

Construction en terre, ressources secondaires et matériaux bio-sourcés : un avenir pour l'Afrique

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Construire ... une question d'actualité

- ▶ 75% de la population mondiale vivra en ville en 2050
- ▶ 50% de la population mondiale dans les pays en développement en développement
- ▶ 60% de la population urbaine vit dans la précarité





Construire ... une question d'actualité

- ▶ Population africaine: 2,4 milliards en 2050 dont 1,34 milliards d'urbains

L'habitat constitue un enjeu majeur pour le développement économique, social, durable et responsable en Afrique (ONU Habitat 2014)

- ▶ 50% des constructions dans le monde sont en terre



Construire ... en terre ... une histoire



<http://www.telegraph.co.uk/travel/news/Iraq-targets-tourists-with-restoration/>



<https://www.pinterest.es/joanbartomeu/shibam-yemen/>

Arche de Ctésiphon
(Irak)

Shibām (Yemen)



<http://www.ufopedia.it/File:Ziggurat-etemenanki-marduk.jpg.html>



<http://www.smithsonianmag.com/travel/endangered-site-chan-chan-peru-51748031/>

Ziggourat
d'Etemenanki
(Babylone)

Cité Chan-Chan
(Pérou)

Construire ... en terre ... une histoire contemporaine



<https://www.phaidon.com/agenda/architecture/articles/2012/october/31/martins-rauchs-mud-house/>



<http://www.maison-terre.com/>

Martin Rauch (Autriche)

Maison en pisé



http://www.customhomeonline.com/houses/award-winning/tucson-mountain-retreat-tucson-ariz_o



<https://www.kinderweltreise.de/kontinente/afrika/burkina-faso/alltag-kinder/schule-in-burkina-faso/>

Rick Joy: Tucson Mountain Retreat (AZ, U.S.A.)

Ecole primaire de Gando, Kéré Architecture



Building with earth

- ▶ Widely available and affordable
- ▶ *Provide healthy indoor environment*
- ▶ *Quality of earth (clay & silt binder) vs required performances*
- ▶ *Earth stabilization yields better & lasting performance*

Building with earth



(<http://craterre.org>)



Building with earth

- ▶ *Widely available and affordable*
- ▶ **Provide healthy indoor environment**
- ▶ *Quality of earth (clay & silt binder) vs techniques and required performances*
- ▶ *Earth stabilization yields better & lasting performance*



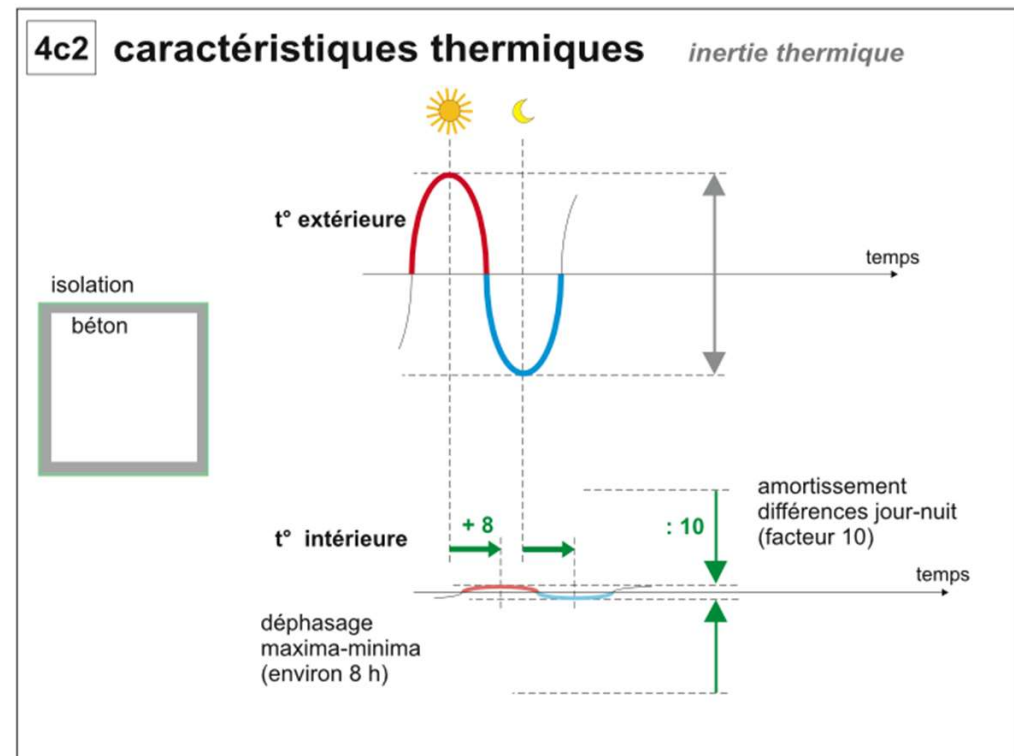
Building with earth

► Healthy indoor environment

✂ Thermal insulation

✂ Thermal inertia

✂ Moisty regulation

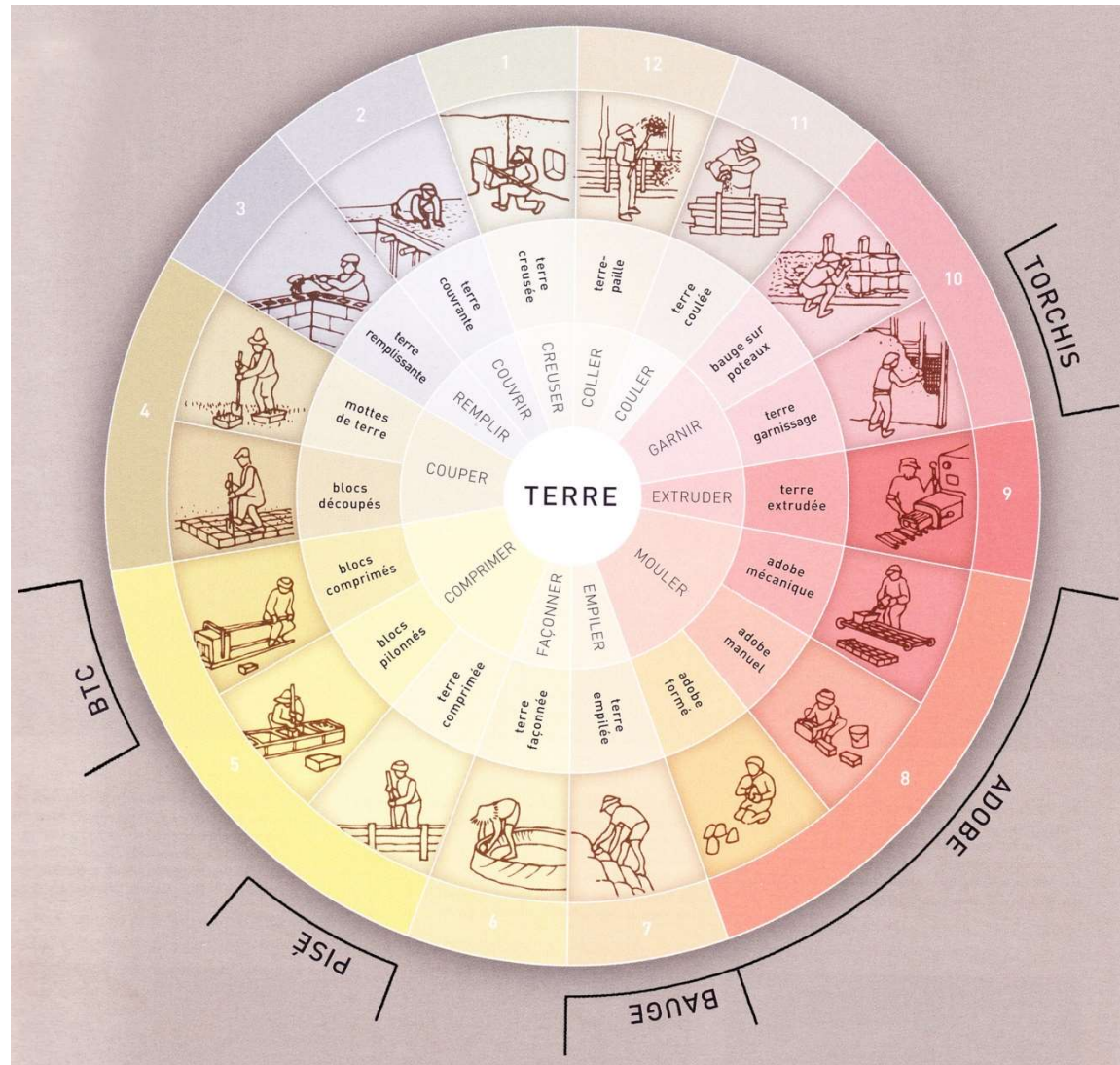




Building with earth

- ▶ *Widely available and affordable*
- ▶ *Provide healthy indoor environment*
- ▶ **Quality of earth (clay & silt binder) vs techniques and required performances**
- ▶ *Earth stabilization yields better & lasting performance*

Building with earth: techniques



(Anger & Fontaine, 2009)



Building with earth

- ▶ *Widely available and affordable*
- ▶ *Provide healthy indoor environment*
- ▶ *Quality of earth (clay & silt binder) vs required performances*
- ▶ **Earth stabilization yields better & lasting performance**

Building with earth



Traditional adobe bricks (1 MPa)



Compressed Earth Blocks (2 MPa)

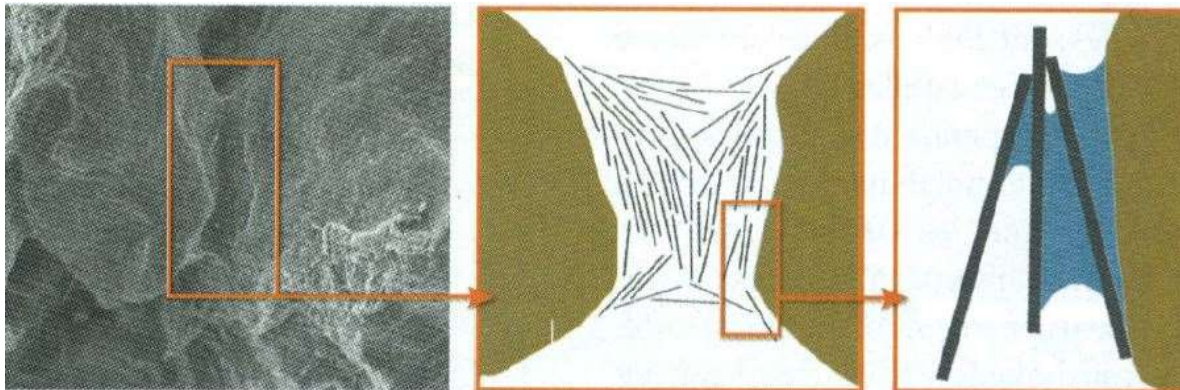


(Zougrana, 2017; Hema, 2016, Millogo et al. 2014; Houben and Guillaud, 2006; Bogas et al. 2018)

Building with earth



Clay particles under ESEM



Capillary bridges between clay sheets

(Van Damme, 2013)



Building with earth

► Earth: < 5 mm (Ouagadougou, Burkina faso)

Mineral (%)	Kaolinite (75)	Quartz (60)
Fine: <80 μm (%)	67	83
PI (LL)	15 (50)	20 (35)
OMC (%) [Kg/m³]	17.4 [1760]	15.6 [1850]
Specific density	2.75	2.66





Building with earth: stabilization

- ▶ Calcium Carbide Residue: by-product from acetylene production (<math><125\mu\text{m}</math>)



- ▶ Contains up to 90 % lime Ca(OH)_2

✂ Fines <math>< 80 \mu\text{m}</math>: 85%

✂ Density: 2,49

- ▶ Used for soil stabilization





Building with earth: stabilization

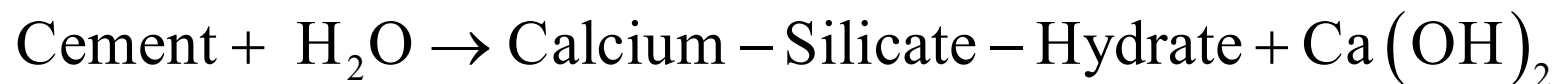
- ▶ Rice Husk Ash : formed by controlled incineration of agricultural by-product (100kg paddy rice = 4 kg ashes)
- ▶ Contains up to 90 % mainly amorphous silica (SiO_2)
- ▶ Offers pozzolanic reaction in cement applications



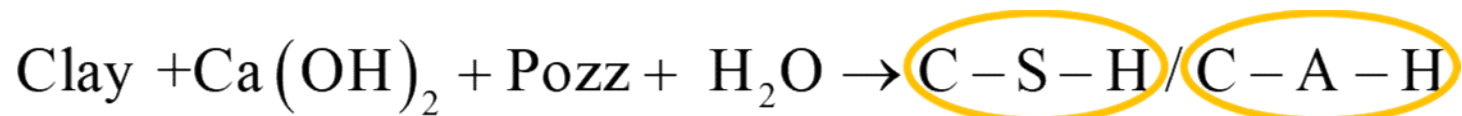


Building with earth: stabilization

- ▶ Hydration reaction occurs when cement is added to sandy earth and cured in ~ 28 days



- ▶ Pozzolanic reaction: when lime $\text{Ca}(\text{OH})_2$ or lime + pozzolan is added to clayey earth



(Houben and Guillaud, 2006; Al-Mukhtar et al. 2010a, 2010b, 2014)

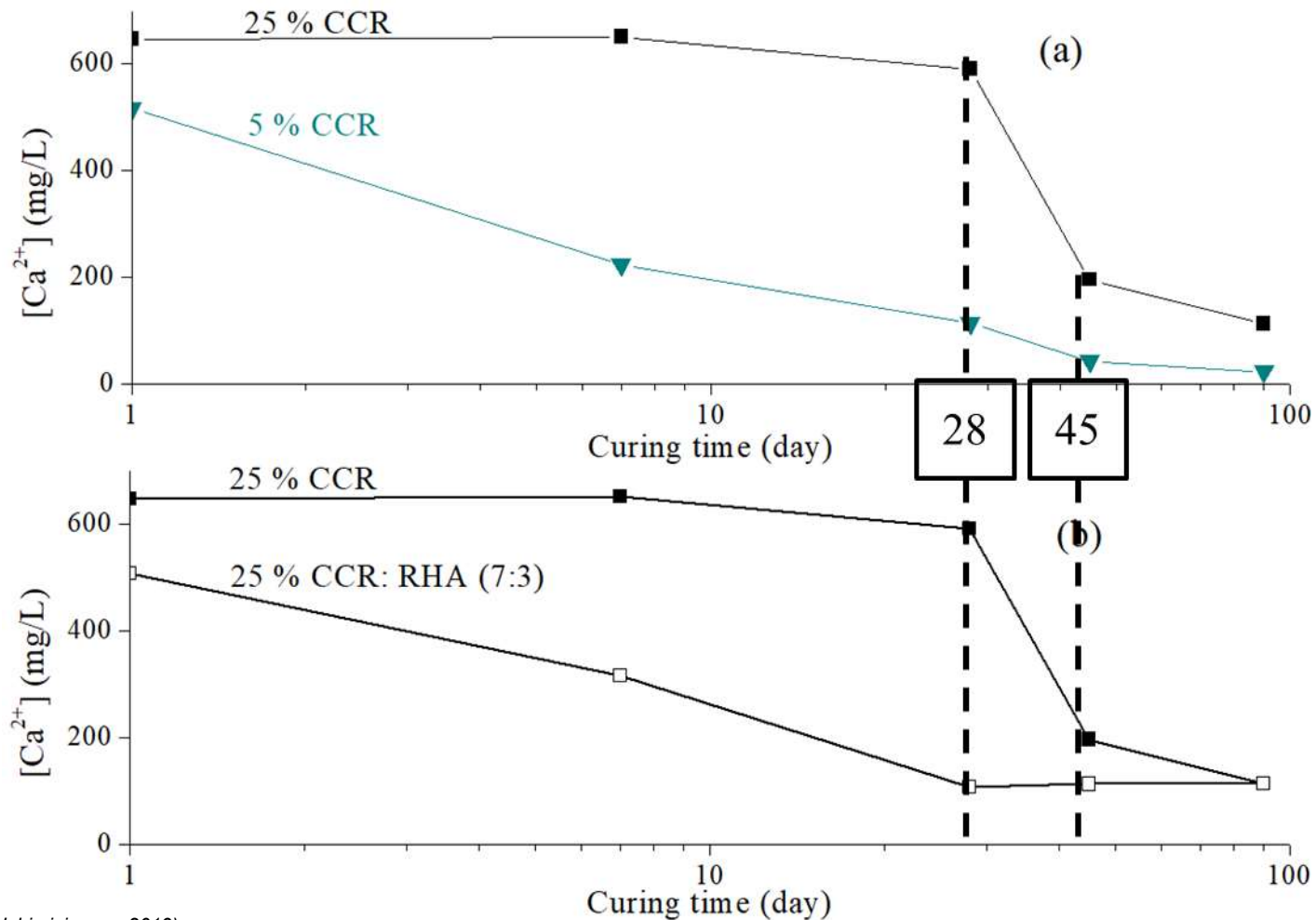
Building with earth: stabilization



Building with earth: stabilization



- Evolution of calcium concentration $[Ca^{2+}]$ in mix solutions

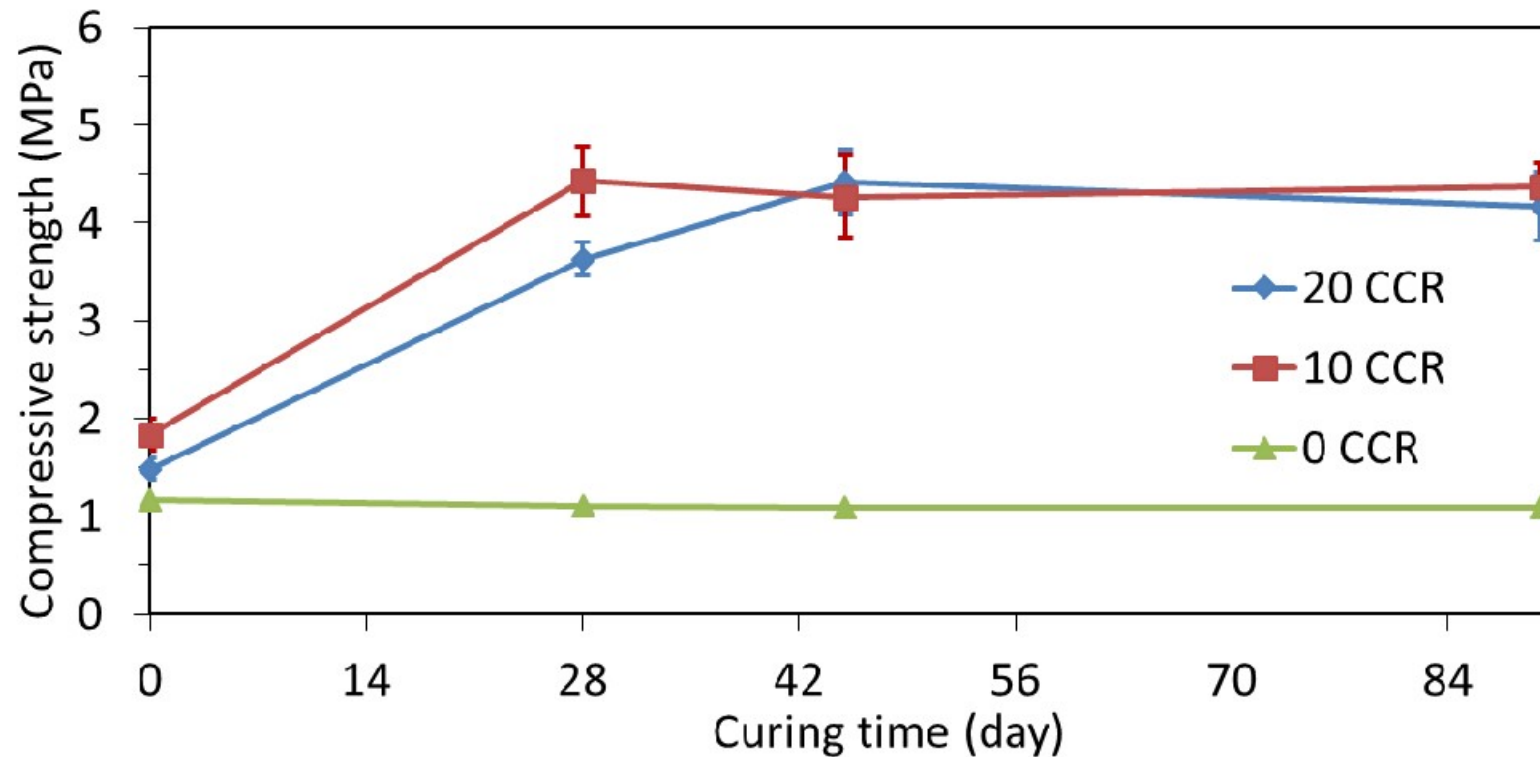


(Nshimiyimana, 2019)

Building with earth: stabilization



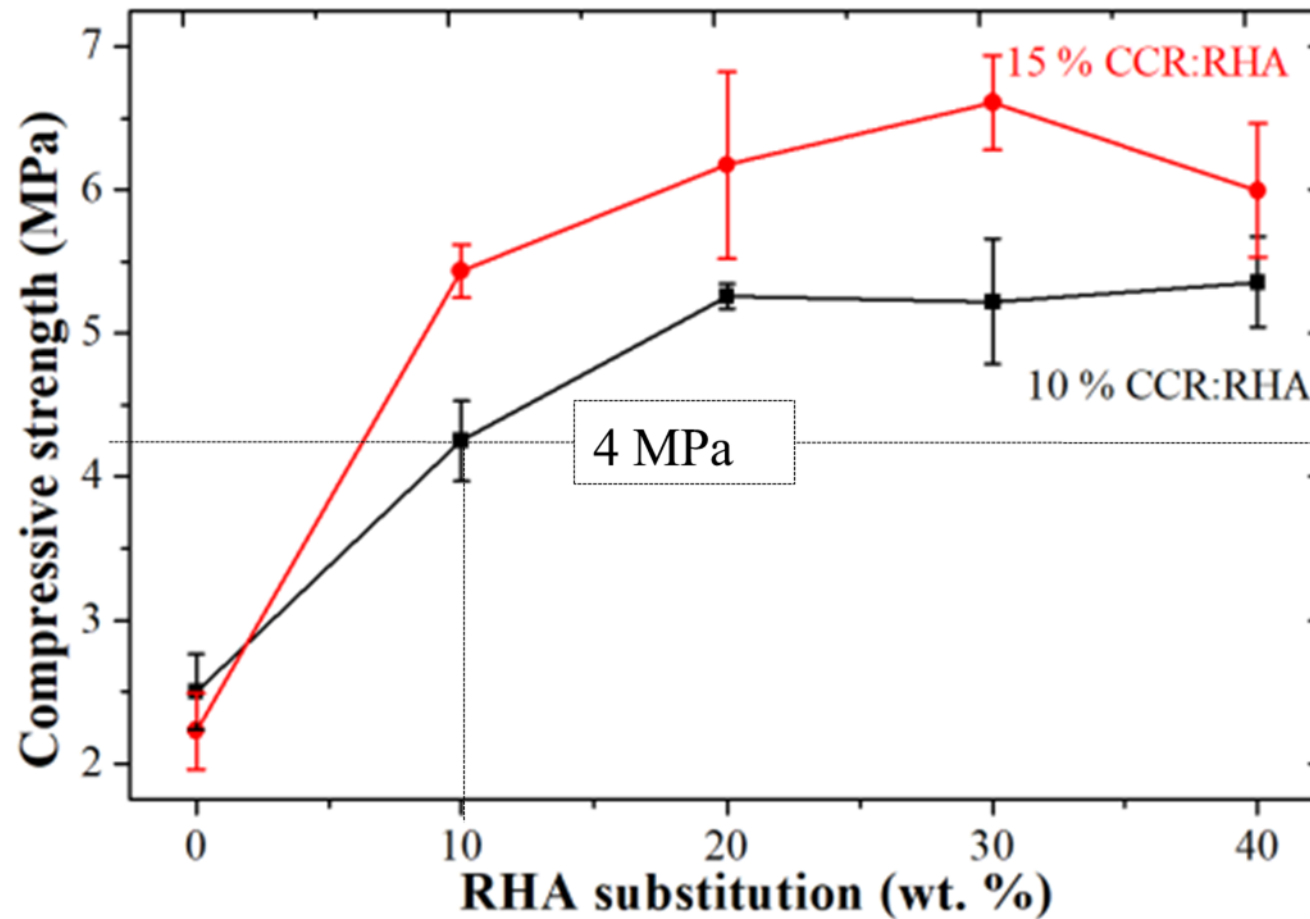
► Curing time (30±5°C)



Building with earth: stabilization



► Mechanical properties (28 days)



(Nshimiyimana et al., 2019)

4 MPa are required for wall construction of two storey housing

Building with earth: stabilization



Unstabilized CEBs (0 % CCR)



Stabilized CEBs (10 % CCR)



K-rich



Q-rich

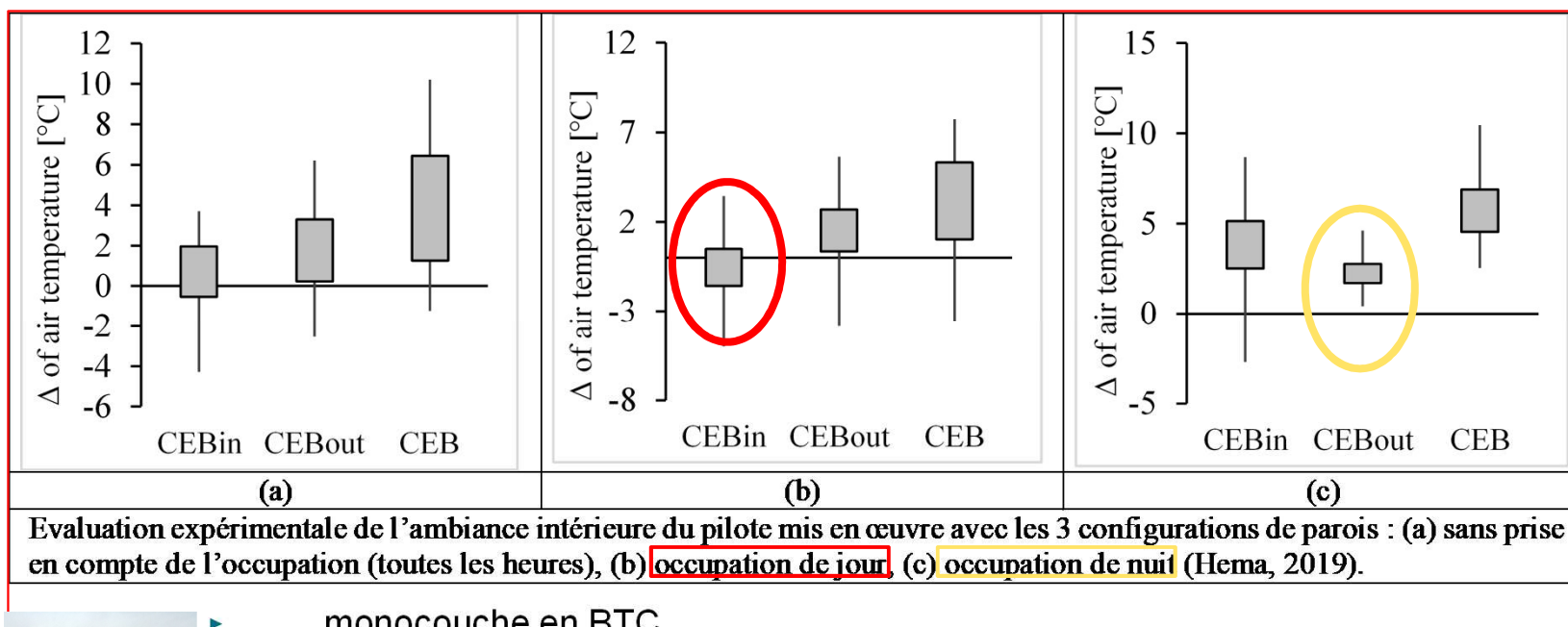


(Nshimiyimana et al., 2019)



Construire avec la terre

- Confort thermique ($\Delta T < 0$: intérieur plus frais)



- monocouche en BTC
- isolant extérieur + BTC intérieur (CEBin)
- BTC extérieur + isolant intérieur (CEBout)

Construire avec la terre



- ▶ Simulation d'un bâtiment sans climatisation : 400 heures de moins d'inconfort hygrothermique (vs murs en blocs de béton).
- ▶ Si climatiseur pour garder l'ambiance dans les deux bâtiments à 28 °C sur l'année: le bâtiment BTC permet d'économiser environ 310 000 FCFA (535 USD)



UNE ECOLE POUR WEMTENGA

PETIT VILLAGE DU BURKINA FASO



ARES

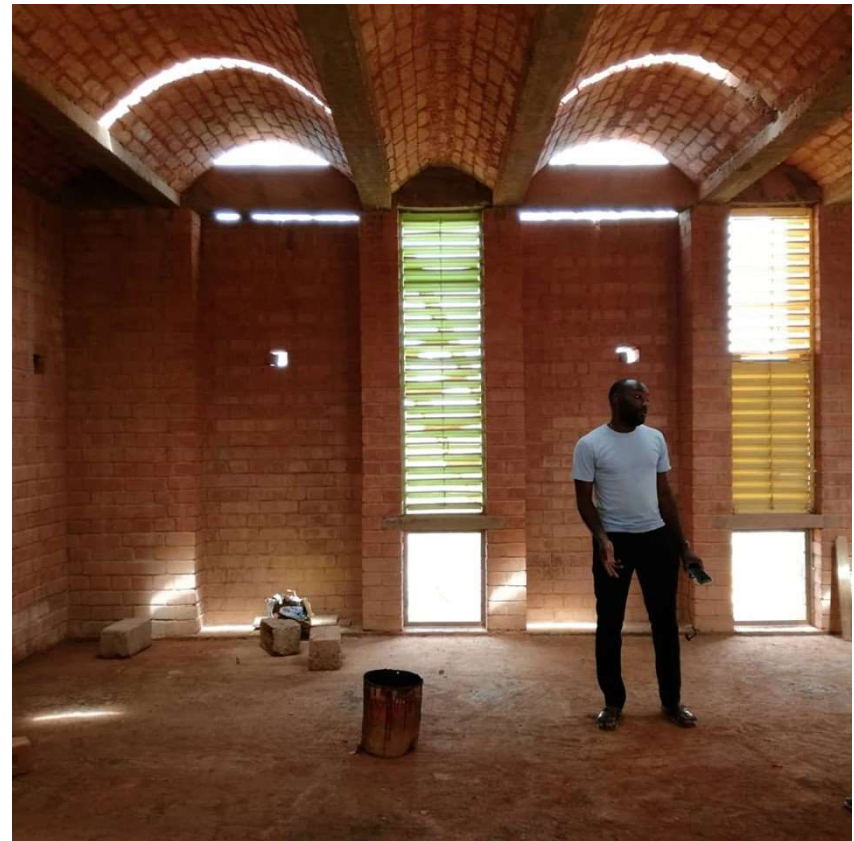
ACADEMIE
DE RECHERCHE ET
D'ENSEIGNEMENT
SUPERIEUR



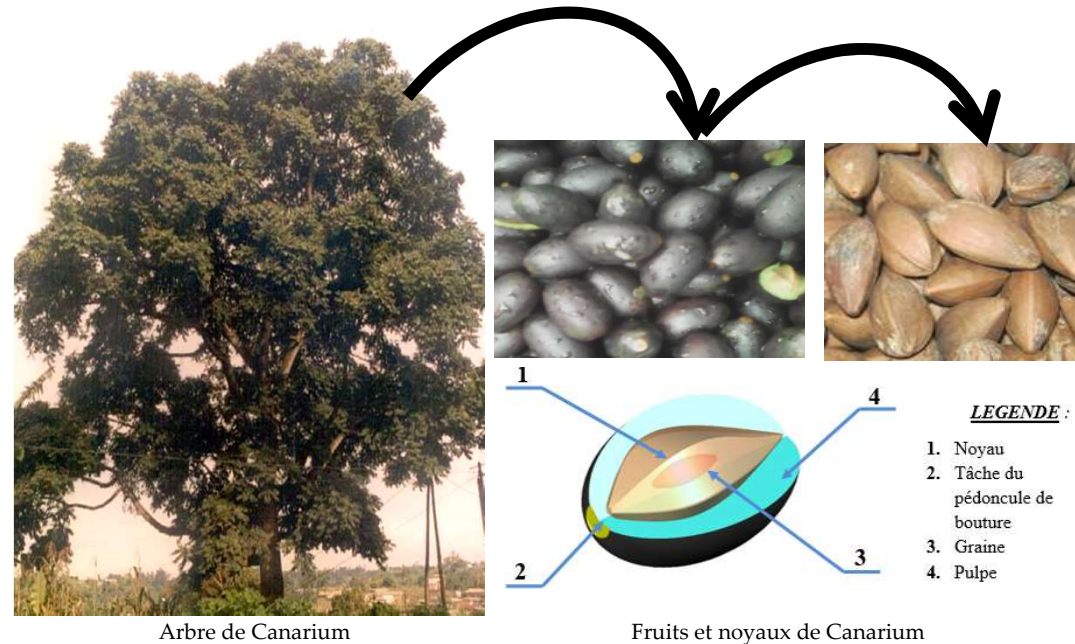
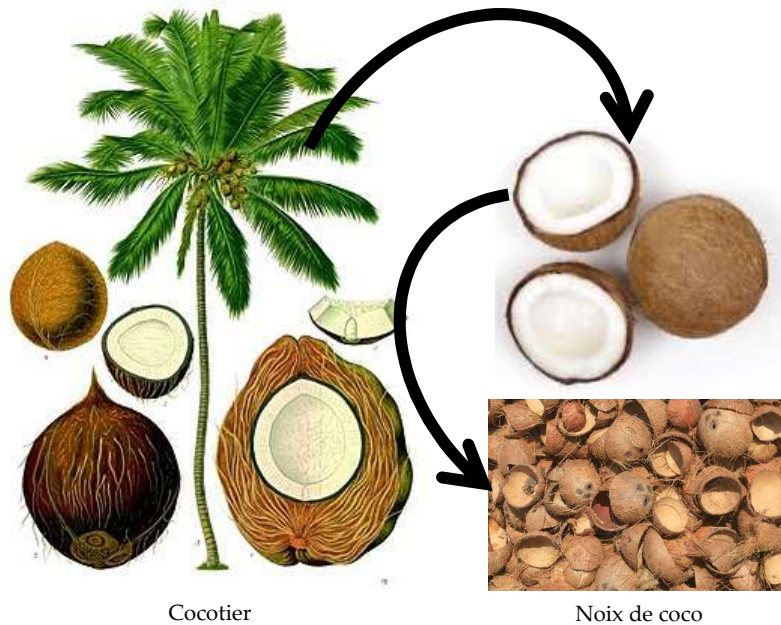
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<https://www.facebook.com/wemtenga.school/>





Construire avec la terre et des produits bio-sourcés



(Ganou et al., 2019)

*Abondance des déchets de Canaryum et Coco
(2.000 tonnes/an au Cameroun – 4.000 tonnes
dans 10 ans)*



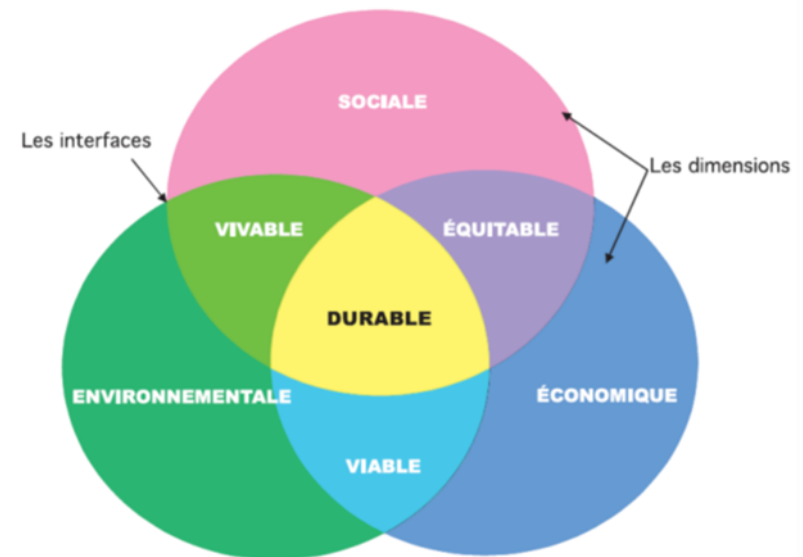
Construire avec la terre et des produits bio-sourcés ou recyclés

- ▶ Bambou de raffia (Cameroun)
- ▶ Fibres de bananiers (Cameroun)
- ▶ Déchets de demolition (Madagascar)
- ▶ Pouzzolanes naturelles (Cameroun)
- ▶ Nattes africaines (Burkina Faso)
- ▶



Construire avec la terre et des produits bio-sourcés ou recyclés

- ▶ Une solution technique efficace
- ▶ Un confort thermique assuré
- ▶ Un habitat durable
- ▶ Une solution équitable



Remerciements



- ▶ ARES CCD, ULiège
- ▶ Ph. Nshimiyimana, C. Hema, O. Zoungrana, B. M. Ganou, A. Messan, G. Van Moeseke (UCLouvain), G. Pirotte
- ▶ 39 stagiaires SeRaMa Valorisation des ressources secondaires dans la construction durable



Références



- ▶ Chemico-microstructural changes in earthen building materials containing calcium carbide residue and rice husk ash A. Messan, Ph. Nshimiyimana, Z. Zhao, L. Bello, L. Courard. Construction and Building Materials 216 (2019), 622-631 (<http://hdl.handle.net/2268/235456>).
- ▶ Effects of production and curing conditions on performances of stabilized compressed earth blocks: Kaolinite vs quartz-rich materials. Ph.Nshimiyimana, S.H. Moussa, A. Messan, L. Courard. 10th International conference of the African materials research society (AMRS2019) Arusha (Tanzania) (<http://hdl.handle.net/2268/242442>)
- ▶ Influence des sous-produits agro-industriels sur la résistance mécanique de brique en terre comprimée Ph. Nshimiyimana, A. Messan, L. Courard, Z. Zhao, L. Bello, N. Fagel, D. Westhondo. NoMaD 2018. Nouveaux Matériaux et Durabilité, Liège, 7-8 novembre 2018, 10p. (<https://popups.uliege.be/NoMaD2018>)
- ▶ Compressive strength of compressed earth blocks stabilized with calcium carbide residue and rice husk ash. Ph. Nshimiyimana, D. Miraucourt, A. Messan, L. Courard. African materials research society, 9th international conference (AMRS2017), Gaborone (Botswana), 11-14 Dec 2017 (<http://hdl.handle.net/2268/227020>)

Construire avec l'argile



Fabrication de briques d'adobe – Ouagadougou, Burkina Faso (S. Brouyère, 2019)