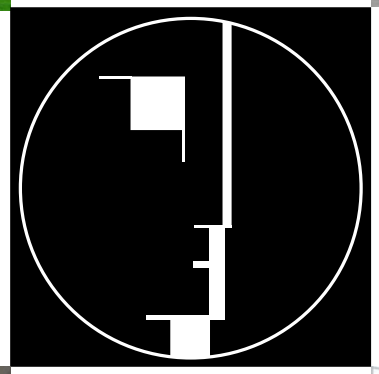
Scanning Electron Microscopy (SEM) Investigations of Portland Cement

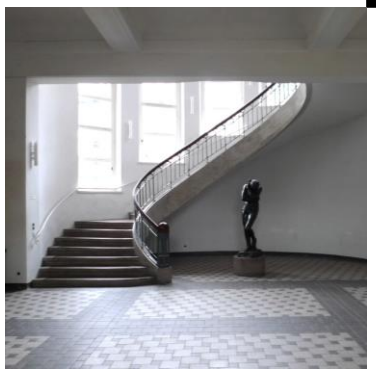
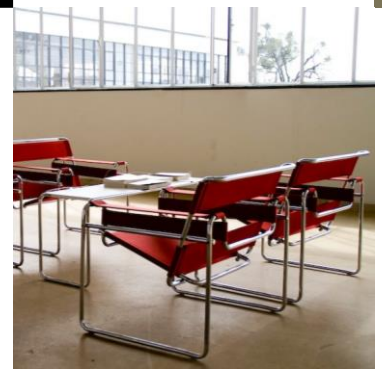
Bauhaus University
Weimar

Celine Beier

25.06.2025



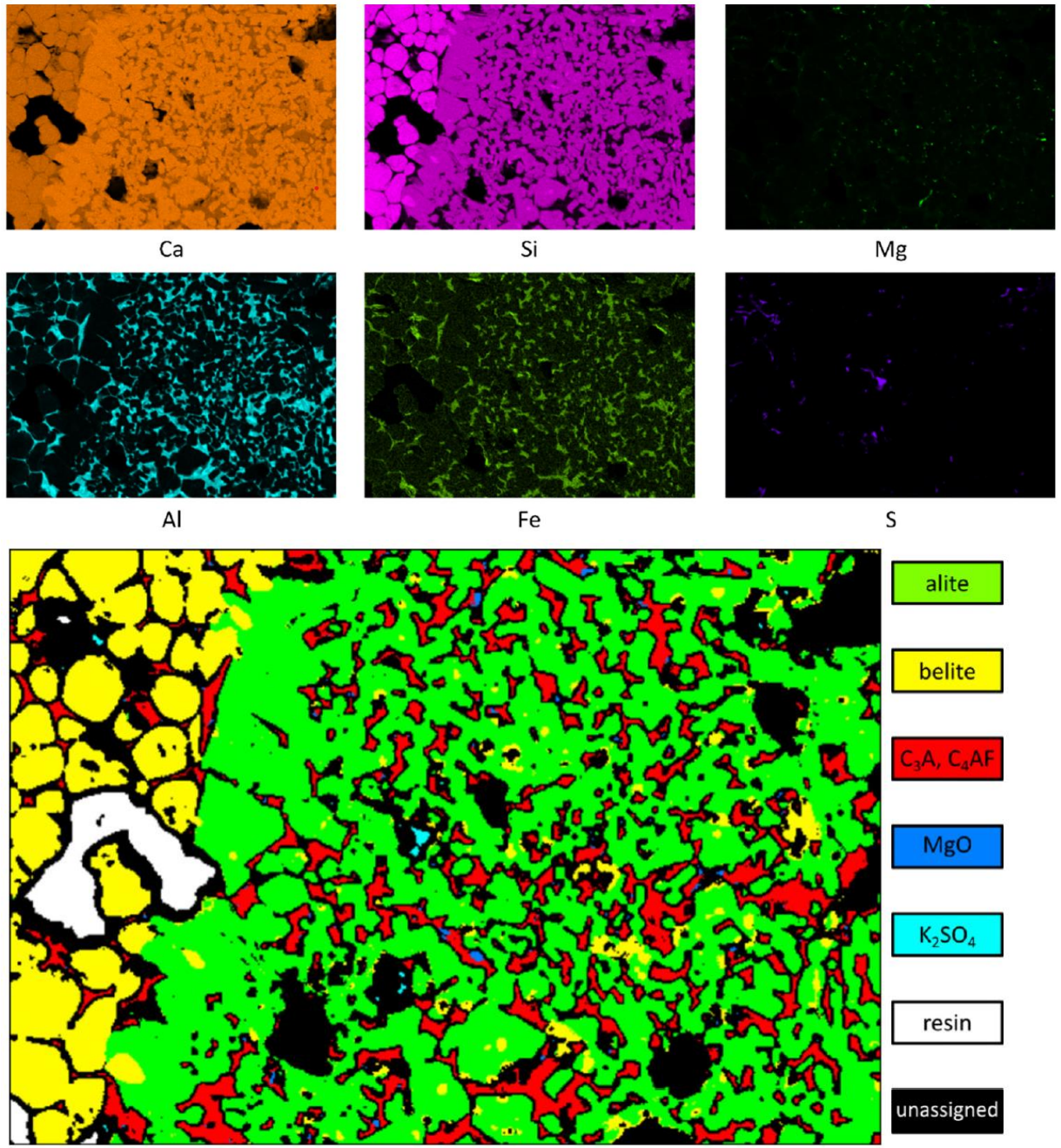
Wikimedia

Portland Cement and Clinker Phases

- Portland cement: 95% clinker and 5% gypsum
- clinker is formed by heating limestone, clay and other materials to ~1450°C
- identification of clinker phases with SEM-EDX using elemental maps

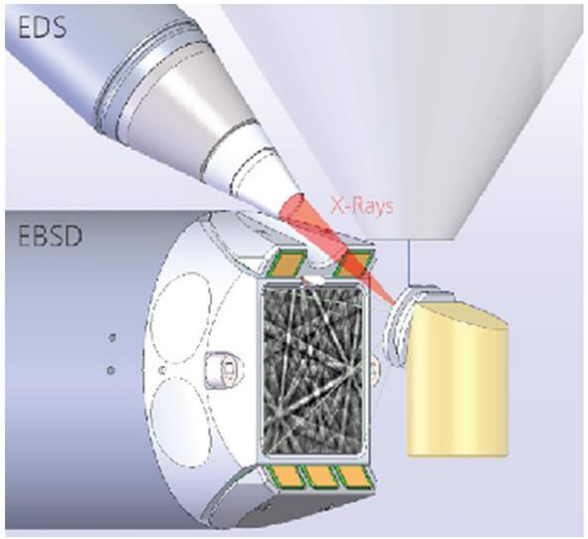
Wikimedia

Kleiner et al. (2022)



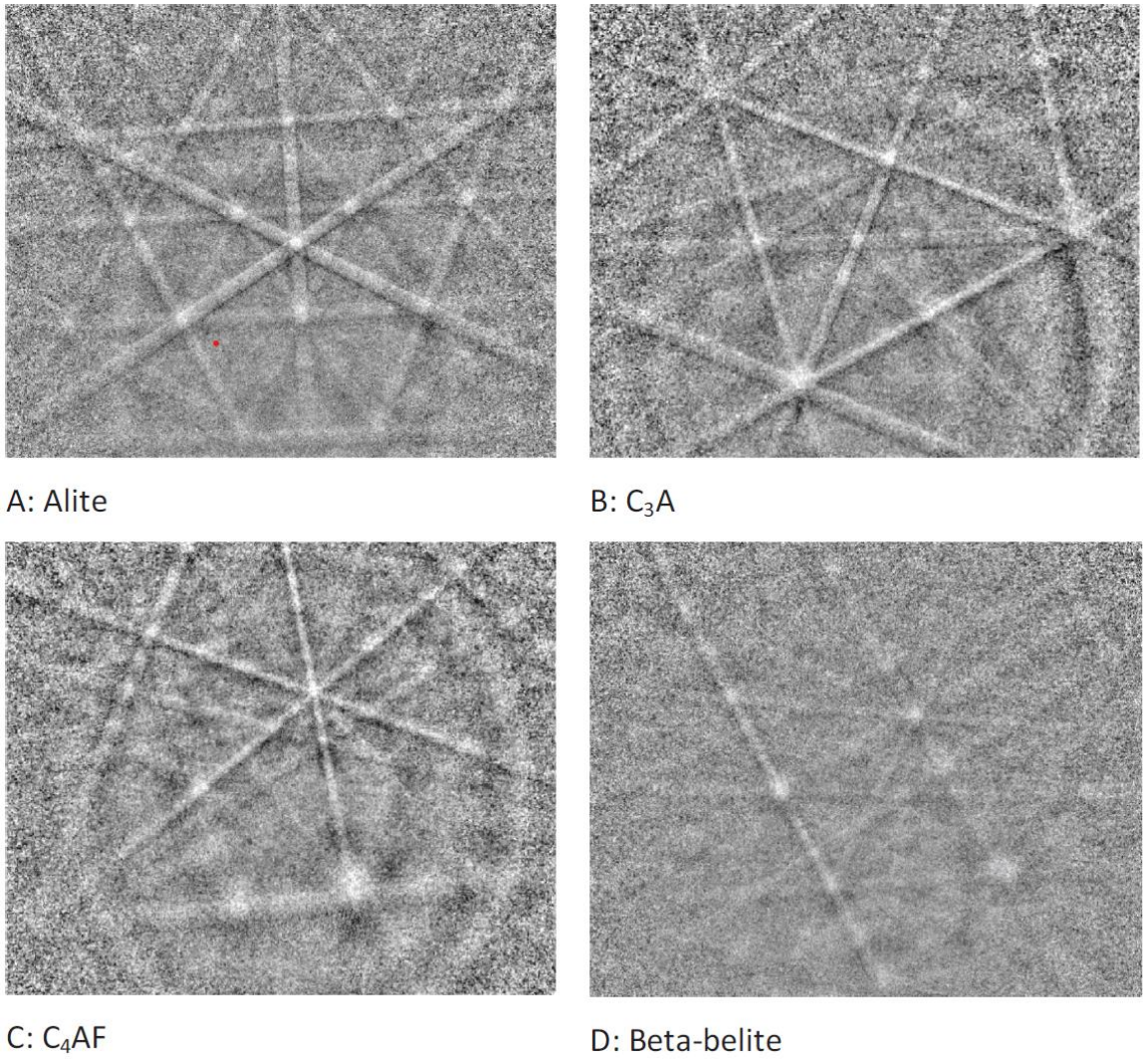
Kleiner et al. (2022)

Electron Backscatter Diffraction
EBSD - SEM



Rößler et al. (2022)

- identify crystalline phases, crystal orientation, grain size and spatial relationships
- formation processes of the clinker formed, predict performance in cement

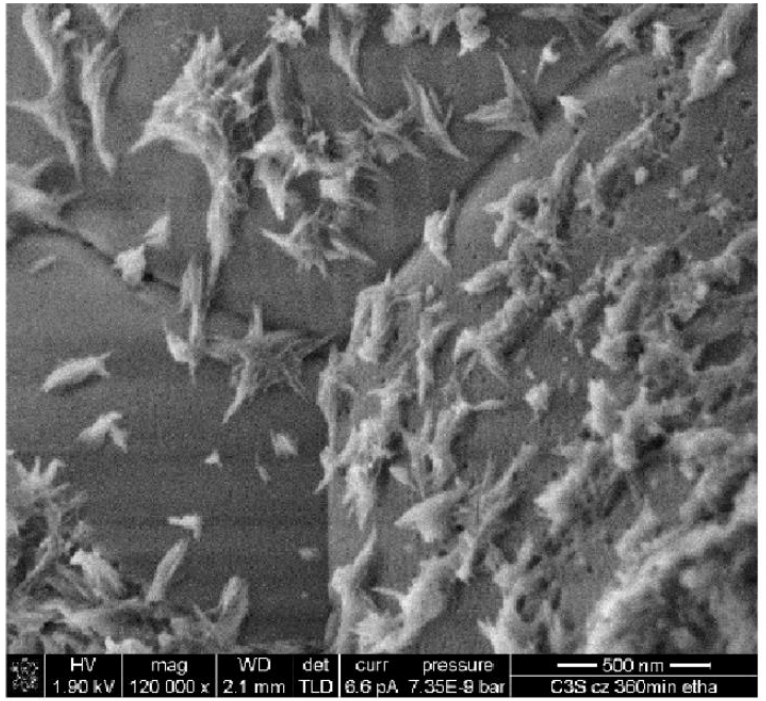


Rößler et al. (2022)

Imaging of Cement Hydration Processes

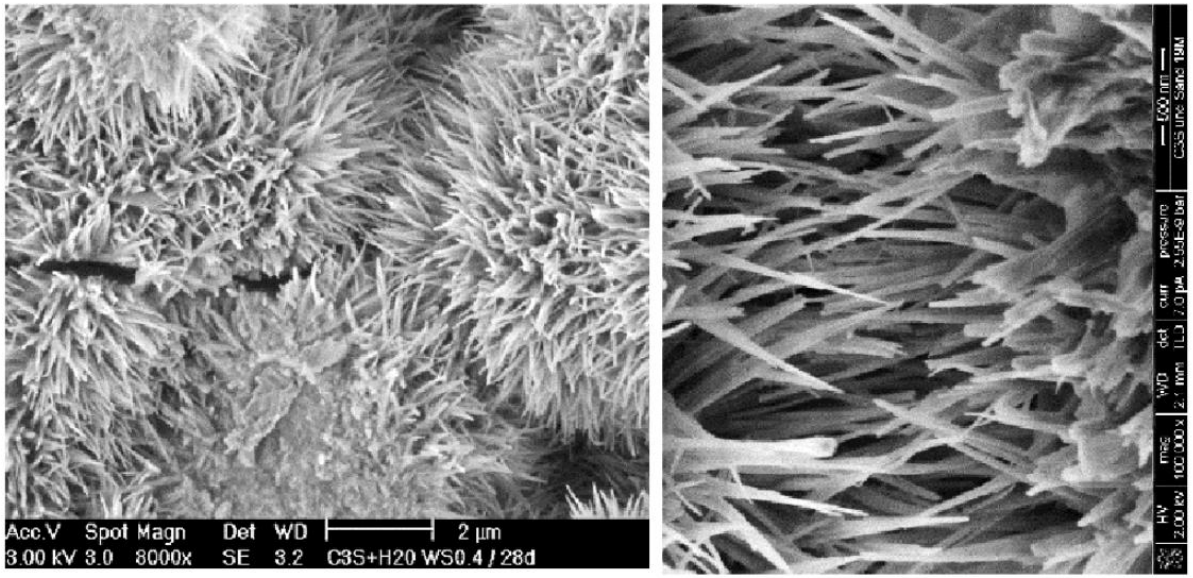
- hydration: addition of water, clinker reacts to form the cement
- alite (C_3S = 3CaO·SiO) reacts to form calcium silicate hydrate (C–S–H) and calcium hydroxide (CH)
- C-S-H determines the strength of the cement
- CH is connected to the porosity and durability
- proper curing time is required to fully allow the C-S-H phases to form

6h



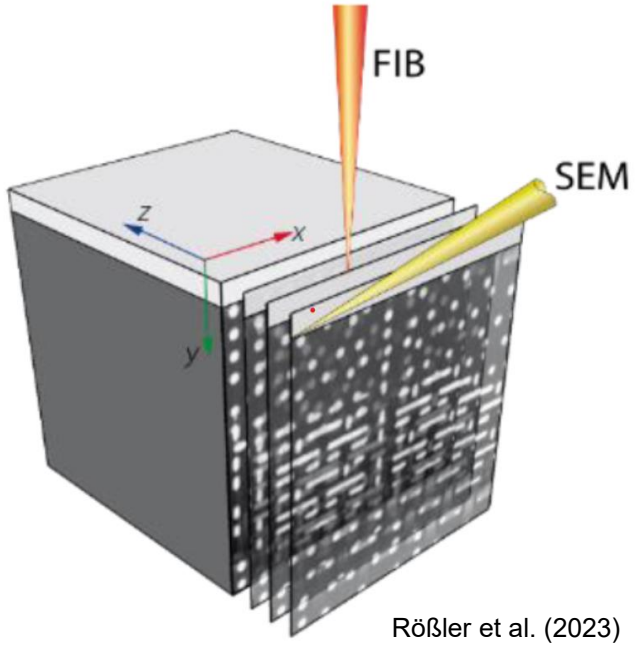
Rößler et al. (2023)

28d



Rößler et al. (2023)

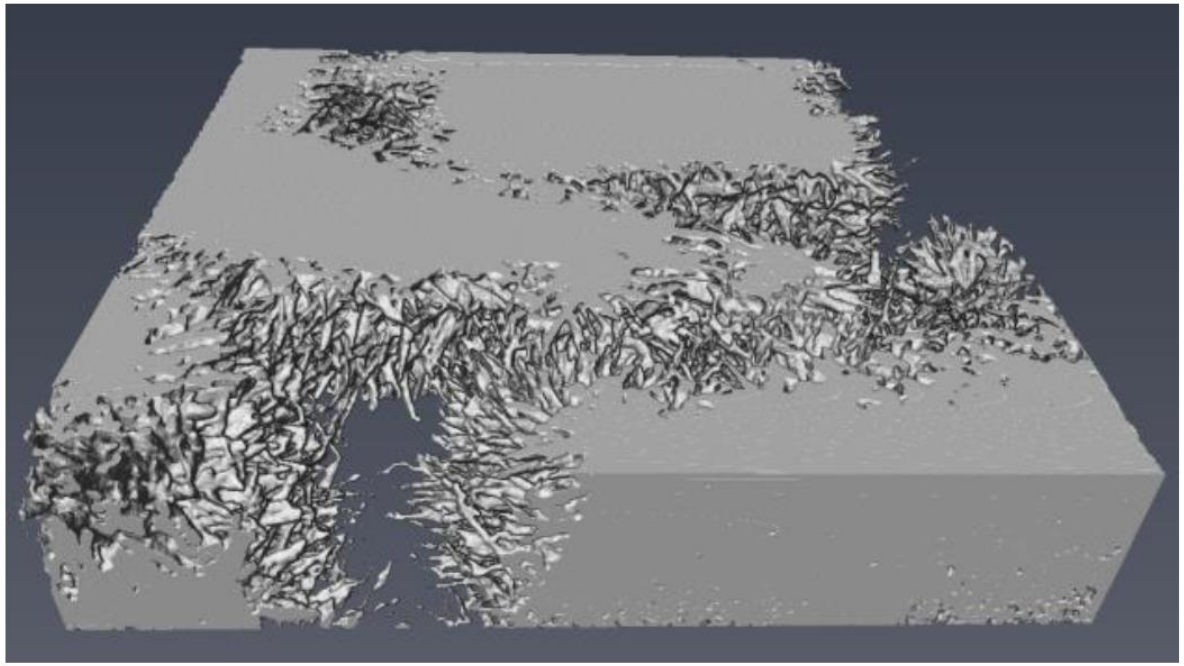
Focused Ion Beam
FIB - SEM

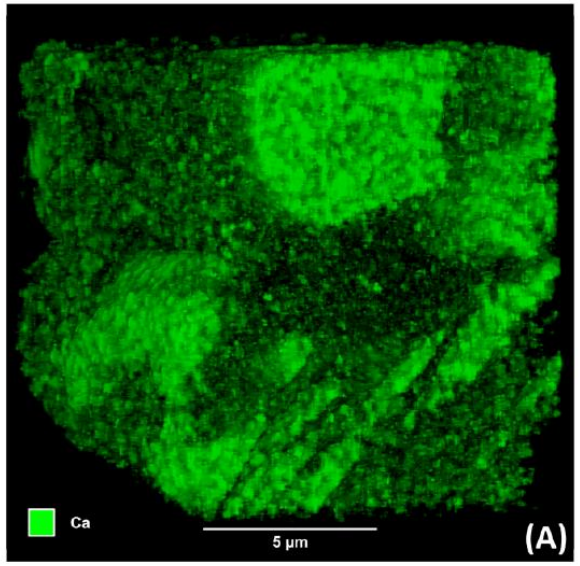


Rößler et al. (2023)

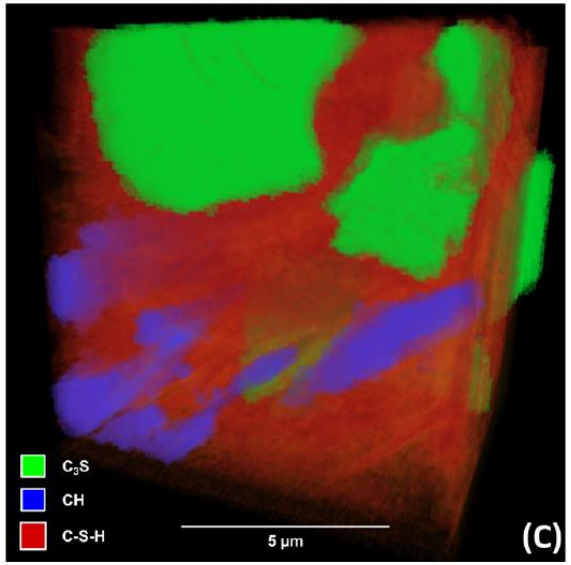
- focused beam of ions is used to cut thin slices (~10nm), SEM investigation of the revealed surface
- allows for reconstruction of the 3D structure

Kleiner et al. (2021a)





Kleiner et al. (2021b)

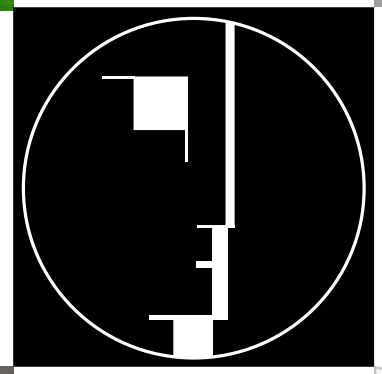


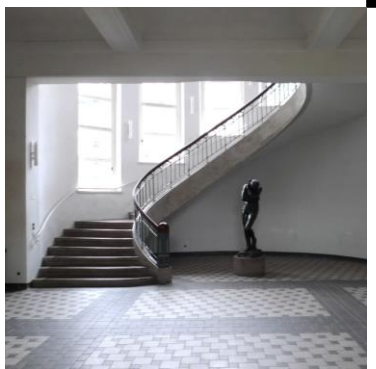
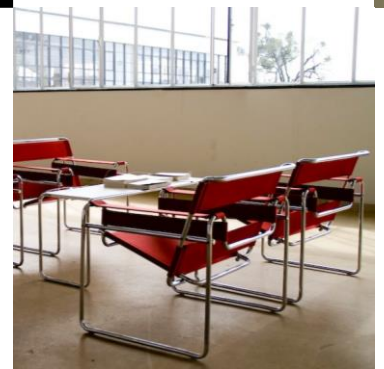
Kleiner et al. (2021b)

Heritage Applications of SEM Portland Cement Analysis

- understanding long-term performance of historic building material:
  - historic cement production
  - C-S-H formation in different environmental conditions
- assessment of current condition:
  - microstructural damage, degradation processes
- restoration: ensure physical, mechanical and chemical compatibility



Wikimedia

Bibliography

Kleiner, F., Decker, M., Rößler, C., Hilbig, H., & Ludwig, H.-M. (2022). Combined LA-ICP-MS and SEM-EDX Analyses for Spatially Resolved Major, Minor and Trace Element Detection in Cement Clinker Phases. Cement and Concrete Research, 159, doi: 10.1016/j.cemconres.2022.106875

Kleiner, F., Decker, M., Rößler, C., Hilbig, H., & Ludwig, H.-M. (2023). LA-ICP-MS and SEM-EDX Analyses for Spatially Resolved Element Detection in Cement Clinker Phases. Proceedings of the 21st ibausil in civil engineering, doi: 10.1002/cepa.2892

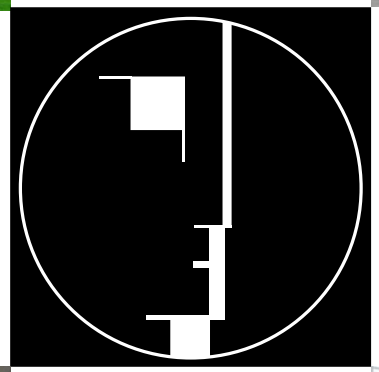
Kleiner, F., Rößler, C., & Ludwig, H.-M. (2021a). Utilizing Modern FIB/SEM Technology and EDS for 3D Imaging of Hydrated Alite and its Pore Space. ERICA-CASH II Final Conference.

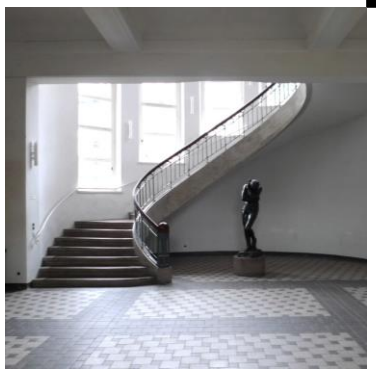
Kleiner, F., Rößler, C., Vogt, F., Osburg, A., & Ludwig, H.-M. (2021b). Reconstruction of Calcium Silicate Hydrates Using Multiple 2D and 3D Imaging Techniques: Light Microscopy, µ-CT, SEM, FIB-nT Combined with EDX. Journal of Microscopy, doi: 10.1111/jmi.13081

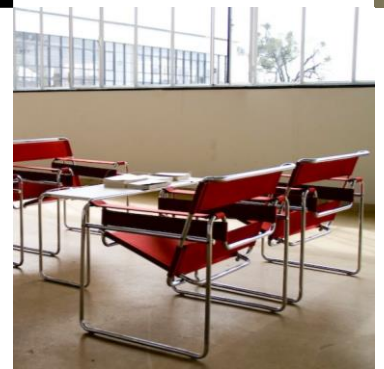
Rößler, C., Kleiner, F., Matthes, C., Hoffmann, C., Dieminger, H., Nguyen-Tuan, L., Kocis, J., Sowoidnich, T., & Ludwig, H.-M. (2023). Characterisation of Cement-Based Materials by 2D and 3D Analytical SEM. Proceedings of the 21st ibausil in civil engineering, doi: 10.1002/cepa.2888

Rößler, C., Zimmer, D., Trimby, P., & Ludwig, H. M. (2022). Chemical–Crystallographic Characterisation of Cement Clinkers by EBSD-EDS Analysis in the SEM. Cement and Concrete Research, 154, 106721, doi: 10.1016/j.cemconres.2022.106721

Thank you!!







[Wikimedia]