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Low investment costs as key driver for upscaling alternative construction technologies

Yudiesky Cancio Diaz[1,2], Hector Archilla[3], Giulia Celentano[2], Guillaume Habert[2], Edwin Zea Escamilla[2]

[1] *Facultad de Ciencias Económicas, Universidad Central de las Villas, Santa Clara, Cuba*

[2] *Chair of Sustainable construction, Swiss federal institute of technology, ETH Zurich, Switzerland*

[3] *BRE Centre for Innovative Construction Materials, Bath University, Great Britain*

Corresponding author:

ETH, Stefano-Franscini-Platz 5, HIL F 28.3, 8093-Zürich, Switzerland

Email: cancio@ibi.baug.ethz.ch

Abstract

This study aims to assess alternative materials withstanding low capital investment, with the potential of providing housing affordability for low-income communities. By combining Life Cycle Assessment and Return on Capital Employed techniques, it has been found that glue laminated bamboo housing projects and low carbon cement-based construction materials could foster the scalability of dwelling-places with higher profitability than conventional Ordinary-Portland-Cement-wise investment strategy. The resulting light capital production materials not only can be able to maintain selling prices at an affordable rate, but also will drive more easily the current market for the bottom of the pyramid populations. Through this shift in the material development, the diffusion of appropriate technology implementation on large scale can be more effectively targeted. Finally, these technologies have a lower environmental impact than conventional ones allowing at the same time as a large scale implementation, a potential low carbon path in least developed emerging economies countries.

Keywords: Low investment, cement, bamboo, CO_2

Author's biography:

Yudiesky Cancio Diaz: Associate Professor at Central University of Las Villas (UCLV), Cuba. Vice-dean for academic affairs at the Faculty of Economic Sciences, UCLV. Bachelor on Economics, Master on Business Administration, PhD. Student on Economic Sciences, member of the international project Limestone calcined clay cement. Currently holding a Swiss government excellence scholarship, in a research fellowship at the Chair of Sustainable Construction, ETH-Zürich.

1. Introduction

The rapid urbanization and the ever-growing human population have brought along an unprecedented housing demand which is estimated to be in the order of hundred thousand housing units a day (UN-Habitat 2013). The housing demand is however heterogeneously distributed around the globe and mainly is concentrated on low income communities in emerging economy countries (Buckley and Kalarickal 2006). This part of the population is difficult to reach with the current practices in the construction sector. This situation leading to what has been coined as the housing gap, in other words, the inability to provide safe and decent housing solutions (Salzer et al. 2016). Furthermore, the appropriate technology movement, based on a bottom up approach to provide low cost materials, is currently not able to keep with the pace of construction (Wallbaum et al. 2012).

This paper proposes a paradigm shift based on the assessment of local initiatives in countries like Cuba, the Philippines. Previous studies in Cuba have addressed the feasibility of introducing a ternary blended cement with 50% of clinker (Sánchez et al. 2016). Case studies in the Philippines have explored the suitability of bamboo-based housing (Zea, Habert, and Wohlmuth 2016). The objective is to assess the economic feasibility of alternative low capital technologies as well as their environmental advantage making special emphasis on the relation between the initial capital investment, operational cost, and number of housing unit produced by the given investment.

2. Methods and Data

Economic potentials of proposed technologies have been assessed by a combination of two economic techniques: the Return on Capital Employed (ROCE) and the multiplier effect of investment. The environmental consequences are appraised by means of Life Cycle Assessment (LCA).

2.1. Economic tools

The Return on Capital Employed is a managerial accounting-based tool widely used by decision-makers to support a variety of fundamental decisions. Some recent applications of ROCE within the cement industry can be found in (Tiwari and Goel 2015, Azhagaiah and Silambarasan 2014, Khan and Khokhar 2015, Narasimhan 2016, Mutune 2014). ROCE lies in the domain of conventional financial ratios capable to feature light on the profitability of an economic activity. By definition, it stands for the relationship between earnings and invested capital. Putting it another way, it represents the relationship between the value of resources used in a business and the return or profit derived therefrom (Bishop 1969). Eq.1 depicts the formula of ROCE in a simple manner.

$$ROCE = \frac{EBIT}{CAPITAL\ EMPLOYED} = \frac{EBIT}{EQUITY + LONG\ TERM\ LIABILITIES} \qquad \text{eqn. (1)}$$

In a regular basis, Earnings before interest and tax (EBIT) derives from the Income Statement (IS) of the business, which is one of the main financial statements. For a deeper understanding on financial statement and its implications for a business financial position, performance and interpretation, see (Berk and DeMarzo 2007). Capital employed represents the sources of funds available to a business as stated on the Liabilities side of a BS. Employment of capital shows the way in which the funds are utilised as described on the Assets side of the BS (Bishop 1969). ROCE is expressed as a percentage and benchmarked against the relevant cost of capital. Common practices use the so-called Weighted Average Cost of Capital (WACC), understood as the weighted sum of different costs of company's financial leverage sources. The rule of thumb when interpreting ROCE can be synthetized as follows: if ROCE > WACC, the capital employed in economic activity is creating value for the shareholders, thus, the system under analysis yields profitability. Contrariwise, the system is non-profitable. A thorough examination on WACC is available in (Pratt 2003, Pearl and Rosenbaum 2013).

The multiplier effect of investment is, by definition, the amount of output rendered by an economic system per unit of money invested, given certain constraints. Output stands for the results obtained after one or more processes have taken place. These outcomes are regularly measured by means of a success economic criteria, being among the most widely used: production volume, turnover and earnings. The underlying philosophy of the multiplier effect analysis is linked to the concept of efficiency, which is defined as the ratio of output to inputs, according to the most generic approach (Charnes, Cooper, and Rhodes 1978). In this paper we assume the number of potentially buildable houses as the main output when comparing the different technologies presented, as well as the their potential jobs creation capacity.

2.2. Life Cycle Assessment (LCA)

The environmental life cycle of a product consists of all the stages from raw material extraction to its waste management. Life cycle assessment, then, is the assessment of the environmental impact of a product across its life cycle (Baumann and Tillman 2004, Hellweg and i Canals 2014).

There is a series of international standards for LCA, ISO 14040-14044, which was issued from 1997 onwards. In the umbrella document (ISO-14040 1997) LCA is defined through the procedure for performing an LCA. "LCA is a technique for assessing the environmental aspects and potential impacts associated with a product by:

- Compiling an inventory of relevant inputs and outputs of a product system;

- Evaluating the potential environmental impacts associated with those inputs and outputs;
- Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study".

In addition, it is stated that LCA describes environmental aspects and potential impacts throughout a product's life cycle, i.e. raw material acquisition, production, use and disposal. Resource use, human health and ecological consequences are the three general impact categories to be considered.
Four steps are depicted and standardised in ISO 14040: (1) the definition of goal and scope, (2) the development of life cycle inventories, (3) impact assessment and (4) interpretation.
SimaPro software supports the implementation of LCA and facilitates the life cycle modelling. Technicalities of SimaPro v.8 can be revised in (Goedkoop et al. 2013), along with a systematic background on LCA theory. The functional unit assessed was a housing unit of 80sqm and IPCC2013 (Edenhofer et al. 2014) was used as evaluation method.

2.3. Description of alternative technologies

Three alternative technologies are assessed in this paper: (i) glue laminated bamboo, (ii) limestone calcined clay cement (LC^3) and (iii) Ordinary Portland Cement (OPC). Option (i) implies setting up of a small glue laminated bamboo production line of yearly capacity of 14 400 m^3 of this type of bamboo product. Option (ii) entails the investment in a flash calciner in order to calcine the kaolinite clay to produce the blended cement low carbon cement (LC^3). Also additional investment for clinker production increase is required. Option (iii) assumes the investment in a new cement plant to produce OPC. Two economic analysis are featured. The first one explores the efficiency of investment as a result of investing in the aforementioned choices, by calculating the number of housing units (80 sq.m of floor area) buildable with one million of USD. The second economic approach is the calculation of ROCE for one year of operation of each alternative investment. LC^3 is a blended cement produced with 50% clinker, 30% metakaolin, 15% limestone and 5% gypsum. Detailed description of LC^3 can be found in (Sánchez et al. 2016) and glue laminated bamboo in (Zea and Habert 2014, Zea, Habert, and Wohlmuth 2016).

2.4. Data

The main input data for the present assessment come from previous case studies undertaken by the authors, which can be found in the previous cited papers. The material consumption for the specified functional unit (80 sq.m housing unit) along with the economic data required to assess the suitability of alternatives is summarized on **Table 1**.

Table 1. Material consumption by house type and economic data

Materials	Unit	Amount		
		Bamboo house		LC3 house
Concrete blocks	u	-		2200
Mortar	kg	-		11520
Steel	kg	200		840
Glue laminated bamboo	kg	3805.5		-
Economic input data according to the production process linked to each technology				
	Unit	Bamboo	LC3	OPC
CAPEX	MUSD	4	42	263
Production capacity	m^3 bamboo/Mt cement	14400	0.27	1
Operation cost	USD	109	57	72
Price	USD	159	97	104

Linear depreciation of CAPEX over the lifetime of different machinery/equipment was considered as assumption for the estimation on capital employed. In the case of LC^3, a flash calciner for kaolinite clay calcination is taken into account, with a yearly capacity of 800 kiloton of metakaolin (calcined clay), which means 0.26 Mt of LC^3 per year. A production line of glue laminated bamboo with a yearly production capacity of 14 400 m^3 has been considered. One housing unit of 80 sq.m consumes 4.3 m^3 of glue laminated bamboo and 1 m^3 of bamboo represents 885 kg. This housing unit consumes 5.7 t of cement when considering options (ii) and (iii). Concrete blocks manufacturing, placement and finishing are taken into account. Concrete required for foundations is not considered in this analysis. The capital investment of LC^3 technology includes the additional CAPEX required to (1) increase clinker capacity, (2) expand aggregates production and (3) enlarge concrete block manufacturing. In the case of new cement plant to produce OPC, due to the very high capital expenditures (CAPEX), the extra costs given by (1), (2) and (3) were not considered, as they are negligible compared to the cost of a new cement plant, which itself makes this option unfeasible if affordable housing technologies are targeted.

3. Results

The results from this research can be used by different stakeholders, to make informed decisions when selecting construction materials. The economic results of the three studied technologies are presented on **Table 2**. These results show that LC^3 technology exhibits the highest possible profitability, while glue laminated bamboo has a marginal result. OPC investment strategy exhibits a ROCE below WACC, which means the inability to achieve profitability, according to the current pricing system and general economic assumptions. Furthermore, both alternative construction materials are able to produce more houses per million USD invested (MUSD) than the benchmark OPC.

Table 2. Economic assessment criteria

Criteria	Unit	Bamboo	LC3	OPC
ROCE	%	4.50	14.8	6.1
Nr. of Houses/MUSD	u	837	1113	667
Potential jobs creation	u	400	40	40

From the environmental perspective, bamboo-based solutions are able to capture and store more CO_2 than what was emitted during their production as seen on **Figure 1**. This value is however highly sensitive to end of life scenario as shown in previous studies (Zea, Habert, and Wohlmuth 2016) Furthermore, LC^3 technology produces a significant reduction on emission when compared to the reference OPC. Given that global warming potential is the most important environmental impact category associated to construction sector, these results highlight the environmental advantage of proposed technologies.

If attention is drawn on house affordability rather than production profitability, the multiplier effect is more significant for Glue laminated bamboo. Moreover, LC^3-based housing projects provide the greater potentials for increasing the total annual construction of houses. This shows that the low capital investment approach of both alternatives ensures setting up the technologies at a faster pace. In the case of bamboo, the initial investment is extremely low compared to almost whichever alternative within the construction sector.

Another important social value to analyse is the potential jobs created with the production of each construction material. The establishment of one bamboo production line, would potentially create ~400 direct jobs as described by (Zea, Habert, and Wohlmuth 2016), especially related to the management of bamboo plantations. Low income population could also be beneficiated from the new employment and income opportunities.

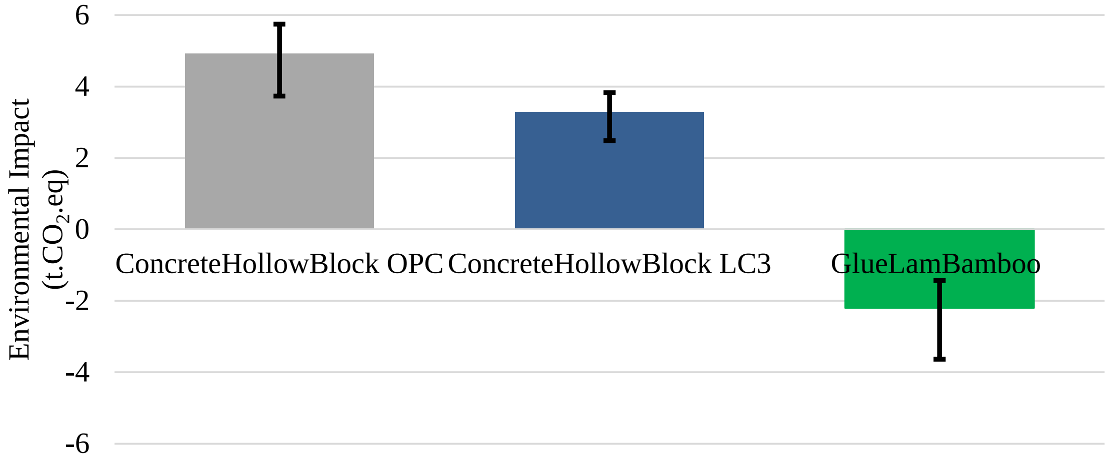

Fig. 1. Environmental impact of alternative technologies. IPCC 2013 GWP 100a

4. Discussion

The results for all the studied technologies were combined on a benchmark which is presented on **Figure 2.** The X axis shows the number of houses produced per million USD invested; the Y axis shows the environmental impact in terms of ton of CO_2 emitted on the production; while the bubble size represents the number of potentially jobs created associated to the production of each construction material. The cost-advantage of alternatives holding a low initial capital investment (bamboo and LC^3) is noticeable. In least developed countries, like those covered by previous case studies, the availability of kaolinite clay and bamboo culms has been proven for the deployment of both technologies.

The inception of glue laminated bamboo and LC^3 in the marketplace in a medium-to-large scale would foster the profitability of producers by reaching economies of scale, but this requires a long-term strategies. From a social standpoint, it could be more advantageous to deploy small workshops of bamboo production lines with relatively low investment cost. Intervention strategies in local communities would also become a key factor when setting up the technology, since they can tackle the need for employment and the lack of housing at the same time with a green contribution to the environment. From the economic point of view, LC^3 provides the fastest return of investment and the highest number of housing units produced per million USD invested.

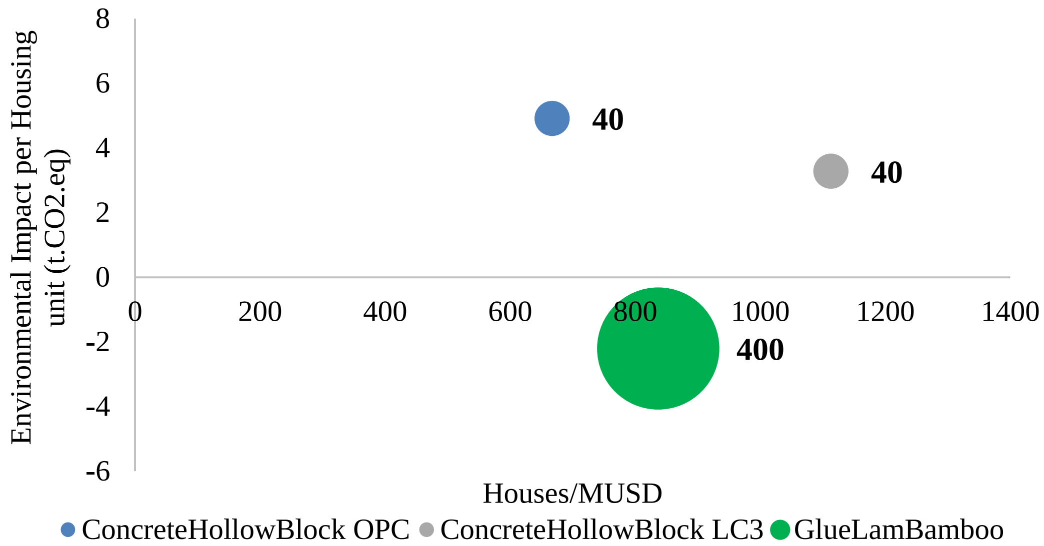

Fig. 2. Multiplier effect of initial investment vs. environmental impact

Despite of the great advantages of kaolinite clay cement and bamboo-based construction materials, two challenges could be identified, such as: the mind-set within construction industry and governmental key players on the uptake of new technologies, the unawareness of potentials for local sourced resources in order to upscale the construction of living spaces.

5. Conclusions

The objective of this study was to assess alternative technologies withstanding low capital cost rather than low operation expenses. By combining LCA and ROCE techniques, main results showed that LC^3 housing projects lie on the frontier of maximum possible profitability. However, bamboo technology exhibits the cost-advantage of low investment strategy leading to increase the affordability of dwellings compared to the reference OPC. Alternative technologies have shown to provide the greatest efficiency of investment, favouring the speed up of construction schemes which would beneficiate low-income communities. Finally, commonalities on lower environmental impacts are demonstrated for both LC^3 and bamboo-based solutions, when compared to OPC. It can be concluded that low investment can foster the development of low-cost construction materials and thus help alleviate the housing crisis we are facing.

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