ESBG 2015

EUROPEAN STRAWBALE GATHERING MONTARGIS | PARIS

Earth plaster for durable straw-bale walls; a PhD research on natural stabilizers

by Matthieu Pedergnana

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Earth plaster for durable straw-bale walls

Outline

- **Introduction**
  - Earthen construction in Turkey
  - Advantages/disadvantages of earthen plasters
  - Specific properties of plasters for straw-bale construction
  - State of the research
- **Research on natural stabilizers**
  - Objectives of the research
  - Materials for plasters
  - Research design
- **First results**
- **Conclusion and further objectives**

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Introduction

Earth plaster and construction in Turkey

Long history of earthen (mud brick) construction

Mud-brick house in Çatal Höyük (6 000 BC) (Museum of Anatolian civilization - http://wha.com.tr/en/world_heritages_of_turkey_10.php#)

Reconstruction of the gate of Hattuşas with traditional techniques (2002-2005) (http://www.hattuscha.de/English/citywall.htm)

Introduction

Earth plaster and construction in Turkey

Main technique = Mud brick

Harran – mudbrick houses
(http://wha.com.tr/en/world_heritages_of_turkey_tentative_lists_6.php)

Safranbolu – wooden framed mudbrick houses
(http://wha.com.tr/en/world_heritages_of_turkey_7.php)

Introduction

Earth plaster and construction in Turkey

Traditional plasters

Gypsum plasters (specific additives: lime, clay)

Lime plasters (specific additives : egg white, tragacanth gum, brick powder, clay)

Earth plasters (specific additives: lime, chaff, cow dung)

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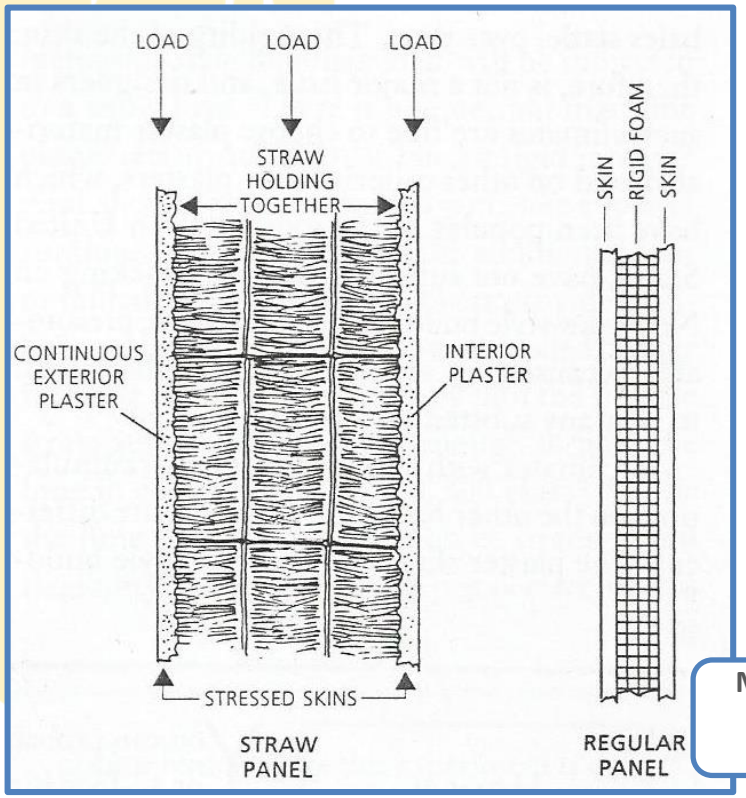
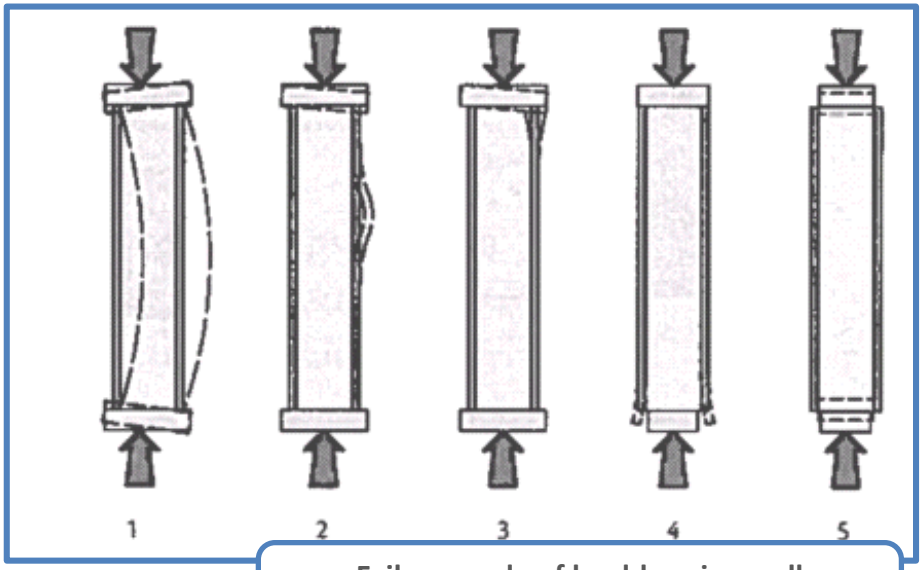
Introduction

Specific functions of plasters on straw-bale walls

Load carrying



Mechanical model of plastered straw-bale load-bearing wall
(Lacinski & Bergeron, 2000, p.117)

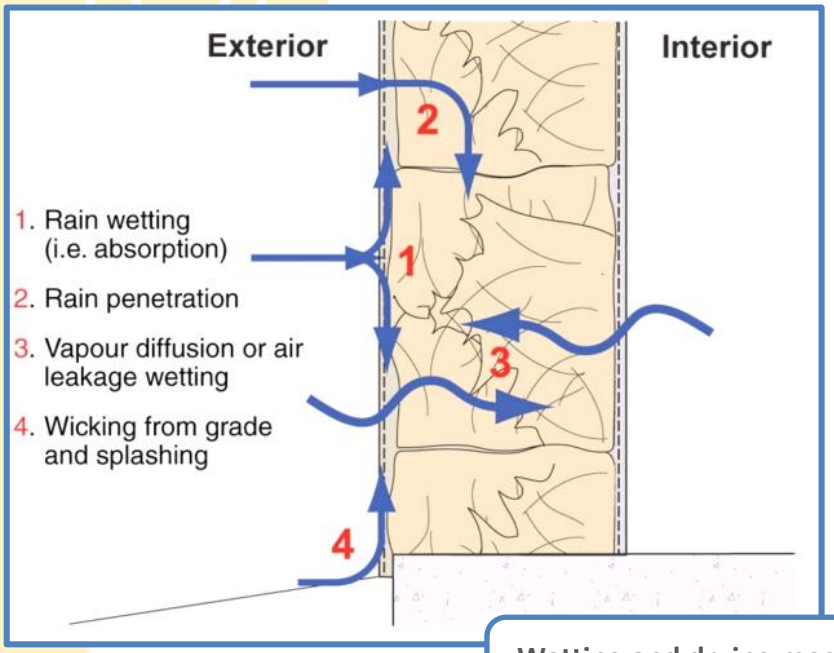


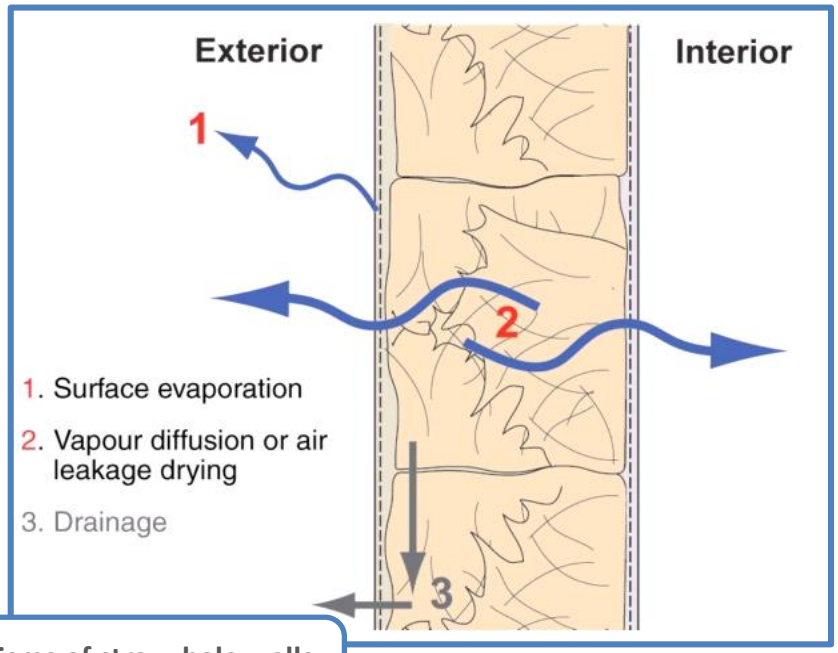
Failure mode of load-bearing wall
(King, 2009, p.69)

Introduction

Specific functions of plasters on straw-bale walls

Bale protection (weather – moisture – animals – fire)





Wetting and drying mechanisms of straw-bale walls
(Straube, 2009, p.8)

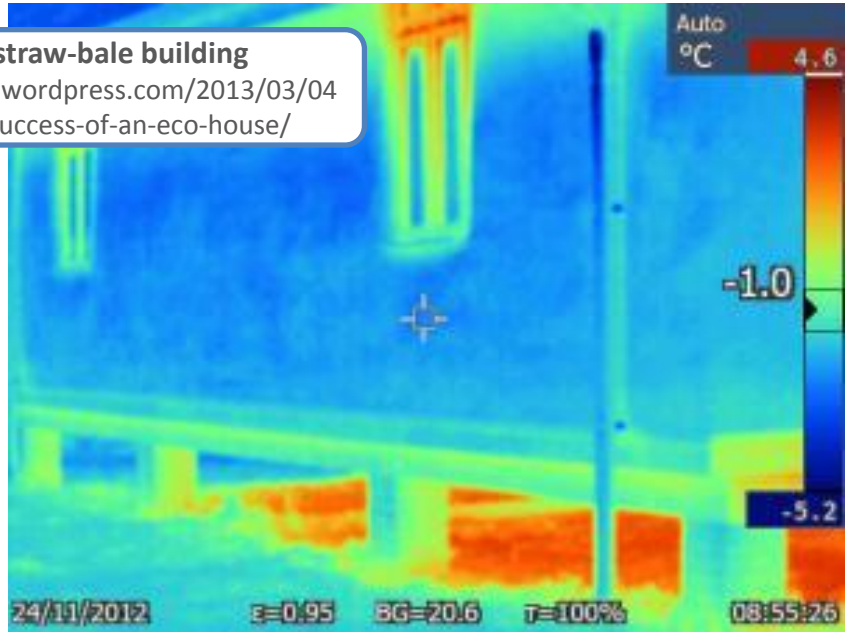
Introduction

Specific functions of plasters on straw-bale walls

Internal comfort

Air tightness details
(http://endeavourcentre.org/2014/10/air-tightness-details-for-straw-bale-walls/)

IR image of straw-bale building
(https://naturalbuild.wordpress.com/2013/03/04/evaluating-the-success-of-an-eco-house/



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Introduction

Specific functions of plasters on straw-bale walls

Aesthetic

3rd Ecological Architecture and Natural Building workshop – Bayramiç, Yeniköy farm (2013)

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Introduction

Advantages / Disadvantages of earth plasters

Advantages	Disadvantages
Low ecological impact material	Low mechanical strength
Large availability of material	Low water/weather resistance
Biodegradable	Need of regular maintenance
High moisture storage capacity and absorption/desorption speed	Social non-acceptance
High thermal capacity and low effusivity	
Aesthetic and workability	

Introduction

State of the research

Naturally stabilized plasters

Improvement of mechanical strength

- **Optimal grain size distribution** *(Monatana, Randazzo and Sabadinni, 2013)*
- **Optimal proportion of fibers (Ashour, Bahnasawey and Wu, 2010)**
- **Additives (Galán-Marín, Rivera-Gómez and Petric, 2010)**

Improvement of water/weather resistance

- **Coating with oil (Minke, 2012)**
- **Additives (dung, eggs, mucilages) (Vargas Neumann, Heredia, Bariola and Mehta, 1987)**

Introduction

State of the research

Main research topics

Chemically stabilized plasters

Weather resistant plasters

(Svoboda and Procházka 2012 – Eires, Camões and Ponte, 2014 – Faria and Santos, 2014)

Introduction

State of the research

Main research topics

Chemically stabilized plasters

Reproduction of historical plasters

(Güdücü, 2003 – Kopelson, 1996 – Oruc and Isik, 2008 – Beas, 1991)

Research on natural additives

Introduction

State of the research

- Main research topics
- Chemically stabilized plasters
- Reproduction of historical plasters
- Research on natural and traditional additives

(Vissac, Fontaine and Anger, 2013 – Beas, 1991)

PhD research on natural stabilizer

Objectives of the research

Impact of different stabilizers on plasters

- Mechanical strength
- Hygric behavior
- Weather resistance
- Durability

Impact of stabilized plasters on walls

- Mechanical strength
- Hygric behavior
- Weather resistance
- Durability

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PhD research on natural stabilizer

Materials for plasters

Earth (3 types)

Stabilizers

- Sand (2 types)
- Fibers (3 types)
- Additives (6 types)

Workmanship

- Setting time
- Application method (layer thickness)
- Drying conditions

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PhD research on natural stabilizer

Materials for plasters

Earth

Metu

Kerkenes A

Kerkenes B

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Materials for plasters

Sand

Non washed calcareous sand

Silica sand (river sand)

Washed calcareous sand

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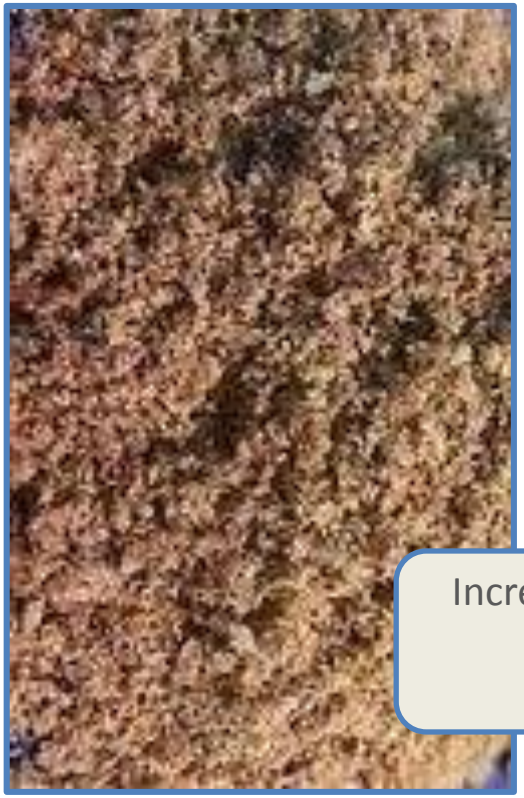
PhD research on natural stabilizer

Materials for plasters

Fibers



Tomatoes + sugar beetroots residues

Increase of compressive strength under dry and wet conditions
(Achenza & Fenu, 2007)

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PhD research on natural stabilizer

Materials for plasters

Fibers

Short straw / chaff

Traditional Middle-East fiber – reduce shrinkage
(Eckart, 1972 – Fodde, 2009 and other)

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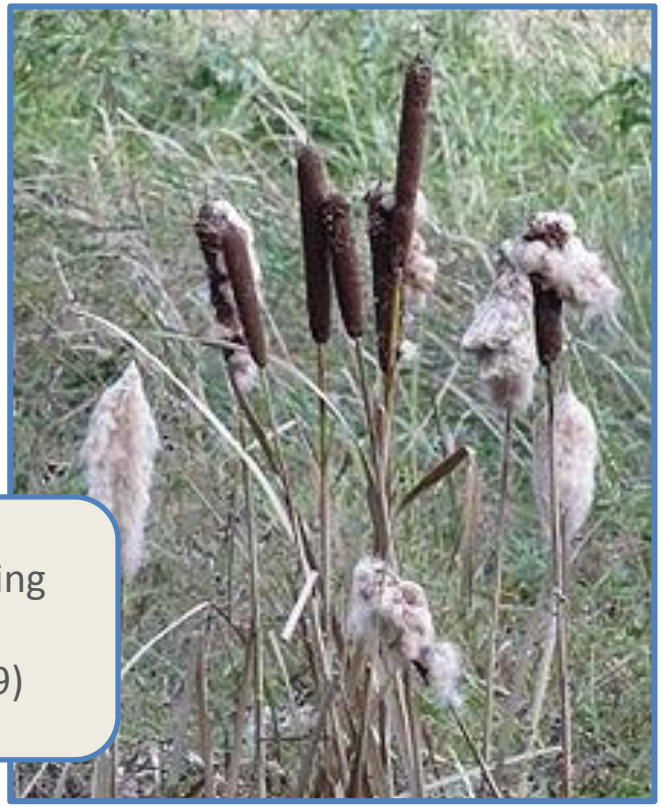
Materials for plasters

Fibers

- Short straw / chaff
- Cattail (reed) fibers



Increase resistance to water and humidity buffering (Georgiev, Theuerkorn, Krus and Kilian 2014 – Maddison, Mauring, Kirsimäe and Mander, 2009)

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PhD research on natural stabilizer

Materials for plasters

Additives

Rotten straw/hay juice

Improve water resistance
(Chris Magwood, 2014 – Tom Rijven, 2009 – traditional Japanese plasters)

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PhD research on natural stabilizer

Materials for plasters

Additives

- Rotten straw/hay juice
- Egg white

Reduction of water capillarity – improve resistance to rain
(Bourges and Colas, 2013)

PhD research on natural stabilizer

Materials for plasters

Additives

- Rotten straw/hay juice
- Egg white
- Oxen blood

Increase compressive strength – reduce water sensitivity
(Kraus, Hirmas and Roberts, 2015)

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PhD research on natural stabilizer

Materials for plasters

Additives

- Molasses
- Rotten straw/hay juice
- Egg white
- Oxen blood

Increase of compressive strength under dry and wet conditions
(Vilane, 2010)

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PhD research on natural stabilizer

Materials for plasters

Additives

- Molasses
- Donkey dung
- Rotten straw/hay juice
- Egg white
- Oxen blood

Traditional additives in Middle-East country – improve water resistance (Minke, 2012 + Hassan Fathy)

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PhD research on natural stabilizer

Materials for plasters

Additives

- Molasses
- Donkey dung
- Cow dung
- Rotten straw/hay juice
- Egg white
- Oxen blood

Traditional additives in Africa and Middle-East – increase hardness and reduce shrinkage
(Vissac, et al, 2013 – Minke, 2012)

PhD research on natural stabilizer

Research design and Experimental set-ups

Survey of local resources and techniques

Identification of raw materials

Properties of local straw-bales

Impact of stabilizers on earth plasters

Impact of plasters on the durability of straw-bale walls

Impact of plasters on the mechanical strength of straw-bale walls

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PhD research on natural stabilizer

Properties of straw-bales

Straw-bale type

- Type of cereal + production
- Size – Density - Humidity
- Fiber length
- Moisture sorption curves

Mechanical properties of bales

- Initial settling and creep
- Compressive strength

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PhD research on natural stabilizer

Preliminary research on earth plasters

- **Mechanical strength**
  - Flexural strength
  - Dry compressive strength
  - Binding (shear) strength
  - Humid compressive strength
- **Hygric behavior**
  - Humidity absorption rate
- **Durability**
  - Surface water capillarity
  - Shrinkage
  - Water resistance

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PhD research on natural stabilizer

Properties of selected earth plasters

Mechanical strength

- Flexural strength
- Dry compressive strength
- Binding (shear) strength
- Humid compressive strength

Hygric and hydric behavior

- Humidity absorption rate
- Humidity absorption capacity
- Sorption isotherms
- Water capillarity absorption
- Drying behavior

Durability

- Erosion rate
- Shrinkage
- Water resistance
- Humidity expansion

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PhD research on natural stabilizer

Impact of plasters on straw-bale walls

Mechanical resistance of plastered walls

- Vertical loading

Hygro-thermal behavior of plastered walls

- Moiture diffusion
- Heat diffusion

Durability of plastered walls

- Erosion rate
- Moisture level
- Surface appearance

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First results – mechanical strength

Production of plasters

First results – mechanical strength

Testing of plasters

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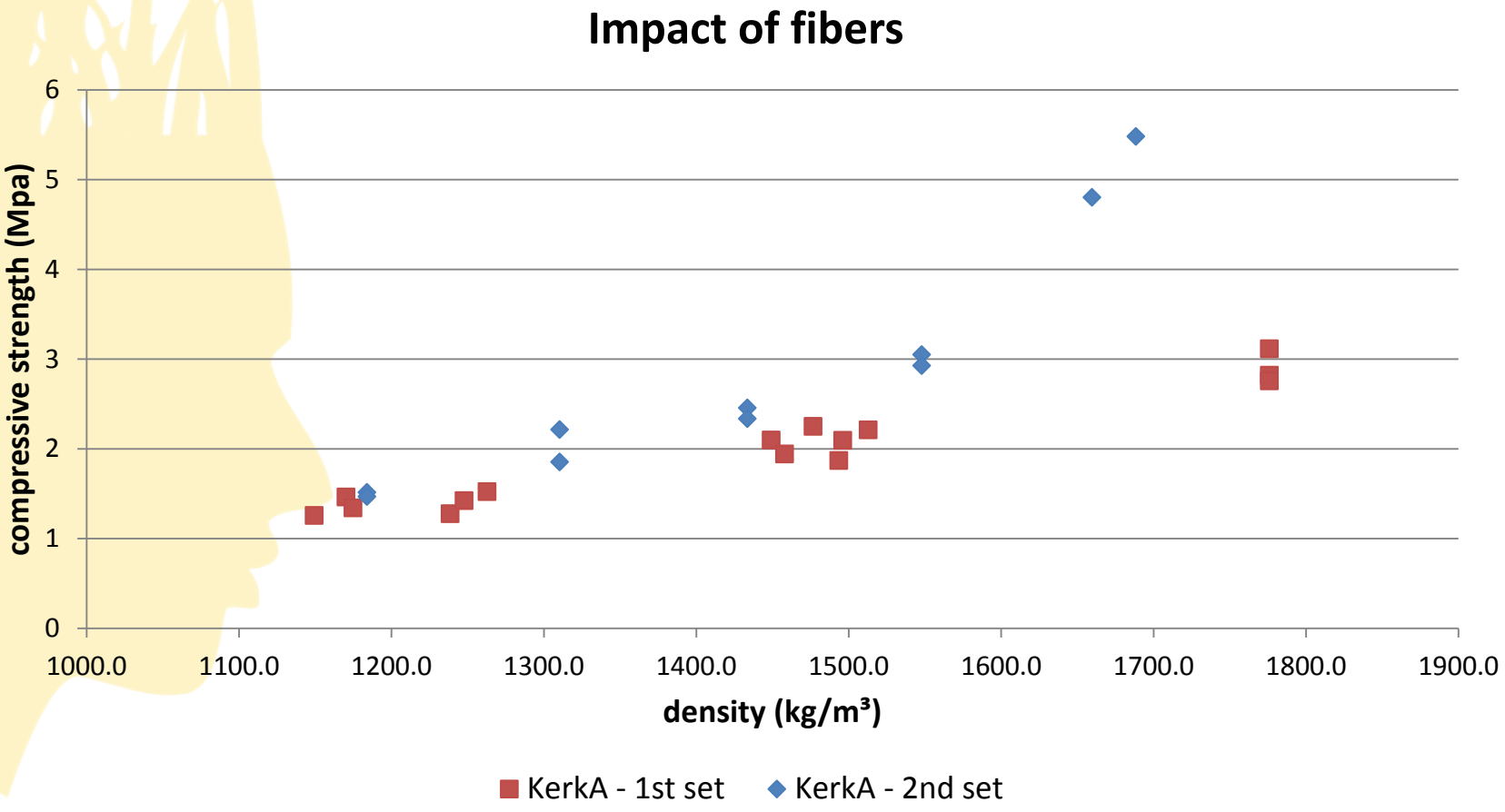
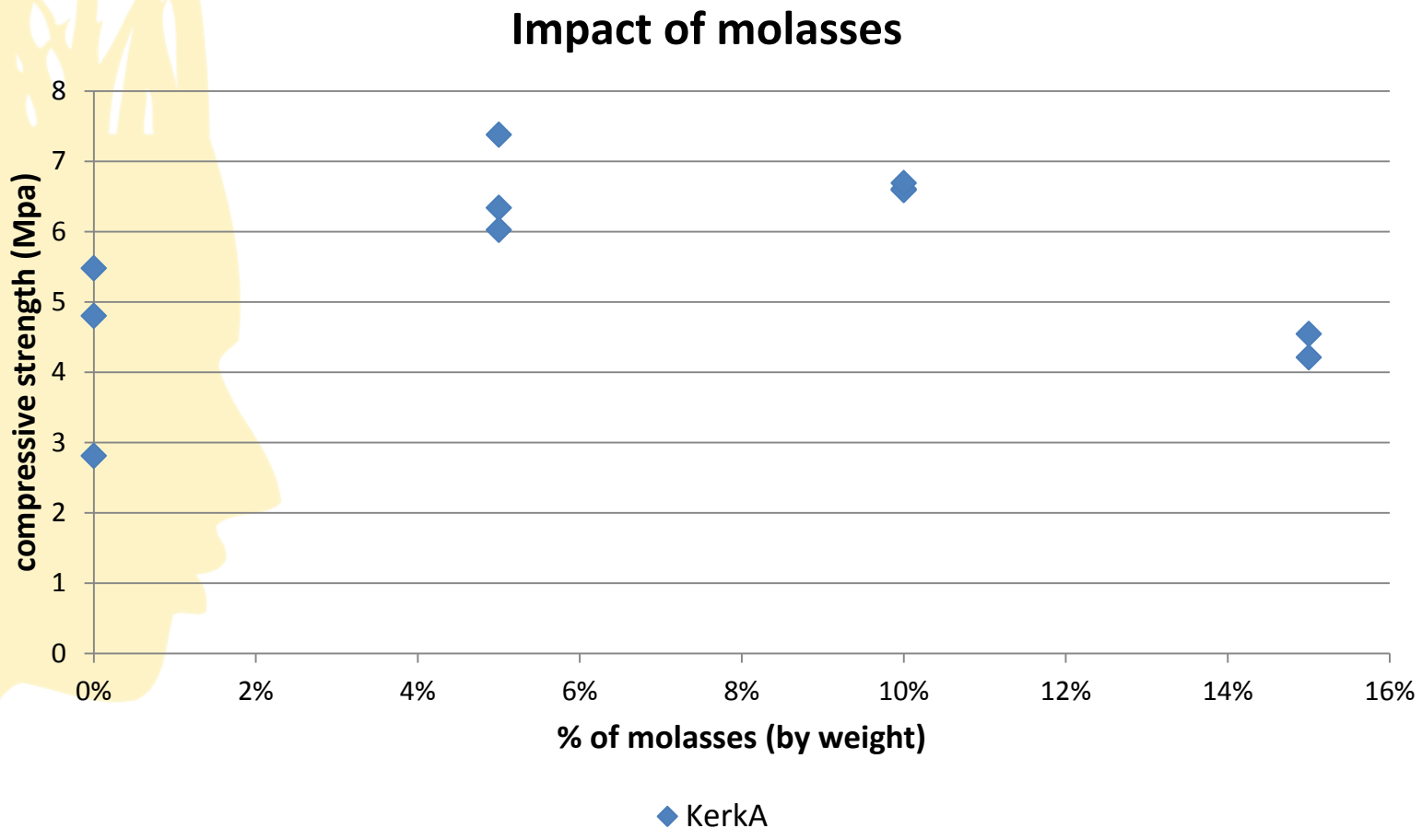
First results – mechanical strength

Impact of fibers content / density



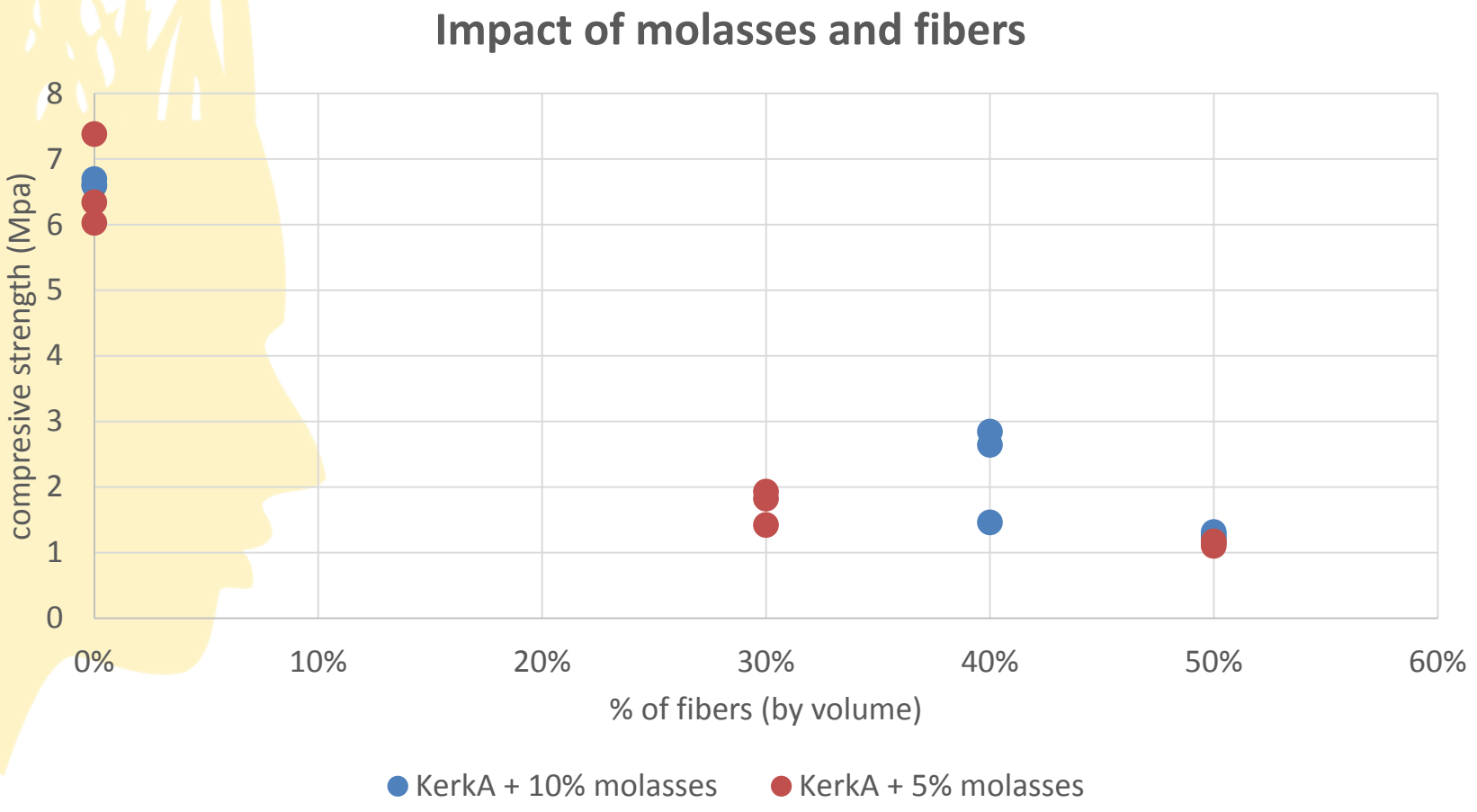
First results – mechanical strength

Impact of molasses



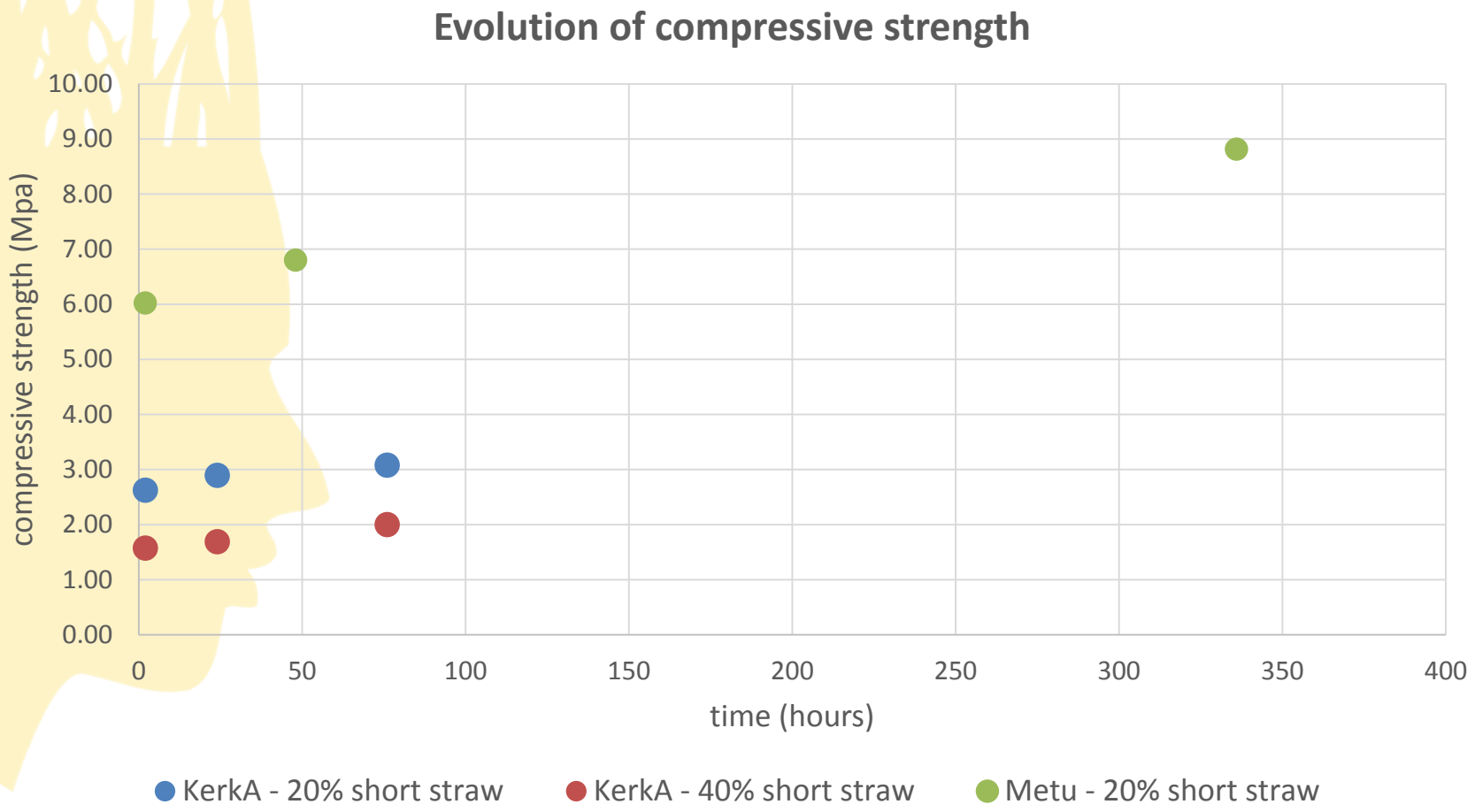
First results – mechanical strength

Impact of molasses



First results – mechanical strength

Impact of setting time



Conclusion and further objectives

Straw-bale construction in Turkey

Develop rules of thumbs and good practices for earthen plasters

Develop low maintenance natural plasters

Develop trust through tested examples and practices

Increase the number of straw-bale buildings in Turkey

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Conclusion and further objectives

Partnership for further research

Partnership with other universities to assess the suitability of straw-bale in every climate

Development of building rules and good practices for seismic areas

2016 – Ankara – Organization of an international builder and researcher workshop on Natural Building Materials

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Conclusion and further objectives

Acknowledgment

The Kerkenes Eco-center for using its facilities for the in-situ research

http://www.kerkenes.metu.edu.tr/keco/index.html
https://www.facebook.com/KerkenesEcoCenter

Middle-East Technical University for its small research grants

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Thank you – Merci a tous

http://riccardodepaoli.com/enduits-decoratifs/larbre-genealogique/

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Conclusion and further objectives

Short bibliography on earthen plasters

Books on plasters:

Guelberth Chiras (2003) *The Natural Plaster Book: Earth, Lime and Gypsum Renders for Natural Homes,* New Society Publishers

Henderson (2013*) Earth Render, The art of clay plaster, render an paints*, Python Press

Moréteau (2011) *Enduits de Terre Crue*, Terre Vivante

Weismann and Bryce (2008) *Using Natural Finishes*, Green Books

FFB, Reseau Ecobatir, Federation Scop-BTP, and ENTPE (2012) “Regles Professionelles Pour La Mise En Oeuvre Des Enduits Sur Supports Composes de Terre Crue.” SEBTP

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Conclusion and further objectives

Short bibliography on earthen plasters

Important scientific articles (1):

Anger, Fontaine, Gandreau, Bourges, and Joffroy (2012) "Earthen Surfaces Stabilization with Biopolymers: Traditional Recipes and Literature Review" In *Terra 2012*

Beas (1991) "Traditional Architectural Renders on Earthen Surfaces" MSc. Thesis, University of Pennsylvania, USA

Bourges, Anger, Fontaine and Joffroy (2012) "Monitoring Methods and Tools Adapted to Evaluate Properties of Earthen Surfaces." In *Terra 2012*

Delinière, Aubert, Rojat, and Gasc-Barbier (2014) "Physical, Mineralogical and Mechanical Characterization of Ready-Mixed Clay Plaster" in *Building and Environment,* 80

Faria, Paulina, Santos, and Aubert (2015) "Experimental Characterization of an Earth Eco-Efficient Plastering Mortar" in *Journal of Materials in Civil Engineering*

Faria, Paulina, Santos, and Silva (2014) "Earth-Based Mortars for Masonry Plastering" In *9th International Masonry Conference*, 1–12, Guimares, Portugal

Hamard, Morel, Salgado, Marcom, and Meunier (2013) "A Procedure to Assess the Suitability of Plaster to Protect Vernacular Earthen Architecture" *Journal of Cultural Heritage* 14 (2)

Conclusion and further objectives

Short bibliography on earthen plasters

Important scientific articles (2):

Lawrence, Mike, Andrew Heath and Peter Walker (2009) “The Impact of External Finishes on the Weather Resistance of Straw Bale Walls” In *11th International Conference on Non-Conventional Materials and Technologies, NOCMAT 2009*, 8

Magwood (2014) “How Clay Plaster May Save the World” *The Last Straw*.

Rojat, Myriam, Mesbah and Millon (2014) “Caractérisation Mécanique Des Enduits En Terre Crue Fibrée” *ECOBAT Sciences & Techniques*, 1–15.

Taylor, Vardy and MacDougall (2006) “Compressive Strength Testing of Earthen Plasters for Straw-Bale Wall Application.” in *Advances in Engineering Structures, Mechanics & Construction*, 140.

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Vissac, Fontaine, and Anger (2013) *Projet : PaTerre + Rapport Final*.

Conclusion and further objectives

Short bibliography on earthen plasters

Other cited references:

Achenza and Fenu (2007) "On Earth Stabilization with Natural Polymers for Earth Masonry Construction." *Materials and Structures* 39: 21–27

Ashour, Bahnasawey, and Wu (2010) "Compressive Strength of Fibre Reinforced Earth Plasters for Straw Bale Buildings." *Australian Journal of Agricultural Engineering* 1 (3): 86–92.

Eckart (1972) "Lehmziegekhauser in der Altinova" in *Keban Project 1970 Activities,* METU

Fodde (2009) "Traditional Earthen Building Techniques in Central Asia" in *International Journal of Architectural Heritage: Conservation, Analysis, and Restoration*

Galán-Marín, Rivera-Gómez, and Petric (2010) "Clay-Based Composite Stabilized with Natural Polymer and Fibre." *Construction and Building Materials* 24 (8): 1462–68.

Georgiev, Theuerkorn, Krus and Kilian (2014) "Cattail-reinforced clay plasters in building heritage preservation and new constructions" in *Vernacular Heritage and Earthen Architecture: Contributions for Sustainable Development*

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Petric-Gray, Galán-Marín, Rivera-Gómez, Rodríguez-García, and Osta-Fort (2009) "On Soil Stabilization with Alginate and Wood for Construction Industry." In *11th International Conference on Non-Conventional Materials and Technologies, NOCMAT 2009*, 8. Bath, UK.

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Svoboda and Procházka (2012) "Outdoor Earthen Plasters." *Organization, Technology and Management in Construction* 4 (1): 2–5

Vargas Neumann, Heredia, Bariola and Mehta (1987) "Preservation of Adobe Constructions in Rainy Areas." In *Middle-East and Mediterranean Regional Conference on Earthen and Low-Strength Masonry Buildings in Seismic Areas* 185–92. Ankara: METU.

Vilane (2010) "Assessment of Stabilisation of Adobes by Confined Compression Tests." *Biosystems Engineering* 106 (4): 551–58