The ecomaterials. Science and Innovation to Tackle Housing in Developing Countries.

Fernando Martirena H[1]

Abstract

Housing, health and food are the most urgent problems that developing countries face. Tackling housing deficit in poorer countries prompts for an innovative approach in order to meet the massive demand for land, building materials and technology. The Latin American Network for the Sustainable Habitat, EcoSur (www.ecosur.org) has developed a model for the decentralized production and use of "ecomaterials" based on (a) use of locally available materials, preferably wastes, (b) small scale of production, tapping a local housing market, (c) labor intensive technologies. Universities in Cuba and Europe have engaged in innovation projects, whose aim was to close the loop fundamental-applied-research-technology-implementation in a pioneer's work of cooperation with local governments, NGOs and the civil society in general. A technology for the local production of binders out of agriculture wastes is presented as exampled of the implementation of the ideas. 20 years of successful implementation in developing countries have proven the potential of the new approach to tackle housing problems in a sustainable way. Only in Cuba there are over 50 production units spread throughout the island producing ecomaterials for the construction of approximately 3000 houses per year. The model has been embraced by the Cuban government as a sustainable solution for providing houses to the poorer sectors of society. This model has also been replicated to other countries like Haiti, where disasters have posed a severe burden to the already existing housing needs. This contribution aims at discussing the model and its main contribution to meet social goals.

Keywords: social housing, science & innovation, building materials, disaster mitigation

Introduction

More than two thirds of the world's population lives in the so-called "developing countries", where most of the basic needs are not yet properly fulfilled. The gap between poor and rich nations is most visible in areas like food provision, mobility or housing. Tackling housing problems in poorer nations, where a weak infrastructure and structural economic problems create resistance to progress, prompts for radical innovation; in order to meet the massive demand for land, building materials and technology for the construction of houses, while preserving Mother Nature.

[1] Director of CIDEM, Universidad Central de las Villas, Carretera Camajuani, Santa Clara, Cuba; f.martirena@enet.cu.

The building materials industry is amongst the most dynamic areas for modern development. A wide variety of new products has overwhelmed the international market for construction in the XXI Century. However this impressive development has not equally benefited industrialized and developing countries, being the latter often affected. The “global market” in building materials often causes great constrain to local industry which can only opt for becoming a “franchised business” of international trusts to locally distribute the international products.

This phenomena becomes a burden for the lower income sectors of population in developing countries, who cannot afford to have access to products having a foreign exchange share in its price. The other side of the problem deals with the discouragement of local productions, which leads to decrease in job opportunities, above all in rural areas far distant from industrial regions.

Ecology is also a problem of great concern. Modern technologies are the major responsible for the negative ecological impacts created by the increasing amount of wastes generated by industrial and agriculture production. Environmental awareness and damage prevention is currently addressed with some success in industrialized countries, mainly because of the existing infrastructure, the well-organized society and the law enforcement system to preserve the environment.

The goal is to find an appropriate solution for the poorer sectors of population in under-industrialized countries, where the capital cost is high and labor costs are low. This approach, basically denominated as “appropriate technology” or “intermediate technology” [1] has proved to be a sound solution in many cases; however a larger social impact must be sought by improving the efficiency of such technologies without abandoning the original concepts.

This paper aims at presenting the experiences of a joint collaboration between an academic institution and an international Non Governmental Organization in the pursuit of solutions to tackle housing problems in developing countries.

The model for decentralized production of ecomaterials

The International Network for Sustainable Habitat, EcoSur (www.ecosur.org) has triggered an intensive exchange among academics and researchers, mainly based in Cuba, and experienced practitioners who worked in social projects throughout Latin America in the areas of production of building materials and housing issues in general on the search for new paths to the solution of housing problems at community level in developing countries[2].

The model embraced by EcoSur becomes an alternative to production carried out in large industries with automated processes, where the products have to be distributed at long distances and quite often raw materials have to be sourced from distant places. This brings unemployment at the short term, while it increases dependency from foreign technology and raw materials import.

The manufacture of reasonably priced building materials is among the most important issues, since it allows people to have access to affordable housing. The cost of building materials represent a high percentage of total construction costs for housing, that some authors estimate as higher than 40% in developing countries. Among these materials, Portland cement takes a major part that in absolute amounts up to 15% of total cost of housing in these countries[3].

Imported raw materials have a significant share in the local cost of traditional building materials. Had the production of building materials been done locally with raw materials available in the vicinity of the workshops, the resulting product could likely be affordable for a wider range of population that normally does not have access to traditional building materials. The resulting products should be able to compete in quality and price with the traditional ones and would likely have a better environmental profile since local raw materials normally come in the form of recycled industrial or agricultural wastes.

This kind of small-scale production would also stimulate local economy mainly by creating new job opportunities. Besides, the environment is preserved since the potential threats in the form of wastes are profitably used. The amount of embodied energy[4, 5] incorporated in the new product is lower as compared to traditional products since transport costs are cut to the minimum and technological processes are quite simple.

This has brought about the concept underlying this paper: ecomaterials. The "ecomaterials" (eco stands for ecology and economy) have become an alternative to traditional building materials manufacture. They are similar to traditional building materials although their manufacturing conditions are significantly different. The ecomaterials are manufactured at a very small scale, with appropriate technologies, using local resources. They become a source of decentralized development since local unskilled labor is used, while the products are traded in the surrounds of the workshop in order to save transport costs.

The technologies for the manufacture of ecomaterials do include flexible systems for quality assurance based on field and lab trials adapted to local possibilities in underdeveloped countries. This allows attaining a reasonable high standard for the manufactured products, which then become competitive at local scale. The concept "ecomaterials" comprises a wide variety of building materials with different origin and end use. However the best experiences are reported in the manufacture of Microconcrete Roofing Tiles (MCR), lime pozzolana binder CP-40, hollow concrete blocks and non-stabilized adobe bricks.

In conclusion, the resulting product does not significantly vary when compared to the traditional one, moreover, it becomes a competitive alternative in the local market once it has attained local acceptance. The target product is good (good performance, high strength and durability, and soft ecological profile), beautiful (high quality, good looks) and cheap (low cost), which is the golden dream of every entrepreneur/manufacturer.

Implementing the model: technology for the production of low cost binder

In this section ideas on the production of alternatives binders developed by CIDEM in interaction with several academic partners in developed countries will be presented. Although the paper will focus on the research and scientific part of this work, most of the technologies developed were implemented at the grassroots level.

(a) <u>Recycling agriculture wastes for the production of pozzolans for lime-pozzolan binders</u>

Sugar cane has the ability of fixing silica in its organic structure. When burnt, the organic volatiles disappear and the remaining ash is rich in micro-crystalline silica. Depending on the burning and cooling régimes, the ash can occur in an amorphous, reactive, state or in less-reactive crystalline forms. To produce a reactive pozzolan out of sugar cane, it must be fired and the temperature must be kept within 400-800 degrees Celsius, in order to prevent the transition to crystalline phases during heating. [6,7,8,11].

Burning is the most frequent way to recycle these wastes. Different procedures have been developed to burn the organic wastes under controlled conditions. Some of them, like the Fluidized Bed Boiler (FBB) require complicated operational systems, and others, like rudimentary incinerators simply burn under very simple conditions. It appears that burning temperature, residence time and cooling regime are the most influencing factors.

The author has studied different approaches to produce pozzolans through recycling processes that involve burning bio-wastes of the sugar industry:

1. Collecting the ashes produced during firing agricultural wastes in boilers.

2. Producing ashes through firing sugar cane straw under controlled conditions in an specially designed incinerator

3. Producing a reactive ash, which consists of thermally activated clay resulting from firing a solid fuel block (SFB), a briquette made of clay and finely shredded sugar cane straw.

<u>Ashes collected from the boilers of the sugar industry</u>

The easiest procedure is to collect the ashes just as they are produce in the industry, without any further treatment. Two types of ash were examined. The SCBA ash was extracted directly from boilers of the sugar factory “10 de Octubre” in the province of Villa Clara, Cuba. The SCSA ash was sampled from the heaps of open air-burnt straw in the fields surrounding the sugar factory. The ash was collected as a representative sample from the entire heap – e.g. by taking several grab samples at different heap depths and then blending them together.

The main results of this study may be summarized as [9]:

1. SCBA-ash that is produced in boilers of the sugar industry shows a poor pozzolanic activity. The high firing temperatures, incomplete non-uniform combustion and slow cooling that take place in the boilers are likely reasons for the low reactivity. The main factors that affect the reactivity are the resultant degree of crystallinity of the silica present in the ash and the presence of impurities like carbon and unburnt material.

2. SCSA that is produced from burning sugar cane straw in the open air has proved to be a reactive pozzolan that fulfills the principal requirements for pozzolanic materials. Probably, this is due to the lower temperatures occurring in the combustion, mainly providing an amorphous structure for the silica present in the ash.

<u>Ash treated in rudimentary incinerators</u>

If one expects a higher reactivity from the pozzolan, the thermal treatment of the biomass during firing must be strictly controlled. With this purpose, a rudimentary incinerator was conceived and built with the aim of firing the bio-wastes at temperature under 700 oC, and the residence time under 2 hours, in order to create optimal conditions to produce a reactive ash. The incinerator was designed to process raw sugar cane straw. The target output of the incinerator is 25 kg of ash per hour. [10]

The incinerator was built so as to guarantee that the airflow in the combustion chamber travels through meshes in the external walls. After the start of combustion, the incoming air drags heat from the burning mass to the chimney outlet, and cools down the burning chamber. The input of cool air can be regulated in order to attain the target burning temperature and residence time. A faster airflow lowers the temperature inside the burning chamber and lowers the residence time, as the biomass burns faster with an ample supply of oxygen.

Based upon the strength results, there appears to be no significant benefit in firing sugar-cane wastes in semi-controlled conditions, when compared to firing in open-air heaps. Although the mineralogical study shows that the ashes resulting from incinerator firing have less crystalline phases and more glass phase, this difference is not reflected in strength gain.

The reason for this could be the relatively long residence time of the ash in the burning chamber of the incinerator, and the slow cooling process afterward, which would not promote the retention of the more-reactive glass phase. This, combined with the low output shown by the incinerators during their use, confirms that from a practical/economic viewpoint transition from open-field firing to rudimentary incinerator firing is not warranted. A more sophisticated, higher output, version of incinerator with better and more uniform temperature control coupled with controlled cooling might prove to be a worthwhile future endeavour.

<u>Ash from Solid Fuel Blocks made out of clay and waste biomass</u>

Previous testing has indicated that if firing-temperature is kept below 750 oC, a reactive ash can be obtained by burning bio-wastes, but the practical applications of this solution are limited because at this low temperature heat recovery devices are difficult to implement.

When firing above 750 oC, the ashes resulting from burning bio-wastes become highly crystalline and thus non reactive[11]. At this range of temperature the only chance to produce reactive pozzolans through thermal treatment is by calcining clay. This is a well-known procedure, which involves a relatively large energy consumption, but yields a highly reactive pozzolan. If the energy needed to calcine clay could come from firing bio-wastes, the whole process would be more economically viable, and less dependant on external energy.

To contribute to this, the author has developed the Solid Fueld Block (SFB) [12]. In this block, the bio-waste is mixed with clay before burning and pressed into briquettes; its high calorific value can be used at its maximum potential and the resulting ash – a mixture of the non-reactive ashes from the biomass (approx. 20-30%) and the likely reactive activated clay (approx 70-80%)- can likely be used as a pozzolan. The SFB can be burnt at temperatures around 800-950°C. The higher firing temperature increases the options for use of the resulting energy -- for instance, to fire clay or fly ash-clay bricks. Various techniques for energy utilization from this process are currently under investigation.

The Solid Fuel Block (SFB) is an attractive alternative to recycle waste biomass for the production of reactive pozzolan. Waste biomass, such as agri-wastes, sawdust or waste paper is shredded to fine particles, wet mixed with a suitable clay and pressed into solid fuel blocks. The clay that is used should be high in silica content because the activated clay becomes the main source of pozzolanic material, as the ashes resulting from firing the bio-wastes at temperature above 750 oC are likely non-reactive. The optimum proportion of clay has been found by experiment to be in the range 20-30% by mass. The SFB typically has a dry density of 800 to 1100 kg/m3. The average calorific value is 15 kJ/kg, which makes the SFB acceptable for use a sole source of fuel in an ordinary furnace.

The ash that results from SFB firing needs to be cooled fairly rapidly in order to form a primarily amorphous reactive silica. Slower cooling results in a higher proportion of non-reactive crystalline compounds. Sophisticated techniques for rapid cooling produce optimum pozzolanic activity of the ash but are not practicable for implementation within an agricultural community. It has been found in experimental trials that a simple process of periodically removing the ash from the furnace and spreading it on a metal surface cools the ash rapidly enough to produce a highly reactive pozzolan, which can be used in the manufacture of lime-pozzolan cements or as a supplementary cementing material.

(b) Using calcined clays as supplementary cementitious materials

Metakaolin (Al2Si2O7) (MK) is a highly reactive pozzolan made through the calcination of a clay rich in kaolin. It is produced from high quality crude clays using state of the art technologies to remove impurities and control particle size. The reactivity of MK depends on various factors, such as temperature, heating rate and cooling regime. The optimal temperature window is 700-800 oC, although the dehydroxylation of clay is known to begin above 500 oC [13].

MK is rich in alumina, thus introducing extra alumina in the system when used as SCM in cement. The pozzolanic reaction of MK in blended cements can be then described as:

$AS_2 + 5CH + 3H \Rightarrow C_4AH_{13} + 2CSH$

The volume of new hydrated alumina phases is increased as a result of adding MK to the system. If calcium carbonate is supplied through an external source to the system, the alumina phases will further react with it and form the following phases:

Hemicarboaluminate $3CaO \cdot Al_2O_3 \cdot 0.5Ca(OH)_2 \cdot 0.5CaCO_3 \cdot 11.5H_2O$

Monocarboaluminate $3CaO \cdot Al_2O_3 \cdot CaCO_3 \cdot 11H_2O$

Based on this cementitious system, a mass of clinker can be replaced by the same mass of a mix of MK/calcium carbonate having a 2:1 molar ratio, and yet form new hydration products capable of filling out the pore system in the matrix, thus contributing to improve strength. A prognosis based on thermodynamic modeling (Antoni M. et al 2012) shows that up to 60% of clinker can be substituted without decreasing the total volume of reaction products produced during cement hydration, thus the strength should not be compromised. The alumina phases are faster in reacting, thus the strength gain at early ages is not compromised. This cementitious system can move the boundaries of clinker substitution further without compromising performance compared to a normal OPC.

<u>Calcining the clay</u>

Characterization of the Cuban clayey soil from Manicaragua revealed that it was composed of a variety of minerals including quartz, feldspar and 3 types of clays (kaolinite, illite and montmorillonite). The kaolinite content of the soil was 17%. In order to increase its pozzolanic potential, the clayey fraction of the soil was extracted by a sedimentation process and the kaolinite content of the clay obtained was 40%. Those two materials (soil and clay) were thermally activated for their use as cement replacement materials [14].

Characterization of the materials after calcination allowed us to identify an optimum temperature window, which was a compromise between loss of crystallinity and agglomeration of the clayey particles due to sintering phenomena. 800°C was found to be the optimum activation temperature for both the soil and the clayey material.

The study of the interactions with cement was done by substituting 30% of cement by calcined clays in the production of pastes and mortars. It was shown that clay calcined at its optimum activation temperature had a high pozzolanic activity that was indicated by a consumption of the calcium hydroxide produced by the cement during its hydration. This contributed to the final compressive strength of the materials (see figure 1).

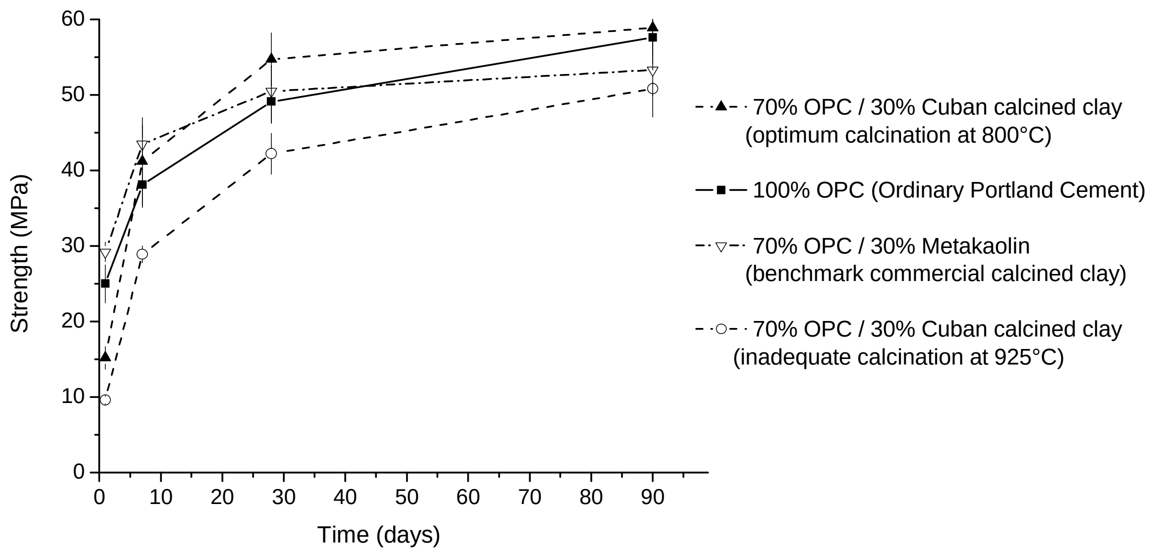

Figure 1: Compressive strength development of Portland-calcined Cuban clays blends compared to standard Portland cement and Portland cement with highly active metakaolin

Ternary blends clinquer-calcined clay-limestone

The aim was to optimize the replacement of cement by calcined clays, including the use of calcium carbonate and gypsum supplementary addition. It has been decided to concentrate on the investigation of the synergies possible in the ternary blends cement – calcined clays – limestone with pure industrial materials, optimize their use in the ternary blends together with limestone and finally study their use in concrete application as well as the durability issues[15].

The new type of cement demands needs optimisation of the sulphate addition at all replacement levels. The replacement of cement by the blend of kaolinitic clay and limestone is associated with increasing reactivity of the aluminates phases, due to the aluminates content of the metakaolin. A correct sulphate level allows a good mechanical strength development by retarding sufficiently the aluminates peak to allow the main peak of the C3S hydration to occur. Gypsum correction for cements made with 15% clinker substitution (B15) and 45% substitution (B45).

Compressive strength of the ternary cement were tested in prisms were cast with a lab made cement using clinker and gypsum from the cement factory Siguaney: (a) SIG-B15, 78% clinker, 10% MK, 5% limestone and 7% gypsum, and (b) SIG-B45, 48% clinker, 30% MK, 15% limestone and 7.5 % gypsum. The mortar prisms were subjected to compressive and bending stress tests. The results (see table 1) prove that the new cements outperform the Ordinary Portland Cement produced in the industry.

Table 1: Compressive strength of mortar prisms made with SIG-B15 and SIG-B45

Index	Parameters	MU	Average CPO in Siguaney	SIG B-15*	SIG B-45*
Mechanical	Bend. Strength 3d	MPa	5.4	10.0	8.2
	7d	MPa	7.1	12.1	11.3
	28d	MPa	9.8	13.1	12.3
	Comp. Strength 3d	MPa	29	36.1	31.9
	7d	MPa	35	51.2	45.0
	28d	MPa	45	61.2	56.1

The whole innovation loop started back in 1992, and the first tonnes of the ternary cement will be produced in Cuba and India in 2013. In the meantime several workshops in Cuba and overseas have produced the lime-pozzolan binder for the local markets. After 20 years, the product has entered a real industrial phase of dissemination, whose impact on economy and environment will be significant.

Appropriate technology? The choice of the scale

Appropriate technology is characterized by: (a) use of locally available raw materials, including the possibility of recycling waste materials, (b) use of machinery adapted to the context, i.e. in rural areas with unskilled labor it should be simple to operate, (c) pursuit of a decrease on the energy consumed in the production process, including transport of raw materials and finished product. In developing countries it could be interpreted as small scale production, mostly done in rural areas [16].

This whole process does not apply for every single technology without exceptions. The author tried in the past to develop a technology for the production of a low cost binder, basically a lime-pozzolan binder, made through intimate mixing and grinding of both raw materials until the desired finesse is reached. The R&D work was done, machinery was developed for the purpose of introducing it at several communities [17], and more than 25 new workshops were created, where pozzolanic cement, together with other materials were produced.

Although still in production, this technology has not been widespread like other similar technologies for several reasons: (a) the production output (1 tpd) did not allow an interesting economic scheme, (b) raw materials processing, above all drying, was extremely complex to implement at a very small scale, and thus the quality of the production was affected, (c) the quality of the resulting product was not consistent through the time, mainly because it proved impossible to scale testing procedures down to the level of field tests, (d) the product had a poor acceptance among the target population, caused by most of the problems described above.

During the 1970´s interesting reports were launched about the “mini-cement plants” in India[18] . The output was between 100-150 tpd and the plant was conceived for a local and regional market. This idea was abandoned due to the low energy efficiency attained, basically because of the firing technology chosen (vertical shaft kilns).

The new chemistry of cement described above in this paper, where clinker substitution has reached 60% without affecting the properties of cement. The technology has been tailored to the conditions of developing countries, that is, simplified to the maximum and the automation is limited only to specific areas. It would be especially interesting –also for developed countries- in a context where oil prices would skyrocket and long distance transportation could be hindered.

If this project takes off, a new alternative for cheap cement shall be made available on the recently opened building materials market in Cuba –non subsidized- . Further, the possibility of replacing Portland cement in many applications such as the production of hollow concrete blocks and roofing tiles could make these products more affordable for the population, and thus could boost local construction. The relatively large scale of the production could enable a relatively large production, and thus a great impact on the target population in a short period of time.

Replication and/or dissemination of this technology elsewhere are not straightforward. It should be coupled with the build-up of local capacity to test local materials for reactivity, either in local research centres, or by creating scientific core groups at universities in target countries at the universities, which again, would imply a change of paradigms in the connection of science with the grassroots. Further, the developers of the technology should devise a comprehensive methodology as to how to implement the project in the target country; financing schemes to foster the creation of partnerships between the academy, civil society and the private or industrial sector; and the engagement of the governments to establish trade policies to benefit the poor, etc.

Social impact. The Cuba case

From 1959-1988, the system for housing provision in Cuba was based on the centralized production of building materials in large, automated facilities operated by the Ministry of Construction. Prefabricated building materials were produced and supplied by road or rail to areas far from the industrial centers; it was an energy-intensive system based upon the supply of cheap oil from the former USSR.

The collapse of the Soviet Union and East European socialist states had a dramatic effect on the system: energy became scarce, roads deteriorated because of the lack of maintenance, the fleet of trucks became obsolete and the supply of spare parts was threatened. This had a great impact on the construction materials industry, which was no longer able to maintain a steady supply of building materials, particularly to areas distant from the production centers.

The lack of availability of building materials led to a decrease in new housing construction and a rapid deterioration of existing housing stock due to lack of maintenance, as the population did not have the means to renovate or maintain their homes in good repair.

The new situation prompted a fundamental shift from centralized production based on long-distance transportation, to the local production of building materials in order to lower energy and transportation costs. Suitable for both rural and suburban areas, the technologies developed by CIDEM are geared towards small-scale production, with a focus on stimulating the local economy through the creation of new job opportunities. The project's main features include:

- An innovative process of technology development and transfer, which has resulted in a set of appropriate technologies for the manufacture of building materials at municipal level. The whole process has been organized as a south-south endeavor, as machinery and know-how come from Cuba and other countries in Latin America. Ecomaterials workshops are carried out that include personnel training and a post-sale advisory service.

- A large-scale decentralized program for production of building materials at municipal level, which contributes to providing affordable and accessible building materials in a sustainable manner, particularly in areas where hurricanes have caused serious damage and a quick post-disaster response is required. This model has been embraced by the Cuban government as the model for housing development, and since June 2009 it has become the official approach of the Cuban government for housing at municipal scale.

- Creation and further improvement of a new decentralized management model for housing renovation, which gives local authorities new opportunities to act independently as well as increase their capacity for resolving urban renewal issues. The model includes the new legal framework for small and medium enterprises working on private (non-state) or collective (cooperative) property, and the launch of pilot projects that stimulate this new production sector in the Cuban society.

CIDEM's work has resulted into a contribution to the gradual migration from a centralized production model based on state-owned, subsidized enterprises to a decentralized production model based on non-state, market oriented production figures operating at municipal scale: 48 municipalities equipped with facilities to locally produce approximately 65% of the materials needed for their own housing programs; a national program for the Local Production of Materials launched by the Ministry of Construction, with funds allocated to progressively expand the model to the rest of the municipalities in Cuba.

Cuba is moving slowly towards an economy where market shall play an important role. The party congress in 2011 has approved a series of measures that will introduce real changes in the municipal economy. However, this is not being implemented as an economic shock, the measures will be solidly planned and implemented within the framework of the constitution and defined in laws (not in decrees). CIDEM has been called to provide advisory service at a very high level at the Cuban government and at Parliament level, to implement a new housing program based on the use of local resources, and a clear emphasis on the non-state productive sector[19].

Concluding remarks

- The collaboration between cutting edge science institutions in industrialized countries and partner in developing countries is feasible and desirable, and can bring about interesting results for both the industrialized and the developing countries.

- The incorporation of fundamental research, coupled to applied research, lowers the possibilities of improvisation, and thus the potential errors or flaws in the technology implementation, which are so common in our environment.

- The collaboration itself becomes a mechanism to build capacity at the partner institution in the developing country, which then –due to the prestige acquired- is called by local clients in the industry to introduce their results.

- Innovation oriented to sustainable production practices could attract industrial stakeholders and thus create potential financing schemes. For instance, a sound partnership with the cement industry in Cuba has helped favouring a sustainable introduction of results, with own funding allocated for the technological transfer.

- The "domino effect" of good scientific partnerships North-South for developing countries can be created: more capacity built, better options for R&D work, more credibility at governmental level, more funding comes.

Literature

[1] Schumacher F.: Small is beautiful. Blond & Briggs ltd. UK, 1978

[2] Pozak K, From mule trails to the electronic highway. A revolutionary decade for south-south knowledge sharing. Published at **www.ecosur.org**, 2003

[3] Salas J.: La importancia de los materiales en las viviendas de muy bajo coste. Revista Materiales de Construcción, Vol 42, No. 227, julio/agosto/septiembre 1992

[4] Blanco Katya: Análisis comparativo de soluciones de techo basado en un análisis de ciclo de vida. Instituto Tecnológico Costa Rica. 1999

[5] Inventory of Carbon & Energy, Version 1.6ª, University of Bath, UK www.bath.sc.uk/mech-eng/sert/embodied/

[6] Mehta K.: The Chemistry and Technology of Rice Husk Ash Cements., Proceeding of the Joint Work Shop organized by UNIDO in Pakistan, 22-26 January 1979.

[7] Boateng A.A., Skeete D.A.: Incineration of Rice Hull for Use as Cementitious Material. The Guyana Experience., Cement and Concrete Research, Vol. 20, pp 795-802, 1990.

[8] Syed Faiz A.: Portland Pozzolana Cement from Sugar Cane Bagasse Ash, Lime and Other Alternative Cements, Intermediate Technology Publication, U.K, 1994

[9] J. Martirena; B. Middendorf; M. Gehrke; H. Budelmann: Use of wastes of the sugar industry as pozzolana in lime pozzolana binders: study of the reaction Cement & Concrete Research Vol 28, No. 11 pp. 1525-1536. November 1998

[10] Martirena J.F., Middendorf B., Day R.L, Gehrke M., Roque P, Martinez L, Betancourt S. Rudimentary, low tech incinerators as a means to produce reactive pozzolan out of sugar cane straw, Cement & Concrete Research 36 (2006) 1056-1061

[11] Shi, C., Day, R.L., Qian, J., Characterization and Utilization of Agriculture, Power-generation and Municipal Wastes for the Manufacture of Pozzolanic Cements, in "State of the Art 2000", published for ENERGEX 2000 International Energy Forum, International Energy Foundation, Las Vegas, 2000.

[12] Martirena, J.F. Biomass for the manufacture of building materials. The efficiency at small scale of production. Journal BASIN NEWS, No. 18, November 1999.

[13] Rodrigo Fernandez, Fernando Martirena, Karen L. Scrivener; The origin of the pozzolanic activity of calcined clay minerals: A comparison between kaolinite, illite and montmorillonite; Cement & Concrete Research. Volume 41, issue 1, January 2011, Pages 113-122

[14] Martirena, JF, Fernandez R, Alujas A, Castillo R; Scrivener K; Production of activated clays for low cost building materials in developing countries, Proceedings of the 13th International Congress On The Chemistry Of Cement Madrid, 3 - 8 July 2011

[15] Antoni M., Rossen J., F. Martirena, Scrivener K. Cement substitution by a combination of metakaolin and limestone. Cement and Concrete Research Issue 42/12, 2012.

[16] Martirena Hernandez José Fernando: Science and Technology Made in the Developing World: A Result of Successful Networking. Swiss Commission for Research Partnerships with Developing Countries-KFPE, 2001

[17] Martirena J.: The development of pozzolanic cement in Cuba. Journal of Appropriate Technology vol. 21, No. 2, Sept. 1994. U.K., pp. 25-27

[18] Small-Scale Production of Portland Cement (HABITAT, 1993, 92 p.)

[19] Martirena F. Ecomaterials for Social Housing in Cuba. Dossier of the work of CIDEM awarded for the UN-HABITAT “Scroll of Honor” 2011, Mexico, October 2011 (www.unhabitat.org)