XVII[èmes] Journées Nationales Génie Côtier – Génie Civil
Chatou, 2022
DOI:10.5150/jngcgc.2022.078 *© Editions Paralia CFL*
disponible en ligne – http://www.paralia.fr – available online

Possible recycling of dredged sediments in earth bricks - case studies of marine, fluvial and dam sediments

Mazhar HUSSAIN [1,2], Daniel LEVACHER [1,2], Nathalie LEBLANC [2], Hafida ZMAMOU [2], Irini DJERAN-MAIGRE [3], Andry RAZAKAMANANTSOA [4]

1. Normandie Université, Unicaen, UMR 6143 CNRS - M2C, 24 rue des Tilleuls, 14000 Caen, France.
   mazhar.hussain@unicaen.fr ; daniel.levacher@unicaen.fr
2. UniLaSalle, Univ.Artois, EA7519 - Transformations & Agro-ressources, Normandie Université, 76130 Mont Saint Aignan, France.
   mazhar.hussain@unilasalle.fr
3. Université Lyon, INSA Lyon, GEOMAS, 69621 Villeurbanne, France.
4. Université Gustave Eiffel, Département GERS, 44344 Bouguenais, France.

Abstract:
Every year, a large quantity of sediments is dredged from ports, reservoirs and waterways to maintain the efficiency of these structures. On the other hand, sediments disposal and management are becoming costly due to environmental regulations. Therefore, the reuse of sediments is increasing in different applications.
The reuse of dredged sediments in building materials such as earth bricks can provide an eco-friendly alternative to manage and handle these sediments. Earth bricks are manufactured with earth and natural fibers. This research focuses on the characterization of dredged sediments for their reuse in earth bricks. The sediments used in this study are coming from Dunkerque port and a local dam in France, and Usumacinta River, Mexico. Sediments characteristics such as Atterberg limits, granulometry, carbonate content, organic matter and chemical composition were determined and sediments suitability for earth bricks was observed with French and international standards.
Local (hemp shiv) and tropical plant fibers (palm oil fibers) were mixed with sediments to make earth bricks. Impact of sediments granulometry, Atterberg limits and chemical composition on tensile and compressive strength of bricks were analysed. Similarly, tensile and compressive strength variation with fibers addition was also observed. Characteristics of bricks such as density and toughness index and flexion stiffness of bricks were also observed.

Keywords:
Dredged sediments, Sediments characterization, Valorization, Earth bricks, Mechanical characteristics

1. Introduction

Sediments are dredged from rivers, lakes, dams and ports. In France, every year 50 million m^3 of sediments are dredged from seaports (SAFHI, 2020). A large quantity of these sediments is discharged into sea. However, presence of pollutants and environmental regulations discourage this practise. As sediments storage is costly, their reuse is a promising option. Sediments are used in building materials, dikes, embankments and road construction. Sediments reuse in building materials such as bricks, mortar and concrete and cement in Usumacinta basin, Mexico is relatively unexplored. Building sector consumes huge energy and non-renewable raw material resources. Overconsumption of earth resources by building sector put stress on agricultural lands. Rouen and Le Havre region of France consumes 0.85 million m^3 of earth resources in fired bricks annually while 6-7 million m^3 of dredged sediments from this region are submerged (SEDIBRIC, 2018). Dredged sediments reuse in building materials can partially or fully replace non-renewable raw materials. However, presence of pollutants and heterogenous nature of dredged sediments makes their reuse tricky. Therefore, a detailed investigation of sediment characteristics is essential.

Building materials such as cement is responsible for 5% of global industrial energy consumption and a huge chunk of CO_2 emissions (SOUSA *et al.*, 2022). Moreover, concrete-based buildings energy consumption is very high. 44% of energy is consumed by building sector alone in France (MINISTRY OF ECOLOGICAL TRANSITION, 2021). Due to cost and environmental concerns, use of eco-friendly construction materials such as earth bricks have promising future.

This study focuses on sediments reuse in earth bricks which are environment-friendly material due to low CO_2 emissions. Earth bricks are the oldest building material, manufactured with earth and natural fibers. Natural fibers are waste materials coming from the agro-industry such as coconut coir, jute, sugarcane bagasse, palm oil fibers and bamboo etc. Natural fibers act as reinforcement in earth bricks and increase the tensile strength of bricks significantly. However, tensile strength of fibers, length, distribution and orientation has also substantial impact on quality of earth bricks. Sediments and fibers mixture is compacted to increase the strength of bricks and remove the voids. Different compaction techniques such as dynamic compaction, static compaction and vibration tables are used to compact earth bricks. Compaction of bricks is affected by moulding moisture content. Higher moulding moisture in sediments mixture prompts fibers upward movement with dynamic compaction. As compressive and tensile strength of earth bricks is limited. Stabilizing agents such as cement, gypsum and lime are sometimes added to increase the strength and durability of bricks.

Objective of this study is to characterization of sediments dredged from port, river and dam sites and their valorisation in earth bricks. Sediments mineralogical and physico-chemical characteristics were investigated for their reuse in earth bricks with plant aggregates at different percentages to observe the influence of sediments characteristics and fiber dosage on the strength of bricks and optimization of the tensile strength of bricks.

2. Materials and methods

In this study, Usumacinta River sediments (USU) from Mexico, Dunkirk port sediments (DK), France and Garonne River sediments (GAR) from Saint-Vidian reservoir, France were used to manufacture earth bricks. Earth bricks were reinforced with tropical fibers and local plant additives *i.e.* palm oil flower fibers (PFOL) in case of Mexican sediments and hemp shiv with sediments dredged from France.

2.1 Dredged sediments

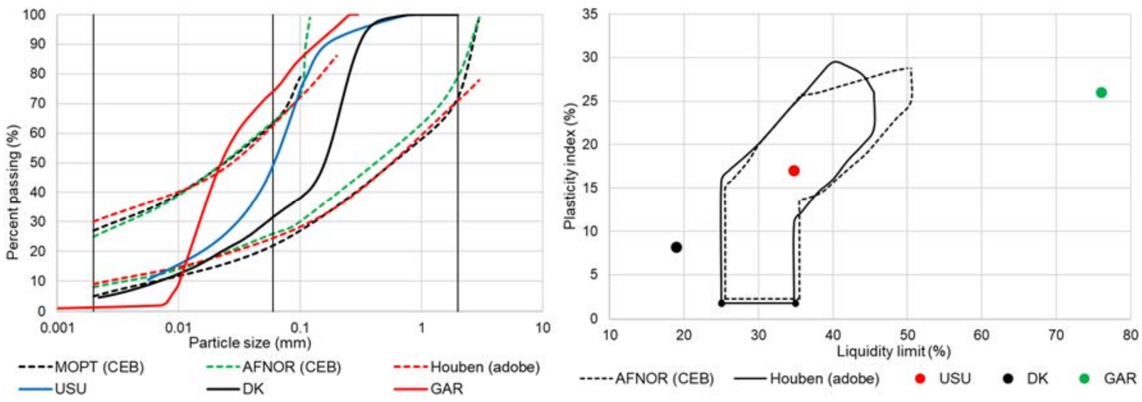
Characteristics of USU, DK and GAR sediments were investigated to observe their suitability for earth bricks and influence of sediments characteristics on strength of bricks. Some important characteristics include granulometry, Atterberg limits, organic matter, and optimum moisture content etc. Characteristics of dredged sediments are summarized in table 1.

Table 1. Characteristics of USU, DK and GAR sediments.

Sediments	Clay (%)	Silt (%)	Sand (%)	LL (%)	PI	OM (%)	ρ_{sed} (g/cm^3)	W_{opt} (%)
USU	5.9	41.3	52.8	37.74	7.83	4.48	2.63	19.3
DK	4.29	24.78	70.92	18.92	8.2	5.29	2.55	20.5
GAR*	3.4	60.6	36	76	26	9.1	2.65	24

**GAR sediments characteristics are investigated by ANGER (2014).*

Table 1 shows that USU sediments have higher clay content than DK and GAR sediments. DK sediments have considerably higher sand percentage. Organic matter of GAR sediments is very high. Liquidity limit of GAR sediments is also very high. Clay, silt, sand percentage and organic matter have a significant influence on consistency limits of sediments. Optimum moisture content of USU and DK sediments is nearly similar. However, GAR sediments have higher optimum moisture content. Sediment's suitability for earth bricks according to their grain size with French (AFNOR XP P13-901, 2001) and Spanish standards (MOPT, 1992) is shown in figure 1a. Figure 1b shows the sediment's suitability for earth bricks with their consistency limits.



Note: CEB = compressed earth blocks.

Figure 1. Sediments suitability for earth bricks with grain size (a) and consistency limits (b).

It can be observed from figure 1a that USU and DK sediments are within the zone recommended for bricks while GAR sediments are initially within the zone, but higher silt content takes the sediments outside the suitable zone. Figure 1b shows the sediment's suitability for earth bricks on the base of consistency limits. USU sediments are within the zone suitable for adobe bricks. However, DK and GAR sediments are outside the zones. This is due to low liquidity limits of DK sediments while GAR sediments have higher liquidity limits due to higher organic matter.

2.2 Plant aggregates

POFL fibers and local hemp shiv were used as additives in earth bricks. Characteristics of fibers such as tensile strength, length, density and water absorption were investigated as they play an important role in strength and durability of earth bricks.

Natural fibers length recommended for composite materials such as concrete is 2.5cm (ASTM D7357-07, 2012). Therefore, extraction of POFL fibers was done with a knife mill by using grid of 3cm while hemp shiv is local agriculture waste produced at an industrial scale in France. Average and maximum length of fibers observed with ImageJ software is shown in table 2. Density of POFL fibers was found with a helium pycnometer. Water absorption of hemp shiv and POFL fibers was found by immersing fibers in water for 24 hours. Tensile strength of POFL fibers was found with tensile strength test. Characteristics of POFL fibers and hemp shiv are summarized in table 2.

Table 2. Characteristics of plant aggregates.

Plant Aggregates	***Average length (mm)***	***Maximum length (mm)***	***Skeletal density (g/cm³)***	***WA (%)***	***σt (MPa)***
Hemp shiv	*11.67*	*50.46*	*1.44-1.52**	*298*	*960 +/-220 ***
POFL	*11.54*	*32.96*	*1.37*	*235*	*29.27-334.60*

*Note: WA = water absorption, σt = tensile strength, * JIANG et al., (2018); ** THYGESEN et al., (2008).*

Average length of hemp shiv and POFL fibers is similar. However, hemp shiv is usually very thick. Density of both plant aggregates is similar. Both aggregates have higher water absorption and tensile strength of hemp shiv is considerably higher. There is significant variation in tensile strength of plant aggregates due to variation in number of elementary fibers and fibers alignment in a fiber bundle tested for tensile strength.

2.3 Earth bricks manufacturing

Earth bricks were manufactured from dredged sediments with the addition of vegetable aggregates. Bricks were manufactured by performing different steps such as material preparation, moulding, compaction and drying. USU, DK and GAR sediments were dried in oven at 60 °C to remove the moisture and passed through 2mm sieve to use for adobe bricks. Sediments were mixed with plant aggregates (POFL fibers and hemp shiv) with addition of moulding moisture content through a mixer to prepare a homogenous solution. Optimum moisture content of sediments was taken as moulding moisture content. Sediments mixture was prepared with 0%, 1%, 2%, 3%, 4% and 5% fibers addition by mass which is common fibers content used in earth bricks (AZHARY *et al*., 2017; ISMAIL *et al*., 2011). Sediment mixture was moulded into prismatic specimens of size 4*4*16 cm^3 and compacted with dynamic compaction energy of 600 $kN.m/m^3$ and finally dried in the oven at 40 °C. Adobe bricks manufacturing is shown in figure 2.

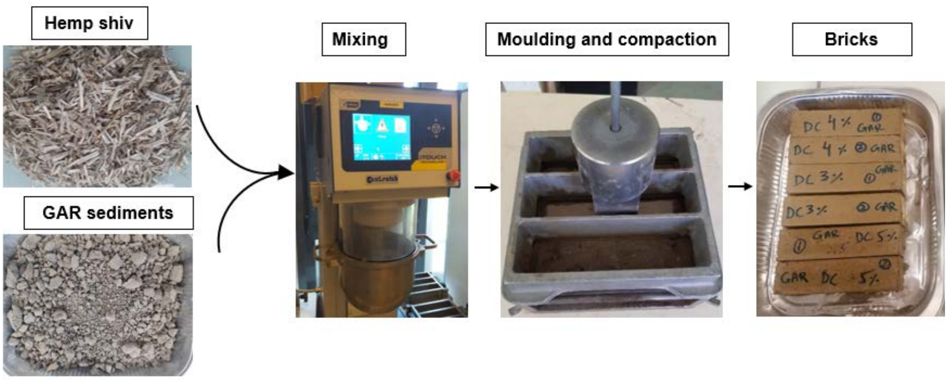


Figure 2. Earth bricks manufacturing process.

Density of dried bricks samples was determined by mass and volume of bricks. Density of bricks is influenced by fiber content and organic matter. Density of USU, DK, and GAR sediments is shown in table 3.

Table 3. Density variation of earth bricks.

Dry Density (kg/m³)	***DC 0%***	***DC 1%***	***DC 2%***	***DC 3%***	***DC 4%***	***DC 5%***
USU	*1521*	*1525*	*1503*	*1475*	*1430*	*1429*
DK	*1585*	*1549*	*1428*	*1478*	*1282*	*1329*
GAR	*1291*	*1174*	*1323*	*1296*	*1218*	*1187*

Density of earth bricks usually decreases with increasing fiber content as natural fibers are lightweight and their addition increases the pores in bricks (CALATAN *et al*., 2016).

It can be observed from table 3 that density USU and DK and GAR bricks decreases from 0% to 5% fibers addition. However, fibers mass difference at 1%, 2%, 3%, 4% and 5% fiber content is not very high. Furthermore, due to manual compaction of bricks, it is difficult to control the quantity of sediments in each brick which leads to density variation in table 3. Density of GAR sediments is considerably lower than DK and USU bricks. For unreinforced bricks, USU and DK bricks density is approximately 18% and 22% higher than GAR sediments bricks. This variation is mainly associated with higher organic matter of GAR sediments.

3. Testing of bricks

Indirect tensile strength of bricks was found with three-point bending test. Flexural and compressive tests on earth bricks are shown in figures 3a and 3b.

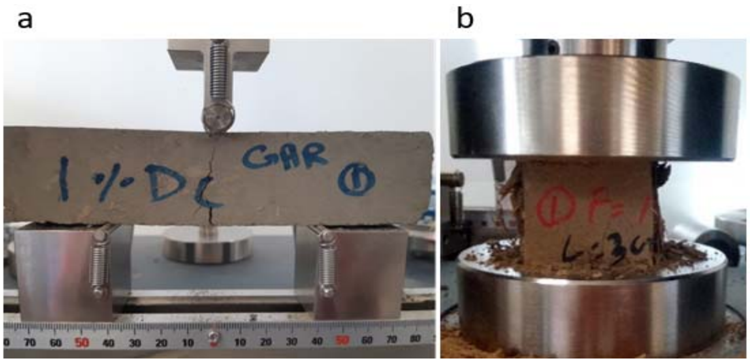


Figure 3. Tensile (a) and compressive strength (b) testing of bricks.

4. Results and discussion

Addition of fibers considerably increases the tensile strength of earth bricks. Unreinforced USU, DK and GAR bricks have brittle behavior. Addition of natural fibers increases the stiffness of these bricks by transforming bricks behavior into ductile. After initial cracking, load is taken by fibers. Flexural load deflection curves of GAR, DK and USU sediments are shown in figures 4a, 4b and 4c.

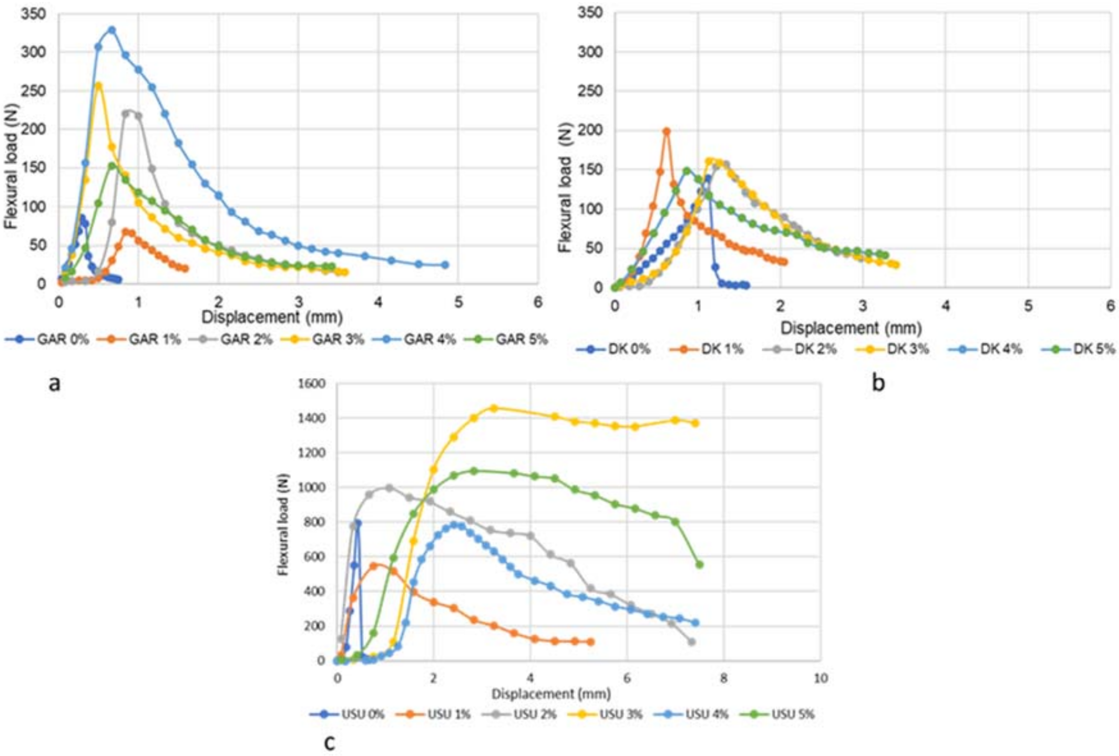


Figure 4. Flexural load deflection curves.

Figure 4 shows that load deflection behavior of unreinforced bricks at 0% fibers is brittle. With addition of fibers behavior changes to ductile as load is transferred to the fibers. Compressive load and deflection are maximum for USU bricks due to higher clay content and low organic matter in USU sediments. Furthermore, morphology and particle size of POFL fibers is also different from hemp shiv they introduce more ductility in bricks. Morphology and particle size of POFL fibers and hemp shiv have huge variations which affect the deformation in bricks.

GAR and DK sediments have low compressive load and deflection due to higher content of coarse particles and the nature of hemp shiv. Strength of hemp shiv is higher and it does not fail but the sediments detached from hemp shiv in case of failure and deflection is limited. Average tensile strength of USU, DK and GAR sediments bricks is summarized in table 4.

Table 4. Tensile strength of earth bricks.

Fiber content (%)	***F = 0%***	***F = 1%***	***F = 2%***	***F = 3%***	***F = 4%***	***F = 5%***
σ_t (MPa) $_{USU}$	*1.79*	*1.79*	*2.56*	*3.19*	*2.02*	*2.59*
σ_t (MPa) $_{DK}$	*0.35*	*0.48*	*0.41*	*0.39*	*0.35*	*0.34*
σ_t (MPa) $_{GAR}$	*0.19*	*0.16*	*0.51*	*0.52*	*0.6*	*0.32*

Note: σ_t = tensile strength

Tensile strength of USU sediments is high and its value is 3.19 MPa with 3% fibers addition. Tensile strength of bricks starts to decrease after optimum moisture content as at high fiber content adhesion between sediments and fibers decreases. Tensile strength of DK and GAR sediments is very low. Both DK and GAR sediments have similar tensile strength and load deflection behavior. Maximum tensile strength in case of DK bricks is at 1% hemp shiv addition while in GAR sediments strength is maximum at 4% fibers addition. In the case of DK and GAR sediments, low percentage of fine particles and higher organic matter in GAR sediments are important reasons behind low strength of bricks. Furthermore, morphology and particle size and tensile load behavior of hemp shiv is quite different from palm oil flower fibers which also influence the performance of DK and GAR sediments bricks. Usually, earth bricks without using stabilizing agents have low strength and tensile strength suggested for adobe bricks varies 0.012 MPa to 0.25 MPa (NZS, 1998; NORMA E.080, 2017; AFNOR XP P13-901, 2001).
Impact of fibers addition on compressive strength of bricks is unclear As the tensile strength of DK bricks is very low, therefore, compressive strength of only USU and GAR bricks was tested. Load deflection curves of USU and GAR bricks are shown in figures 5a and 5b.

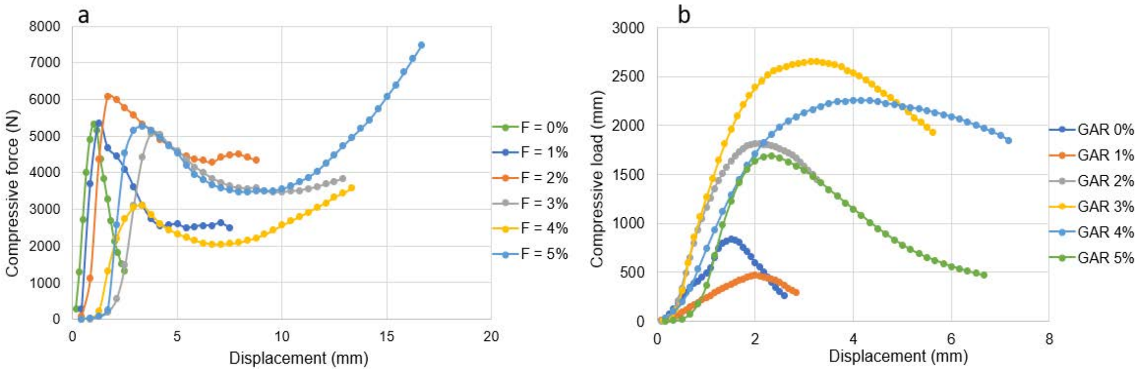


Figure 5. Compressive load deflection curves of USU (a) and GAR bricks (b).

Compressive strength of USU and GAR bricks is shown in table 5. Compressive strength of USU sediments is high and ranges from 2.29 to 4.85 MPa. French standard (AFNOR XP P13-901, 2001) recommends 1 MPa compressive strength for earth bricks. However, compressive strength of GAR sediments is low but GAR bricks have higher strength than 1 MPa at 2%, 3%, 4% and 5% fibers addition. Sediments and plant aggregates characteristics are reasons behind the low strength of GAR sediments.

Table 5. Compressive strength of USU and GAR sediments

Sediments	***F= 0%***	***F= 1%***	***F= 2%***	***F= 3%***	***F= 4%***	***F= 5%***
σc (MPa) $_{USU}$	*3.03*	*3.34*	*3.84*	*3.21*	*2.29*	*4.85*
σc (MPa) $_{GAR}$	*0.41*	*0.39*	*1.14*	*1.52*	*1.2*	*1.02*

5. Conclusion

Characteristics of USU, DK and GAR sediments were studied to use in earth bricks. It is observed that GAR sediments have low clay content, high organic matter and higher consistency limits. Granulometry and Atterberg limits of sediments show Usumacinta sediments are suitable for earth bricks, but GAR sediments and DK sediments are unsuitable Granulometry of GAR sediments is also not appropriate for earth bricks.
Earth bricks were manufactured with USU, DK and GAR sediments with addition of POFL fibers and hemp shiv with 0%,1%,2%,3%,4% and 5% plant aggregates and compacted with Proctor energy of 600 kN.m/m^3. It is observed that DK and GAR bricks have low tensile strength due to low fine particle percentage and high organic matter. DK and GAR bricks have maximum tensile strength at 1% and 4% hemp shiv content. USU bricks have maximum tensile strength at 3% POFL fiber content of G-3cm long fibers. USU bricks tensile and compressive strength satisfies the recommended strength in French and Mexican standards.

Acknowledgments

This work has been funded by the project "From traditional uses to an integrated valorisation of sediments in the Usumacinta River basin (VAL-USES)" from the Agence Nationale de la Recherche of France (ANR-17-CE03-0012-01) and the Consejo Nacional de Ciencia y Tecnología of Mexico (FONCICYT-290792).

6. References

AFNOR XP P13-901 (2001). *Compressed earth blocks for walls and partitions: definitions– specifications – test methods*.

ANGER B. (2014). *Caractérisation des sédiments fins des retenues hydroélectriques en vue d'une orientation vers des filières de valorisation matière*. PhD thesis, Unicaen, France. https://hal-normandie-univ.archives-ouvertes.fr/tel-01938082

ASTM D7357 07. (2012). *Standard specification for cellulose fibers for fiber-reinforced concrete*.

AZHARY K. E., CHIHAB Y., MANSOUR M., LAAROUSSI N., GAROUM M. (2017). *Energy efficiency and thermal properties of the composite material clay-straw*. Energy Procedia 2017, vol. 141, pp. 160–164. https://doi.org/10.1016/j.egypro.2017.11.030

CALATAN, G. HEGYI, A., DICO, C. MIRCEA, C., (2016). *Determining the optimum addition of vegetable materials in adobe bricks*. Procedia Technology 22: 259 – 265. https://doi.org/10.1016/j.protcy.2016.01.077

ISMAIL S., YAACOB Z. (2011). *Properties of laterite brick reinforced with oil palm empty fruit bunch fibres*. Pertanika Journal of Science and Technology, Vol. 19, pp. 33 – 43. doi: 10.1016/j.protcy.2016.01.077

JIANG Y., LAWRENCE M., ANSELL M.P., HUSSAIN A. (2018). *Cell wall microstructure, pore size distribution and absolute density of hemp shiv*, April 2018, Royal Society Open Science, 5(4):171945, doi: 10.1098/rsos.171945

MINISTRY OF ECOLOGICAL TRANSITION (2021). *Energie dans les bâtiments*. https://www.ecologie.gouv.fr/energie-dans-batiments

MOPT (1992). *Bases para el diseno y construccion con tapial*. Madrid, Spain : Centro de Publicaciones, Secretarıa General Tecnica, Ministerio de Obras Publicas y Transportes.

NORMA E.080 (2017). *Diseño y construcción con tierra reforzada. Ministerio de Vivienda, Construcción y Saneamiento*. Anexo-Resolución Ministerial, 21-2017-Vivienda.

NZS 4298 (1998). *Materials and workmanship for earth buildings*. Building Code Compliance Document E2 (AS2), 91p.

SAFHI A.M. (2020). *Valorisation des sédiments des dragage dans des bétons autoplaçants : Optimisation de la formulation et étude de la durabilité*. Ecole nationale supérieure Mines-Télécom Lille Douai -Université de Sherbrooke, Canada.

SEDIBRIC (2018). *Valorisation de sédiments en briques et tuiles*. Projet AMI, Transition Ecologique et Valorisation Economique. CPIER Vallée de la Seine

SOUSA V., BOGAS J.A., REAL S., MEIRELES I. (2022). *Industrial production of recycled cement: energy consumption and carbon dioxide emission estimation*. Environmental Science and Pollution Research, https://doi.org/10.1007/s11356-022-20887-7

THYGESEN A., DANIEL G., LILHOLT H., THOMSEN A.B. (2008). *Hemp fiber microstructure and use of fungal defibration to obtain fibers for composite materials*, JONF, volume 2, issue 4, 19-37, doi:10.1300/J395v02n04_02