original SimCLR)
- **75.89 %** (improved augmentations)
- **97.43 %** (finetuned train station)





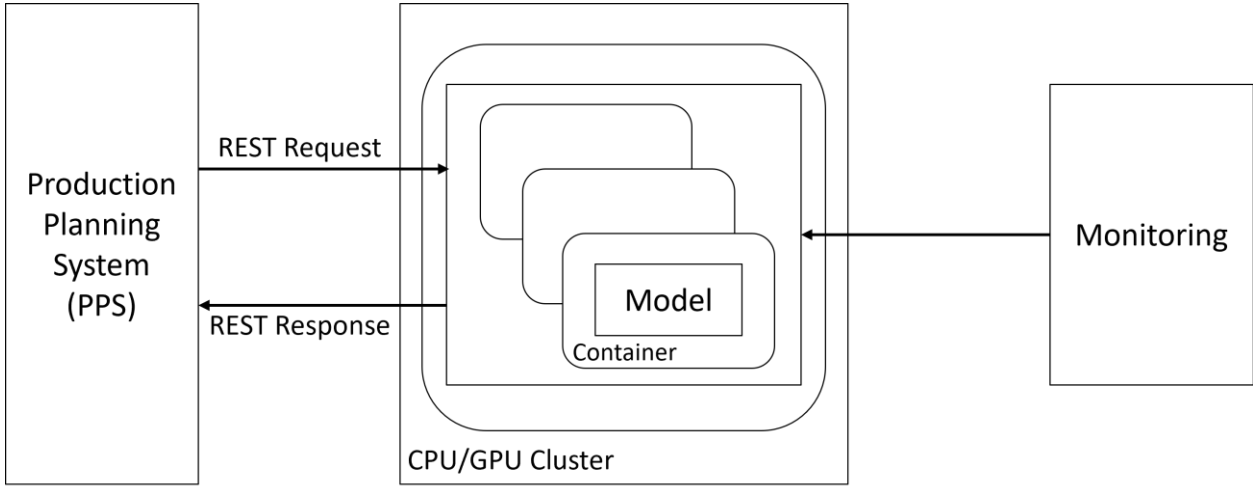
Results | Element Prediction



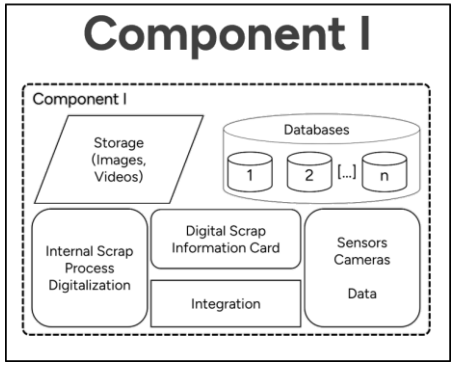


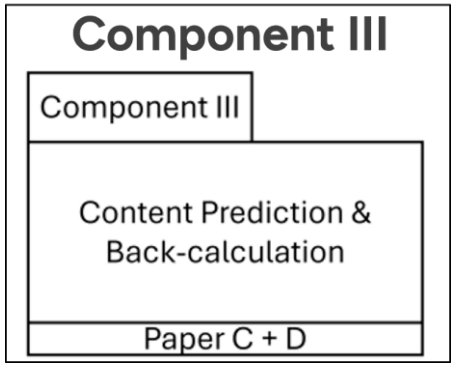
Element	MAPE TM	MAPE AI	MAE TM	MAE AI
Cu	22.578	**18.966**	0.00382	**0.0033**
Cr	**9.085**	13.727	**0.0054**	0.0077
Ni	**23.391**	25.048	**0.0073**	0.0084
Mo	102.046	**34.526**	0.0056	**0.0031**
P	33.257	**23.848**	0.0045	**0.0033**
S	**19.57**	20.34	0.0035	**0.003**
Sn	409.631	**41.371**	0.0032	**0.0004**

Table 3.3: Performance metrics results and comparison (MAE - Mean Absolute Error, MAPE - Mean Average Percentage Error, TM - Traditional Model, AI - XGBoost Model).



Results | Back-calculation

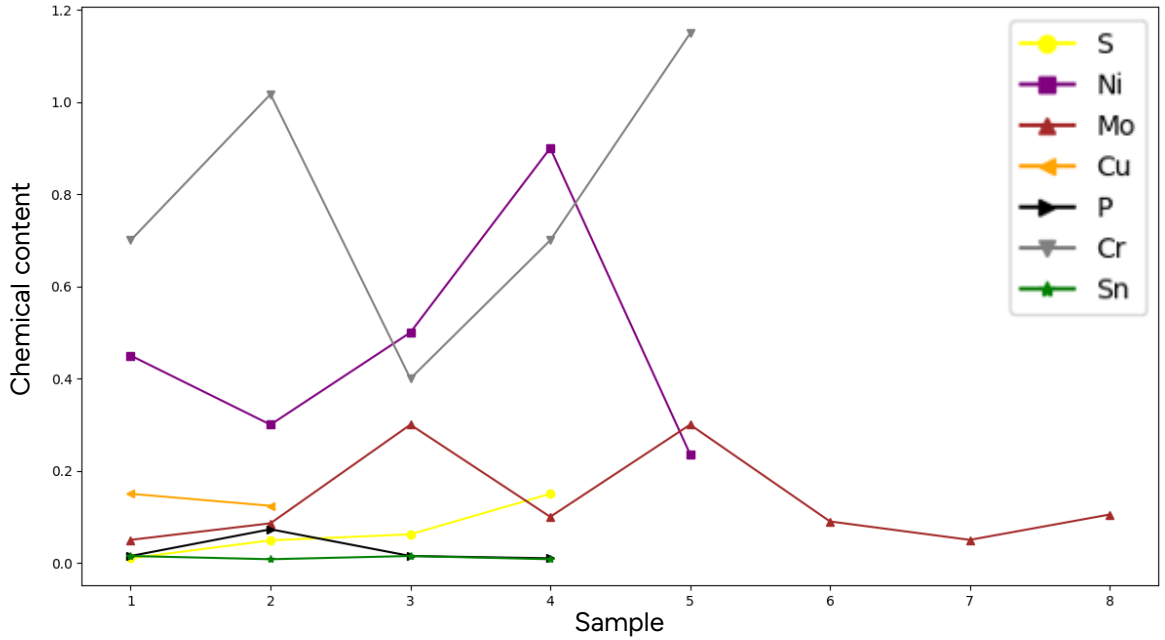




$$G\frac{(s_{Xb}-s_{Xa})}{(m_{X_b}-m_{Xa})}=\frac{192520\cdot 0.0213116}{21760}=0.188552814\approx 0.189$$

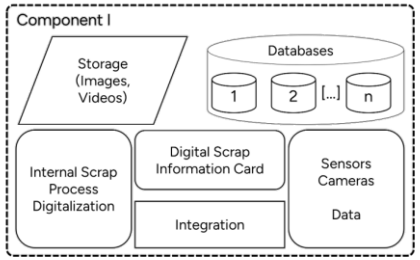
Input Mat.	mat_1^{Cu}	mat_7^{Cu}	mat_1^{Mo}	mat_3^{Mo}	mat_9^{Ni}	mat_{10}^{Ni}	mat_2^{Cr}	mat_4^{Cr}	mat_1^{Sn}	mat_2^{Sn}	mat_3^{S}	mat_4^{S}	mat_1^{P}	mat_4^{P}
No. ex.	2067	1336	1324	1503	566	118	3523	1890	448	1864	4181	1243	3101	5338
Mean	0.427	0.032	59.479	0.231	96.583	98.595	0.393	0.165	0.123	0.006	0.051	0.134	0.012	0.007
Std. Dev.	0.017	0.009	0.789	0.014	9.863	23.013	0.020	0.007	0.007	0.000	0.004	0.004	0.001	0.001
Hist. Est.	0.406	0.065	60	0.23	99.5	99.8	0.7	0.17	0.17	0.008	0.066	0.26	0.0128	0.01

Molybdenum briquettes



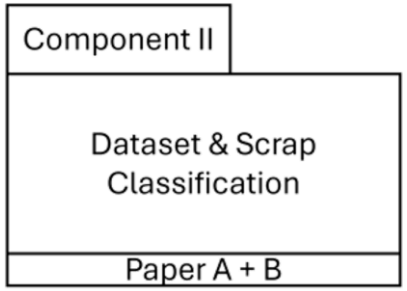
Conclusion

Component I



- Development of the infrastructure and interfaces
- Created a standardized exchange format for steel producer and scrap dealer

Component II



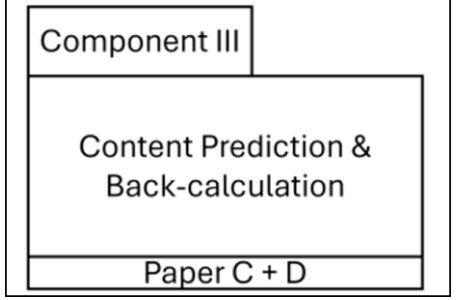
Paper A:

- First freely available steel scrap dataset
- New tiling approach

Paper B:

- Scrap classification with SSL for input and usage control
- Improved SSL for intrinsically unordered stuff-objects

Component III



Paper C:

- Prediction of the chemical content (tramp elements) at the end of the BOF process
- Online models

Paper D:

- Novel framework for estimating the chemical content of the respective input material

Future Work

- Industry:
  - Adaptation of the approaches to the EAF or processes such as secondary metallurgy
  - Improving the traceability of scrap in the scrap yard
  - Combination of the classification algorithms with other technologies such as Laser Induced Breakdown Spectroscopy
  - Development of an architecture for regular automated retraining of online models
- Research
  - Transfer of the developed SSL approach to new domains and tasks
  - Use of SSL to analyze and detect surface defects in different materials

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SHS - STAHL-HOLDING-SAAR

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