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Gypsum-LDPE composite boards for a low cost improvement of the inside-living condition in Burkina Faso.

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Abstract

The main goal of this research is that of finding a way to improve inside-living condition in Burikina Faso by using local resources.
Located in the Sub-Saharian Africa, the Burkina Faso is one of the poorest country in the world and, with no access to the sea, it has very difficult climatic conditions.
For what it concerns architecture, the main traditional material used for building walls is earth, usually with the abobe technique. This technology works pretty good both from an ecological and a performance point of view. A critical point is instead the roof.
Traditionally the roof was build with straw and wooden branches which was a cheap but problematic solution. In recent times, the lack of vegetation, together with the introduction of new imported materials, made metal sheets the best option for a good and safe roof.
In many senses this is a good solution: it is healthy, long-lasting, easy to be built and, in the end, it is also economically affordable. On the other hand, metal is a great heat conductor and this implies very uncomfortable inside thermal conditions.
While facing this problem, we thought that, instead of finding a new and innovative way of building roofs, it was better to look for a complementary element that could be added to the existing roof: ceiling boards. We focused on the possibility of transforming plastic (LDPE) from refusal to resource through the production of gypsum-LDPE composite panels.
Twenty-two panels were produced and tested and remarkable results were obtained in terms of mechanical and thermal performances. Compared to simple gypsum board, those with LDPE have a better behavior because the presence of fibers transforms the material from brittle to plastic. In fact, if overloaded, gypsum panels reach a clean break that splits the board in two parts, while composite panels cracks but do not split, making the ceiling safer and longer lasting.
From the thermal point of view, temperature simulations have shown that inside-temperature is approximately 10°C lower when ceiling boards are used.
Finally, the panels are almost completely recyclable which means that this technology is also environmentally sustainable.

Keywords: Developing countries, Do-it-yourself buildings, Recycling, Sustainability.

Introduction

The main goal of this research is that of finding a way to improve inside-living condition in developing countries with warm and dry climate.

In particular we analyzed the Burkina Faso situation; located in the Sub-Saharian Africa, it is one of the poorest country in the world. With no access to the sea, it has very problematic climatic and economic conditions.

Analyzing the problem

Water brings life, but can also take it away [1]. This is absolutely true in Africa. Because of the global warming and climate change, countries by the sea side are now facing big problems due to sea level raise and all linked consequences or disasters; at the same time, most of the African surface is facing the opposite problem: no water and desertification. These critical factors make life very hard. The lack of water and resources in general, together with the extreme weather have always been cause of serious difficulties in living and also in building houses.

In recent times, other problems have been added: landscape pollution (Fig.1Figure) and desertification. The first point refers in particular to plastic bags (shoppers made of Low Density Polyethylene - LDPE) that literally cover the environment; this is a problems for animals that could accidentally eat plastic and die, for kids that play and stay in dirty places and also for the vegetation that is not able to grow from underneath the plastic [2].

Figure 1: Plastic waste pollutes the environment, Burkina Faso.

The second point, desertification, is linked to the first one and causes other kind of problems: lack of food (both for animals and humans) and lack of natural material such as wood or leaves or straw. This means less resources for buildings and also for creating energy. Given this unhappy overview of the context, it will follow the description of the work done.

For what it concerns architecture, both poor and “rich” houses have basically the same problem: the roof. The impossibility of building the structure of the roof with wood, together with the difficulty to produce baked bricks made metal sheets the best option for a good and safe roof. In many senses this is a good solution: it is healthy, long-lasting, easy to be built, it allows to collect water and in the end is also economically affordable. On the other hand, metal is a great heat conductor and this implies very uncomfortable inside thermal conditions.

The proposal

Starting from the considerations done till this point, we worked on finding a way of improving the internal comfort keeping in mind few crucial guiding point:

- sustainability for the environment;
- low cost in terms of energy, resources and money;
- possibly suitable for do it yourself constructions;

It was evaluated that, instead of finding a new and innovative way of building roofs, it was better to look for a complementary element that could be added to the existing roof to reduce the heat given by the metal sheet: ceiling boards.
The boards needed to be cheap and to be easy to be produced “at home”.
For what it concerns the material, we thought that we could transform plastic (LDPE) from refusal to resource.
Starting from the idea of using plastic, we needed to find a way of fixing it without using energy and therefore without melting it. We needed to add another material that could function as matrix; by doing this, the final material was a composite material.
The matrix, apart from being resistant and suitable, had to be environmentally sustainable, cheap and easy to be found.
Gypsum was evaluated to be the best choice because it does not need expensive processes (in terms of costs and energy) both during production and use.

Many studies had been done on composite materials made with gypsum and natural fiber as, for instance, Sisal[1], coconuts fiber and others.
It came out that physical and mechanical performances of composite materials are much better than those of the single materials [3].

Therefore we decided to produce and test gypsum-LDPE composite panels to be used meanwhile as ceiling boards and if worthy also for other purposes.

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1 **- Sisal:** (*Agave sisalana*) is an agave that yields a stiff fibre traditionally used in making twine, rope [3].

The production phase

Twenty two panels of different kinds were produced, tested and compared.
Each one of them is 40x40x2 cm; what changes between them is the kind and the quantity of fiber introduced in the gypsum. Those with sisal fiber were made in order to compare the obtained performances. In Table 1 are shown all the basic information about them.

Table 1: Basic information about the produced panels

n°	production date	water (l)	gypsum (kg)	w/g	kind of fiber	fiber quantity		
						(kg)	% V	% P
1	24-mar-11	3,2	3,8	0,84	-	0	0,00%	0,0%
2	24-mar-11	2,6	3,2	0,81	-	0	0,00%	0,0%
3	24-mar-11	2,6	3,2	0,81	-	0	0,00%	0,0%
4	24-mar-11	2,6	3,2	0,81	-	0	0,00%	0,0%
S1	4-apr-11	2,4	3	0,80	Sisal	0,140	5,83%	4,7%
S2	4-apr-11	2,25	2,8	0,80	Sisal	0,140	5,83%	5,0%
S3	4-apr-11	2,25	2,8	0,80	Sisal	0,140	5,83%	5,0%
S4	4-apr-11	2,25	2,8	0,80	Sisal	0,140	5,83%	5,0%
S5	5-apr-11	2,4	2,8	0,86	Sisal	0,280	11,67%	10,0%
S6	5-apr-11	2,4	2,8	0,86	Sisal	0,280	11,67%	10,0%
S7	21-apr-11	2,4	2,8	0,86	Sisal	0,280	11,67%	10,0%
S8	21-apr-11	2,4	2,8	0,86	Sisal	0,280	11,67%	10,0%
P1	6-apr-11	2,4	2,8	0,86	LDPE	0,140	4,76%	5,0%
P2	6-apr-11	2,4	2,8	0,86	LDPE	0,140	4,76%	5,0%
P3	8-apr-11	2,4	2,8	0,86	LDPE	0,140	4,76%	5,0%
P3 b	21-apr-11	2,4	2,8	0,86	LDPE	0,140	4,76%	5,0%
P4	8-apr-11	2,4	2,8	0,86	LDPE	0,140	4,76%	5,0%
P5	8-apr-11	2,4	2,8	0,86	LDPE	0,070	2,38%	2,5%
P6	8-apr-11	2,4	2,8	0,86	LDPE	0,070	2,38%	2,5%
P7	14-apr-11	2,4	2,8	0,86	LDPE	0,070	2,38%	2,5%
P8	14-apr-11	2,4	2,8	0,86	LDPE	0,070	2,38%	2,5%
P8 b	21-apr-11	2,4	2,8	0,86	LDPE	0,070	2,38%	2,5%

Tests, evaluations and analysis: summing up the obtained result

After at least on month of natural drying, each panel has been tested and evaluated from different points of view:

- weight
- component % (gypsum, water, fiber)
- density
- thermal conductivity
- bending strength

When the fiber (sisal or LDPE) is added, lighter boards are obtained and less gypsum is necessary. Around 400 g of gypsum were saved for each panel (nearly 12,5%). This means an important saving in terms of material and money.
Beside this, with lighter panels the structure to support the ceiling can be smaller and therefore cheaper.
For what it concerns the thermal conductivity, the calculated coefficient are very similar for all the different panels (around 0,36 W/mK) [4].

The best obtained result is the bending behavior's one.
The bending test was done by using the following instruments:

- one metal frame (39x35 cm)
- one manual pump ENERPAC SCR-55 with digital pressure reader
- one hydraulic jack ENERPAC RC55
- two load-distribution plates
- three displacement transducers

A simplified scheme is shown in Fig. 2.

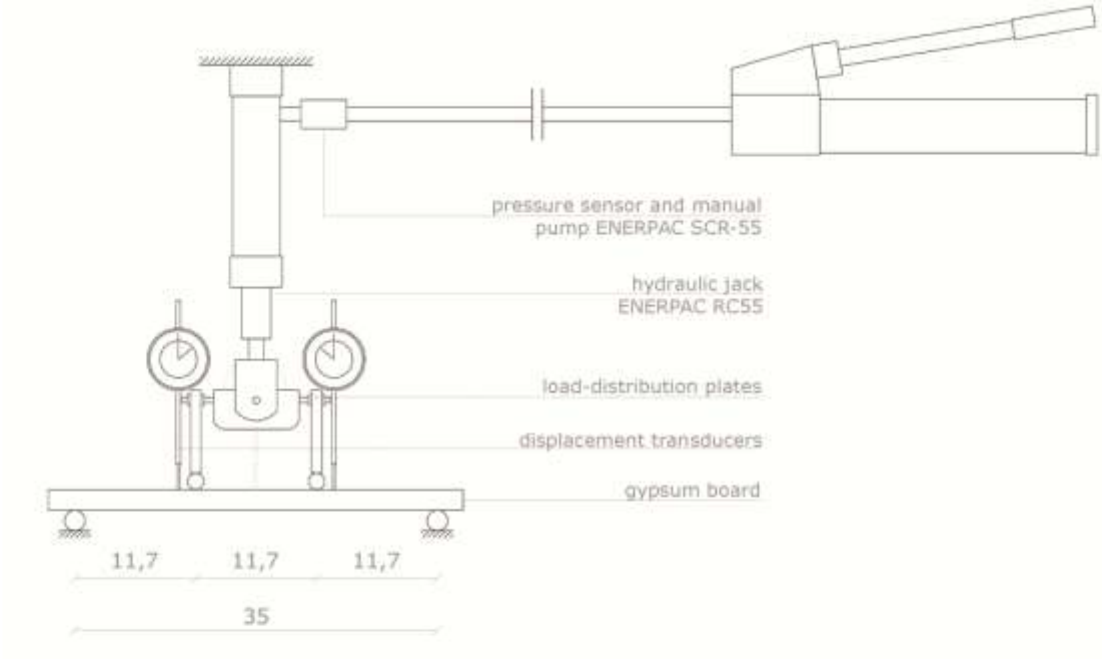

Figure 2: Bending test - instruments scheme

Upload and download cycles were done on each panel till failure. For each panel was calculated and obtained:

- maximum load characteristics (q_{max}=max load, M_{max}=max bending moment, σ_{max}=max effor) (Tab. 2)
- graphs of load/deformation for each displacement transducer (Fig.3)

Table 2: Bending test - main results (canceled values are considered not reliable).

n°	q_{max}	M_{max}	W	σ_{max}	σ_{max}
	(kN)	(kN · cm)	(cm^3)	(kN/cm^2)	(Mpa)
1	0,68	3,99	25,3	0,158	1,58
~~2~~	~~1,06~~	~~6,20~~	~~25,3~~	~~0,245~~	~~2,45~~
3	0,52	3,04	25,3	0,120	1,20
4	0,75	4,37	25,3	0,173	1,73
S1	0,62	3,61	25,3	0,143	1,43
S2	0,63	3,69	25,3	0,146	1,46
S3	0,50	2,93	25,3	0,116	1,16
S4	0,59	3,42	25,3	0,135	1,35
S5	0,94	5,51	25,3	0,218	2,18
S6	0,62	3,61	25,3	0,143	1,43
S7	1,72	10,08	25,3	0,398	3,98
S8	0,98	5,70	25,3	0,225	2,25
P1	0,49	2,85	25,3	0,113	1,13
P2	0,39	2,28	25,3	0,090	0,90
P3	0,46	2,66	25,3	0,105	1,05
~~P3bis~~	~~0,36~~	~~2,09~~	~~25,3~~	~~0,083~~	~~0,83~~
P4	0,51	2,97	25,3	0,117	1,17
P5	0,40	2,32	25,3	0,092	0,92
P6	0,46	2,66	25,3	0,105	1,05
P7	0,42	2,47	25,3	0,098	0,98
P8	0,40	2,32	25,3	0,092	0,92
~~P8bis~~	~~0,35~~	~~2,05~~	~~25,3~~	~~0,081~~	~~0,81~~

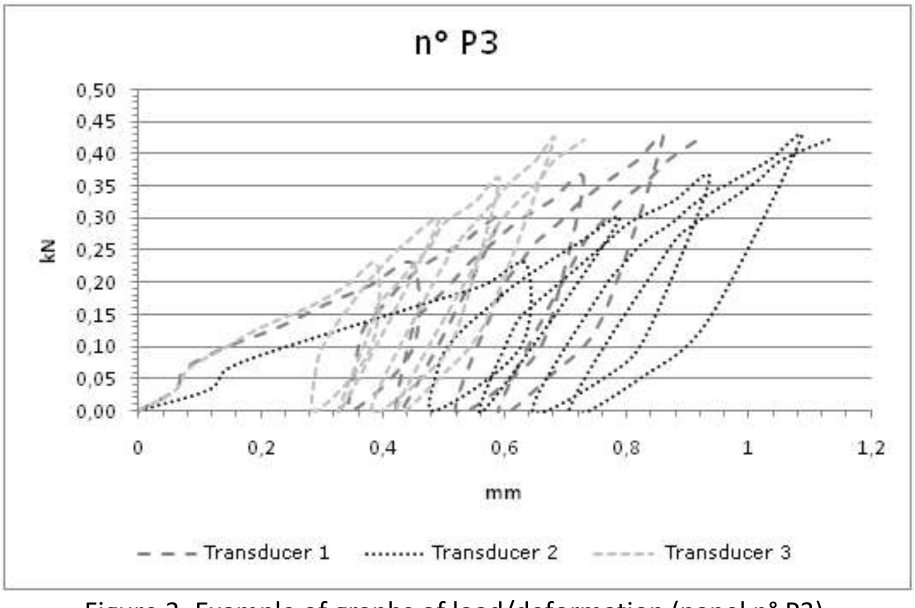

Figure 3: Example of graphs of load/deformation (panel n° P3).

The obtained results were pretty good because the presence of fibers changes the behavior of the material at break, transforming it from brittle to plastic.

Figure 4 : On the left, gypsum panel at break; on the right, gypsum-LDPE panel at break.

As show in Fig.4, gypsum panels reach a clean break that split the board in two parts. On the contrary, composite panels cracks but do not split because only the matrix actually breaks, while the fibers keep it together; this makes the ceiling safer and longer lasting.
Gypsum-sisal panels are the best performing in terms of mechanical resistance, but, for the purpose they have, gypsum-LDPE panels are very good too. Moreover, from the point of view of environment sustainability, using recycled plastic is of course much better than using vegetable fibers.

Recyclability

Given that the obtained results were good for the purpose we had, and that transforming the plastic found in the environment from refusal to resource was a cheap solution and a good way of cleaning up the landscape and reducing pollution, we asked ourselves one more question: "Is the new composite material that we are going to produce recyclable? Or we are just postponing the problem of plastic waste?"
The main point was to find out if it was possible to separate the gypsum from the polyethylene. Obtained the separation of the matrix from the fiber the two materials were then recyclable.
We went through a few experimental ways and in the end we could obtain the complete separation of the 95% of the material. The remaining 5% was not pure LDPE or gypsum but it could be used for other purposes (filling, aggregate or other).

Comfort simulation

In addition to the analysis on the panel itself, we analyzed the performances of the whole roof comparing three different scenarios:

1- Roof made with metal sheet
2- Roof made with metal sheet + inclined gypsum-LDPE ceiling boards (with small air interspace ~ 5 cm)
3- Roof made with metal sheet + horizontal gypsum-LDPE ceiling boards with major air interspace ~ 80 cm)

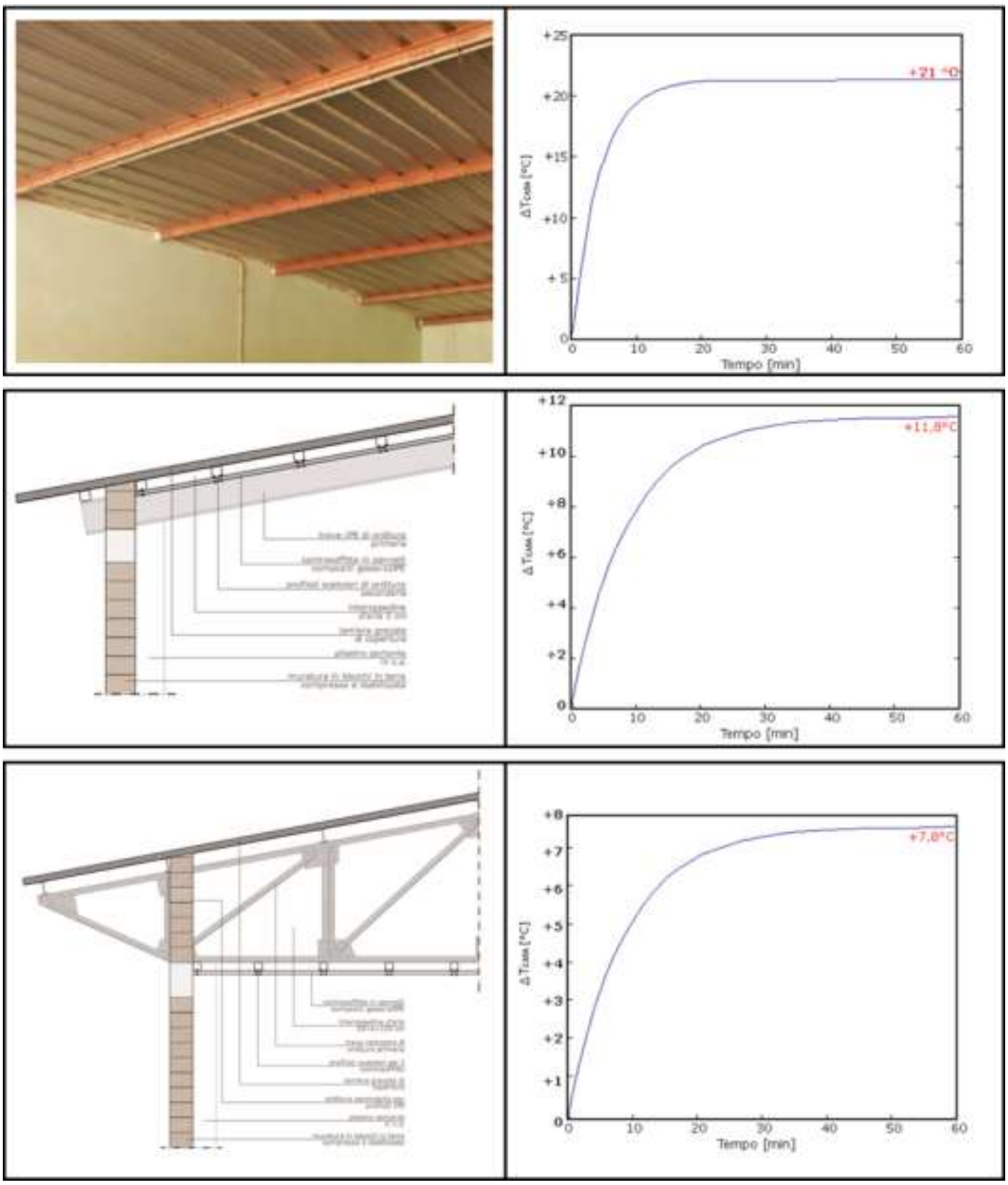

Figure 5: Three scenarios: scheme + inside temperature simulation.

In order to evaluate and compare only the performances of the roof, for the simulation it was considered a building with no ventilation (no windows) made with earth walls.
It comes up that the ceiling board are very efficient and basically allow to halve the inside temperature given by the metal sheet.

Conclusion

Can we, in the end, state that the initial goal is achieved?
Does the idea of realizing gypsum-LDPE composite ceiling board satisfy the needs underlined in the initial analysis?
Consistent with the fact that, to be considered effective, a technology or project must be tested on site and, most importantly, must generate an interest among local people, we can assume positive results.
The plastic recovered from the environment, when used as a fiber actually becomes a resource and, at the same time, allows to clean the landscape and reduce problems related to that kind of waste.
The panels have good mechanical performances because the presence of the fiber transform the material from brittle to ductile and increases the duration of use; beside, by using the fiber, there is also a good saving in terms of material and costs.
If compared to the effort which is necessary to produce those panels (very low in terms of money, energy and time), the obtained results in terms of inside thermal comfort are remarkable.
Finally, the possibility of recycling almost the whole material makes this technology sustainable in all respects.
The following step could be to that of verify on site the feasibility and the efficiency of this research.

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