Local materials, between regional diversity and energy performance to build efficient buildings in a transborder context (morocco-spain)

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Abstract. Located on the Southern shore of the Mediterranean, and at the same time at the gates of Europe and the North of the African continent, Morocco is distinguished by its richness in terms of climate and geography which constitute specific features providing a diversity of local materials required in the eco-construction and renovation. In this regard, the Kingdom of Morocco has launched a transition to a new development model that is more respectful of its human and natural resources through the strategy of energy and energy efficiency. This leads it to deploy an important part of research and development to choose innovative and pragmatic solutions adapted to different sectors. Including the building and thermal comfort. The innovative solutions are based on the choice of an energy mix associated with local materials. The objective of this communication is to realize the variety of materials potentially available in the northern region of Morocco and to evaluate their contribution in terms of thermal comfort and by listing the constraints of short circuit, environmental preservation and possible fields (concrete, wood, bricks...). Then comes the scientific contribution which consists in quantifying, characterizing, understanding and certifying between Universities and other organizations. Focusing on multi-physical characterization methods. The reflection closes with a study about the cost and the global socio-economic benefits of this approach and the implementation of a methodology for the selection of eco-materials in order to establish later a chain of eco-renovation and eco-construction operating on the trans-border area of northern Morocco.

1 Introduction

In recent years, the construction of more sustainable buildings has acquired great importance due to the need to protect the environment. This growing interest in sustainability is due to the intense activity that the construction sector has experienced and which has caused enormous environmental deterioration. Facing this problem, it is necessary to search for new methods to reduce the impact caused by construction on the environment.

According to the IEA the primary energy production was increased by 49% and CO2 emissions by 43% in the World over the past 20 years. Furthermore, 30 - 40% of total energy consumption in developed countries comes from the private sector buildings including houses and offices.

In Morocco, the insulation of buildings is not of a common occurrence [1]. Therefore, several steps have been adopted to introduce strong concepts and techniques to enhance the energy efficiency in the local building sector[2]. This paper compares two neighboring regions which are the Southern Spain and Northern Morocco, in terms of the presently common used building materials aiming at efficient buildings regarding energy and comfort. The focus is put on the used local material, and especially on the bio-sourced ones. The paper stars by a comparison of the dominant climatic conditions in the two regions, then the local regulation and fulfilled standards for the building sector are considered and compared. In fact, regulations and standards are of huge influences on the used material.

The national regulations and policies in different countries usually define inside the same countries different so-called "Climatic Zones". Indeed, the identification of these climatic zones for building energy efficiency proposals is a key element of the national's programs and policies in order to improve the thermal performances of the buildings.

In Spain, a country zoning on twelve climatic zones have been adopted based on a climatic "severity" defined taking into account the degree-days and the annual solar radiation in the zone[3] . In addition, within each of these twelve zones, there may be sub-climatic zones depending on their altitude regarding the one of the region city capital. While in Morocco, it has been decided to establish a zoning that is the result of a dynamic simulation of a unique standard building carried out considering several Moroccan localities climate conditions using the Trnsys Software [4].Consequently, six different climatic zones have been defined throughout the country where, relevant differences in term of annual heating and cooling needs have been observed

Fig. 1: Distribution of climate zones in Spain [6]

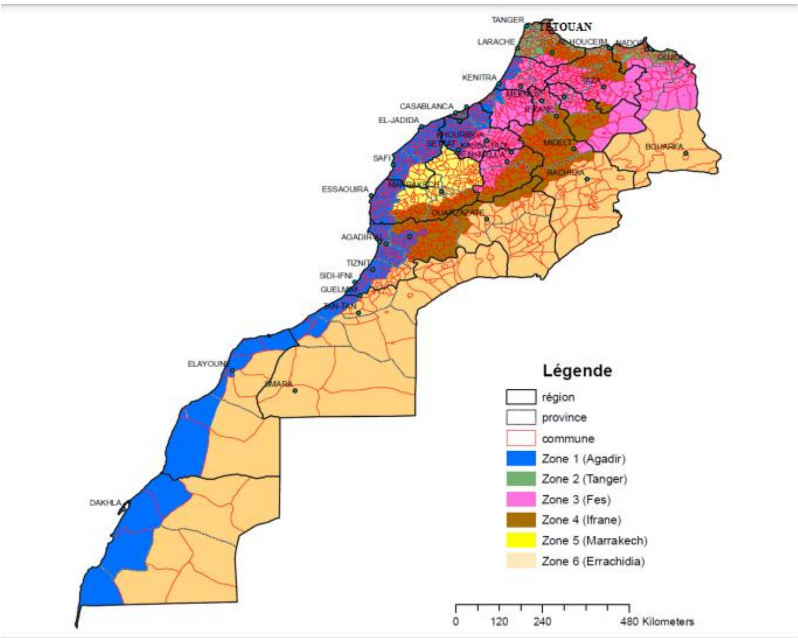

Fig. 2: Distribution of climate zones in Morocco [5]

2Building requirement in Morocco vs Spain

Fulfilling regulations and standards is mandatory nowadays for the design and the construction of buildings to ensure people health the safety , as well as the energy efficiency [5].The Spain regulations encompass the thermal and energy performances that the building had to globally ensure, the construction materials characteristics as well as the used HVAC equipment. The regulation authority operates a double *a priori* and a *posteriori* control of the construction operation to check the correct respect of the national standards. In the case of non-standard compliance, gradual sanctions, that may go till a strict prohibition to occupy the building. Furthermore, Spain belong to the European Union countries that have been committed to converge toward a common regulation related to the energy efficiency by 2020 including the building sector. In this frame, Southern Europe new buildings have to be compliant with the standard for the buildings with almost Zero Energy consumption (NZEB) whose annual energy demand is less than 15 kwh/m2 year[3]. In Morocco the building thermal standards are hold by the RTCM rules [5]. However, the violation of the established rules is not sanctioned. In fact, the main Moroccan national law [11] that constitutes the RTCM does not contain any control procedure, nor sanctions mean in case of non-conformity.

Table 1. Comparison between RTCM and CTE results in terms of Heating and Cooling demand

		Annual Heating/Cooling Demand Limit
RTCM 2019	Z2	46 kWh/m2.year
CTE 2017	A3	30 kWh/m2.year

A comparison between the Spanish CTE and the Moroccan RTCM standards in term of energy requirement, energy consumption for the Moroccan and the Spanish respective climatic zones Z2 and A3 are presented in Table 1.

For these two regions, with near identical climates conditions, the CTE requirement are around 28% higher in comparison to RTCM. The low requirements of the Moroccan standard are mainly due to the fact that in one hand, the RTCM is the first building thermal standard adopted in the country in 2014, and in the other hand, promulgate more severe standard for the building performances may induces higher construction costs that are incompatible with the local living standard. Furthermore, as aforementioned, the Spanish CTE higher requirement, for has to be compliant with the EU regulations, that is obviously more rigorous regarding the performances and the comfort of the building.
However, in Morocco, regarding both the lack of coercive measure aiming at applying the thermal building regulation laws, and the relative low requirement of these law, engineers and researchers are committed to found local materials to use, and to develop newer construction method that may be easily adopted by the local craftsman to enhance the buildings thermal performances and comfort.

The following section focuses on a comparative study of the construction material commonly used in the two Spanish and Moroccan studied regions.

3Materials – energy

3.1.Evaluation of the materials and constructive solutions commonly used in construction

3.1.1. In Spain

A comprehensive previous studies from the University of Seville 6 7 8 lists the commonly used construction materials in Spanish as well as the most used residential typologies with the most common construction used technics and solutions.
It was obtained that the materials that have the most presence in Spanish buildings, either due to their percentage by weight or due to their high environmental impact related their Live Cycle Assessment are the following:

▪ Concrete: represents more than 50% by weight of the materials used in construction
▪ Ceramics: constructions in Spain are intensively in bricks, ceramic tiles, and materials of the same nature. The Ceramic percentage by weight represents between 10 and 15% of the total construction of residential buildings in Spain.
▪ Steel: little relevance in weight but high incidence in environmental impact of the building (10-20%)
▪ Aluminum: also, a little relevance in weight, but high environmental impact due to manufacturing energy consumption of the Aluminum. However, the used Aluminum is usually a recycled material and has much lower environmental impact.
▪ Polystyrene: used as insulating material. It may be relatively simply recycled, and new blocks are obtained with up to 50% recycled material.
▪ PVC: It's a plastic material highly used in buildings. Its environmental impact is similar to polystyrene.

Of the six materials, five of them that are: concrete, steel, ceramics, polystyrene, and PVC represent approximately 80% of the environmental impact generated by materials in the construction of buildings in Spain.On the other hand, the study of innovatice construction solutions in construction materials and construction processes, alternatives to conventional ones, which have something to contribute in terms of sustainability in the construction process, acquires a main role in solving the problems derived from the sector of the construction. There are numerous researches works in this concept that develop construction products and try to improve the degree of sustainability of buildings.

Table 2. Use of sustainable materials in the current bibliography [14]

Autours	Materials/Constructive solution	Results
(Dixon et al., 2015)	bamboo	It is a little used resource that is available in developing economies. It is a resistant, light and moldable material that is quickly renewed, so its collection does not cause deforestation
(Jamekhorshid, Sadrameli, Barzin, & Farid, 2017)	Composite of wood and plastic with phase change microencapsulated PCM (MEPCM) Composite of wood and plastic with phase change microencapsulated PCM (MEPCM)	Energy storage. Improved energy efficiency.
(Gramineae, 2016)	House made entirely with bamboo as a construction material	Housing made with bamboo as a construction material
(Teixeira, Bastos, & Almeida, 2015) (Shah, Bock, Mulligan, & Ramage, 2016) (Shah et al., 2016) (Luna, Lizarazo-Marriaga, & Marino, 2016)	Laminate/composite panels with bamboo	Sufficient strength and minimum thickness
(Morales-conde, Rodríguez-liñán, & Pedreño-rojas,2016)	Gypsum-based compound and wood aggregates from demolitions in rehabilitation works	Improvement of the thermal properties of the compound. Decrease in mechanical resistance
(Baÿpÿnar, MS, & Kahraman, 2011) (del Río	Plaster with aggregates of mica or verniculite	
Merino, M., García, CP, & Piñeiro, 2013)	Plaster reinforced with RCD mineral wool fibers	
(Jamshidi, Kurumisawa, Nawa, & Igarashi, 2016)	Structural concrete and paving blocks incorporating glass waste	The addition of glass waste improves the product's life cycle, durability and structural behavior
(R. De, De, & De, 2015)	Hydraulic mortars using recycled plastic bottles	Improved behavior against fire and sustainability
(Marrero, Martinez-Escobar, Mercader Moyano, & Leiva, 2013)	Panels incorporating plasterboard and recycled concrete	Minimization of the environmental impact in the execution of facades. Same mechanical performance as those made with natural resources
(Meijide, 2015)	Cold bituminous mixtures with RCD aggregates	
(Bedoya & Dzul, 2015)	Structural concrete with recycled aggregates	
(Coast of the Well, 2012)	Blocks from recycled plastics (including EPS) and cement	
(Aliabdo, Abd-Elmoaty, & Hassan, 2014) (Miliÿeviÿ, Bjegoviÿ, &	Bricks with recycled aggregate brick dust and clay roof tiles	mproves thermal resistance, lower weight and cost, compliance with the environmental values established in the country of origin, although there is a

Siddique, 2015) (Sadek, 2012)		notable decrease in the compressive strength of the block and an increase in the absorption of water
(Valdés et al., 2010)	Concretes that incorporate RCD and cement	They intend to be used to replace conventional structural concrete
(González Madariaga & Lloveras Macia, 2008)	Gypsum or plaster boards that incorporate recycled EPS	
(Poon & Chan, 2006) (Wattanasiriwech, Saiton, & Wattanasiriwech, 2009)	Pavers incorporating crushed ceramic materials	Higher water absorption than similar products on the market.
(del Río Merino, MR, Astorqui, JSC, & Olivares, 2005)	Fiberglass reinforced plaster	
(Cherki, AB, Remy, B., Khabbazi, A., Jannot, Y., & Baillis, 2014)	Plaster with lightening cork aggregates	
(De Melo & Silva, 2013)	Non-structural concrete blocks that incorporate EVA waste (footwear)	
(del Río Merino, M., Domínguez, JD, & Hernández Olivares, 1998)	Lightened plaster with cellular solids: Expanded clay	
(Machado & Pereira, 2016)	Composites with cork as base material	improved energy efficiency
(Conception & Minor, 2015)	Structural concrete and concrete blocks with cork aggregates	Lightened parts. Decrease in thermal conductivity
(Serna, Á., del Río, M., Palomo, JG, & González, 2012)(Parres, F., Crespo Amorós, JE, & NadalGisbert, 2009)	Gypsum reinforced with shredded tire aggregates	
(Aguilera, 2013) ("197-708-1-PB.pdf," n.d.)	Plaster with aggregates of crushed rice husk residues	
(Engineer, Agriculture, Livestock, & Specialty, 2011)	Brick Employing Marginal Soil vs. Fired Clay	Cooking is not necessary. Improved sustainability
(Gatani, 2000)	Compact earth bricks and cement	(Gatani, 2000) Increased degree of humidity compared to traditional
(Sustainable, De, Patricia, & Sánchez, 2015)	compressed earth blocks	
(Ruan & Unluer, 2016)	Cement with magnesium aggregates (MgO)	Minimization of the necessary reactive energy compared to Portland cements
(Building, 2016)	Photocatalytic materials:	Reduction of environmental impact

	mortars	
(Sugr, nd)	Mortars with self-cleaning and decontaminating properties	Reduction of environmental impact
(RF De, 2016)	Sheep wool as insulating material	
(Baglivo & Congedo, 2016)	Lightweight multilayer composite walls	High level of thermal behavior and interior comfort
(Neila, Bedoya, Acha, Olivieri, & Barbero, 2008)	cover.	

3.1.2. In Morocco

In this study, the selection of building materials used in Morocco will be based on a database of building materials of which the thermophysical properties measurement have been mentioned
Most of these materials there are current used in Moroccan in a National level. However, among them, there are some specific locally used materials in the Northern Morocco. Identifying the lasts allows one to identify a chain of local construction and insulation material that may be used as biosourced material in the frame of transborder regions that constitutes the climatic zone Z3 and A2 respectively in Morocco and in Spain.
The building materials used at the national level in construction and building sector are given as follows [15]:

- Concrete according to the classes used in Morocco (B20, B25, and B30)
- Cellular concrete
- Mortar
- Gypsum
- Lime
- Natural stone
- Sandstone
- Ceramic tiles (group BIa, BIIa and BIII)
- Traditional zellige
- Solid terracotta brick

The Insulating materials used at the Moroccan National level in the building are gathered hereinafter:

- Different wood species (beech, mahogany, cedar, fir, thuja...)
- Products derived from wood (plywood, chipboard ...)
- Rock wool in bulk and in panels
- Perlite in bulk
- Glass wool in bulk and in panels
- Expanded cork in bulk and consolidated
- Expanded polystyrene
- Extruded polystyrene
- Polyurethane

The following table represents a summary of the basic properties of the most used materials used in construction in Morocco

Table 3. Typical values of various construction and thermal insulating materials [15]

MATERIALS	**DRY DENSITY ρ kg.m-3**	**THERMAL CONDUCTIVITY**	**THERMAL DIFFUSIVITY a m2s-1 x**	**MASS HEAT c J.kg-1.K-1**

		λ W.K-1.m-1	**10-6**	
Concrete	$1800 < \rho \leq 2\ 000$	$1.15 < \lambda \leq 2.00$	0,638	1 000
Autoclaved cellular concrete	$365 < \rho \leq 825$	$0,145 < \lambda \leq 0,27$	$0,330 < a \leq 0,397$	1 000
Wood chip concrete	$450 \leq \rho \leq 650$	0,16	$0,246 < a \leq 0,355$	1 000
ROCKS AND NATURAL STONES The thermal conductivities given in this paragraph are in fact equivalent thermal conductivities taking into account the joints.				
Heavy stones (granite, gneiss, basalt, porphyry)	$2\ 700 \leq \rho \leq 3\ 000$	3.50	$1.17 < a \leq 1.26$	1 000
Schist, slate	$2\ 000 \leq \rho \leq 2\ 800$	2.2	$0,785 < a \leq 1,1$	1 000
Porous natural stones, ex. lava	$\rho \leq 1\ 600$	0,55	$\leq 0,343$	1 000
Marbles	$2\ 600 \leq \rho \leq 2\ 800$	2.91 – 3.50	$0,04 < a \leq 1,34$	1 000
SOIL, EARTH BLOCKS, SAND-LIME BRICKS/BLOCKS, BAKED CLAY				
Sand-lime bricks/blocks	$800 \leq \rho \leq 2\ 200$	0,36 – 3.71	$0,36 < a \leq 1,76$	1 000
Baked clay used in masonry elements	$900 < \rho \leq 2\ 400$	0,34-1,04	$0,33 < a \leq 0,452$	1 000
		PLASTER-GYPSUM-LIME		
Plaster	$600 \leq \rho \leq 1300$	0.18-0,57	$0,3 < a \leq 0,438$	1 000
(Lime or gypsum)+Sand	$\rho = 1600$	0.7	0,437	1 000
SAND, PLASTER AND JOINT MORTARS OF CEMENT OR LIME AND CERAMIC				
Mortar The average density of a laying mortar is 1900 kg/m3.	$500 < \rho \leq 3000$	0,3-1,8	$0,4 < a \leq 1$	1 000
Lime mortar	1600	0.70 – 1.20	$0,43 < a \leq 0,75$	1 000
Glazed ceramic	2500	1.40	0,666	840
CONCRETE BLOCKS WITH ORDINARY AGGREGATES				
Concrete blocks with ordinary aggregates	$1500 < \rho \leq 2400$	1.07 – 2.71	$0,66 < a \leq 1.17$	1000
CONCRETE BLOCKS WITH OTHER LIGHT AGGREGATES				
Concrete blocks with other light aggregates	$400 < \rho \leq 1800$	1.30 – 1.70	$0,51 < a \leq 1.06$	1000
CLAY BRICKS				
Clay brick	$600 < \rho \leq 2\ 100$	0.22 – 1.61	$0,12 < a \leq 0,80$	1 000
WOOD AND WOOD PRODUCTS				
Wood	$\rho = 500\text{-}700$	0.13-0,18	0,162-0,160	1600
Lumber	≤ 600	0.13 – 0.15	0.12 – 0.14	1880
	> 600	0.18 – 0.20	0.16 – 0.18	1880
Plywood panels defined according to the NF EN 313-1 and NF EN 313-2 standards and panelled wood	$250 < \rho \leq 1000$	0,09-0,24	0.15 – 0.275	1 600

defined according to the EN 12775 standard.				
Particleboard or chipboard	$350 \leq \rho < 800$	0.10-0,18	0.10-0,17	1880
Particleboard defined according to the NF EN 309 standard	$180< \rho \leq 900$	0,10-0,18	0,117- 0,326	1 700
Wood fibre panels	$250 \leq \rho < 700$	0.07-0,18	0.10-0.15	1880
INSULATING MATERIALS				
Glass wool in panels or rolls	$12 \leq \rho < 150$	0,04-0,055	$0,258<a\leq7,62$	1 030
Glass wool in bulk	10 à 60	0,06-0,065	$0,97<a\leq6,31$	1030
Rockwool in panel or in roll	$15 \leq \rho < 200$	0,05-0,041	0,233 - 3,23	1 030
Rockwool in bulk	10 à 60	0,06-0,065	0,97 - 6,32	1030
Cork panel	120	0.040	0,239	1390
Pure expanded cork in compliance with the NF EN 13170 standard	$100 \leq \rho \leq 150$	0,049	$0,209<a\leq0,314$	1 560

In the following parts, a selection is made of the candidate materials to be a part of an eco-material chain in the aforementioned transborder context. This selection is made as follows:

- The selected materials are compared regarding their thermophysical properties.
- From a total of a257 candidate material, only 30 material are preselected.
- A final selection among these preselected materials is made regarding their cost of sale using a short-circuit market schema.

4 Principles and platforms of characterization

4.1 Boxes method

The device for measuring both the thermal conductivity and the diffusivity developed at the Laboratory of Thermal, Solar Energy and Environment (LTEE) of the Faculty of Sciences of Tetouan in Morocco, is based on the " boxes method " developed at the French Laboratory of Thermal and Solar Studies of the Claude Bernard University of Lyon I [16],[17].

The "Box" method allows measuring the thermal conductivity in steady-state and the thermal diffusivity in unsteady-state of one or two samples depending on the configuration of the measuring cell. This technique is based on the one-dimensional thermal heat flow through the thickness of a parallelepiped sample of thickness e which is very thin compared to the dimensions of the sample. The apparent thermal conductivity is obtained only after establishing the steady-state. While the thermal diffusivity is obtained at any time during the evolution of the dynamic regime.

Estimation of Thermal Conductivity

When the steady-state is attained, considering the thermal balance of the box. We get the expression of the thermal conductivity as:

$$\lambda=\frac{e}{S.\Delta T}\left(\frac{U^2}{R}+C\Delta T'\right) \quad (1)$$

e: Sample thickness.
S: Useful surface of the sample
U: Voltage applied to the heating resistor R
$\Delta T'$: Temperature difference between the inside and outside of the box.
ΔT: Temperature difference between the two hot and cold sides of the sample.
C: Being the global heat loss coefficient through the measuring box
The theoretical value of C is given by the Carslaw formulas [9]: C=0.16 W/°C

To determine the apparent thermal conductivity of granular materials placed in a special frame having a parallelepiped shape (identical to that of the consolidated material).

In this case, the created heat flux passes through the surface of the wooden frame and the aggregates, a correction of the measurement of the thermal conductivity is necessary. (Martin, 1988)[10]:

$$\lambda_a=\left(\frac{S_T}{S_g}\right)\lambda_{mes}-\left(\frac{S_b}{S_g}\right)\lambda_b \quad (2)$$

Sg= surface of aggregates.
Sb= wood surface.
ST= total surface
λb=thermal conductivity of wood
λmes=measured thermal conductivity

The relative error on the determination of the thermal conductivity in a steady-state by the box method is 6% [11]

4.2 Flash method

The flash method is one of the most widely used experimental techniques in laboratories and industries. It is accepted as a standard method for the determination of thermal diffusivity [20].

The principle of the flash method is to emit a short time pulse heat flux on front side of a sample and to recover the temperature evolution on the rear side, as a function of time using an experimental thermogram. Heat conduction is assumed to be one-dimensional (i.e. no lateral heat losses).

The pulses are usually created by flash lamps, pulse lasers or electron guns. The temperature measurements are performed either by contact thermocouples or with by infrared cameras.

There have been several developments in the method since its introduction by Parker et al [21]. In a second stage, knowing the thermal diffusivity value, the thermal conductivity is obtained by performing measurement of the specific heat capacity.

Estimation of Thermal Conductivity

The analysis of the experimental thermogram recorded on the rear-side allows to determine, using already existing stripping techniques, the thermal diffusivity of the sample.

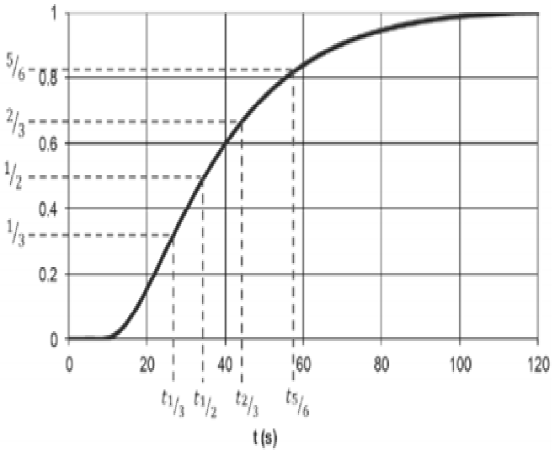

Fig. 3: Reduced temperature of the rear side during a Flash measurement

This method has been the subject of several researches due to the development of theoretical models that allow identifying the thermal diffusivity from the measured thermogram. [12],[13],[14]. The mean used methods are partial times method [15] and the temporal moments method:

$$\alpha = 0.139\frac{e^2}{t_{\frac{1}{2}}} \tag{3}$$

Where t1/2 is the time that takes for the sample to heat to one half maximum temperature on the rear surface and e is the thickness of the sample

Conclusions

The first objective of this work is to provide in a transborder context of the Northern Morocco and Southern Spain, a comparison between Spain and Morocco in terms of energy efficiency regulation, norms and requirements, discussing the parameters taken into account in both countries to determine their building thermal comfort levels, as well as proposes improvements for the case of Morocco. In fact, the study focuses on two neighboring climatic zones that are the Moroccan Z3 and the Spanish A2 with very close climatic conditions in order to point out the relevant standard and norm that are currently applicable in the Spanish zone A2 that may be applicable in the Moroccan zone A2. These norms and standards may also be considered to be enlarged for the whole climatic Moroccan zones with the convenient adaptation their respective climatic conditions.

Thus, our research consists in carrying out an investigation of a local ecomaterials production chain for eco- construction/renovation in the transborder Morocco- Spain context. The analysis of these types of materials has led us to identify different promising materials in the northern Region of Morocco. The list of the category has been treated in order to determine the thermophysical characterization of materials used in construction in Morocco

An important requirement influencing the sustainability of these ecomaterials is related to the availability of its components since the use of local materials lead to a reduction of economic and environmental impacts. Creating new jobs through the promotion of efficient tools and technologies in the building sector, mainly in the northern region; a more sustainable management of energy demands based on economic incentives, taking into account social and environmental dimensions; and finally, the choice of the least energy-intensive and lowest-emission options.

However, the majority of the investigated materials are not completely characterized. As far as thermal properties, thermal conductivity is always reported or measured but data about life cycle and cost of production and transportation is often missing. This lack of data is mainly caused by the absence of a common referential data file provided by the building materials and thermal insulation manufacturers.

In conclusion there are still issues that remain to be solved before the rational achievement of a method of realization of a local chain of ecomaterials that will be used on the cross-border context and then adopted by other inter-countries

5 References

1. Rachida Idchabani, Ahmed Khyad, Mohamed El Ganaoui, Optimizing insulation thickness of external walls in cold region of Morocco based on life cycle cost analysis, Energy Procedia, Volume 139, 2017, Pages 117-121,
2. Kharbouch, Y., Mimet, A. & El Ganaoui, M. A Simulation based-optimization method for energy efficiency of a multi-zone house integrated PCM. Energy Procedia 139, 450–455 (2017).
3. Merini, I., Molina-García, A., García-Cascales, Ma. S. & Ahachad, M. Energy Efficiency Regulation and Requirements: Comparison Between Morocco and Spain. in Advanced Intelligent Systems for Sustainable Development (AI2SD'2018) (ed. Ezziyyani, M.) 197–209 (Springer International Publishing, 2019). doi:10.1007/978-3-030-12065-8_19.
4. Reglement_thermique_de_construction_au_Maroc.pdf. https://www.amee.ma/sites/default/files/inline-files/Reglement_thermique_de_construction_au_Maroc.pdf.
5. Chandel, S., Sharma, A. & Marwaha, B. Review of energy efficiency initiatives and regulations for residential buildings in India. Renew. Sustain. Energy Rev. Volume 54, pages 1443-1458 (2015).
6. Martínez-Rocamora, A., Solís-Guzmán, J. & Marrero, M. LCA databases focused on construction materials: A review. Renew. Sustain. Energy Rev. 58, 565–573 (2016).
7. González-Vallejo, P., Solís-Guzmán, J., Llácer, R. & Marrero, M. La construcción de edificios residenciales en España en el período 2007-2010 y su impacto según el indicador Huella Ecológica. Inf. Constr. 67, e111–e111 (2015).
8. González-Vallejo, P., Marrero, M. & Solís-Guzmán, J. The ecological footprint of dwelling construction in Spain. Ecol. Indic. 52, 75–84 (2015).
9. Carslaw, H. S. & Jaeger, J. C. Conduction of heat in solids. (Clarendon Press, 1959).
10. Martin, B. Étude de l'anisotropie de la conductivité thermique des superisolants. (Vandoeuvre-les-Nancy, INPL, 1988).
11. D. Taoukil, A. El Bouardi, T. Ajzoul, H. Ezbakhe, Caracterisation thermique, hydrique et mecanique du beton allege avec les residus de bois, Revue Internationale d'Héliotechnique N° 43 (2011) 1-7.

12. Parker, W. J., Jenkins, R. J., Butler, C. P. & Abbott, G. L. Flash Method of Determining Thermal Diffusivity, Heat Capacity, and Thermal Conductivity. J. Appl. Phys. 32, 1679–1684 (1961).
13. Degiovanni, A. & Laurent, M. Une nouvelle technique d'identification de la diffusivité thermique pour la méthode « flash ». Rev. Phys. Appliquée 21, 229–237 (1986).
14. Yezou, R., Cubaud, J.-C., Contribution à l'étude des propriétés thermophysiques des matériaux de construction cohérents et non cohérents. Thèse de Docteur-Ingénieur : Sciences : Lyon 1 : 1978.
15. Milošević, N. Mesure de la diffusivité thermique et de la résistance de contact thermique des couches minces sur des substrats par la méthode impulsionnelle. Thèse de doctorat en Énergétique et thermique, INSA Lyon, 2008.