Float-Ram: A Sustainable Machine for Buildings Made by Compressed Earth Blocks

Float-Ram: a sustainable machine for buildings made by compressed earth blocks

Giuseppe Quaglia [0000-0003-4951-9228], Carlo Ferraresi [0000-0002-9703-9395] and Walter Franco [0000-0002-0783-6308]

Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Torino, Italy
giuseppe.quaglia@polito.it

Abstract. This article describes a sequence of research, design, prototyping and utilization of a new manually operated press, which has the purpose of facilitating a construction technology that uses compressed earth blocks, CEB. Buildings and houses made of CEB have better quality than traditional in poor region. They are also economical, robust, aesthetically pleasing, and sustainable from an environmental point of view. The research is addressed to some targets of the SDG 11, Sustainable Cities and Communities: (i) “ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums”; (ii) “support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials”.
The paper presents the project path, the results and finally the impact in a specific context, the rural areas in Tanzania.

Keywords: SDG11, earth construction, compressed earth block, human powered press, manual operated machine

1 Introduction

The right to adequate shelter is recognized as a basic and fundamental human right since 1948, with its introduction in article 25 of the Universal Declaration of Human Rights. Other international treaties have addressed the right to adequate housing with different approaches. The United Nations agency UN-Habitat promote socially and environmentally sustainable towns and cities to improve living conditions for all. Among the targets of the SDG 11, Sustainable Cities and Communities, we find: (i) “ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums”;(ii) “support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials”[1].

Nevertheless, the right to adequate shelter is far from its full implementation. The amount of slum dwellers reached more than 1 billion in 2018, the 24% of the urban population, even recording a slight increase compared to the 23% in 2014. In Eastern and South-Eastern Asia, 370 million people live in slums, 238 million in sub-Saharan Africa and 226 million in Central and Southern Asia [1]. In Latin America, 10 to 15 million households live in substandard housing and the deficit in adequate housing continues to grow. Faced with a demand of 2.5 million homes per year, only 1.5 million are adequately built [2].

This chronic lack of housing opens to practices of self-help housing in informal settlement, which house up to 60% of the urban population in some Latin American cities [2]. In fact, due to the limited planning and financing capacities of public bodies, the inefficiency of assistance mechanisms, the lack of interest of private individuals, and also the scarcity of resources on the part of single families, it seems that a contribution to the mitigation of the problem may come from low-cost construction technologies suitable for self-construction [3], that make use of local, widespread, easily available and low-cost materials, such straw [4, 5, 6], timber [7] or earth.

The history of earth construction technologies is as old as that of urban society. The first settlements in the Fertile Crescent, 10,000 years ago, were almost entirely in earth. Much of the building widespread in European cities until the industrial revolution was built with raw earth techniques [8]. Raw earth construction is widespread in a large part of the globe, in climatic regions very different from each other: in coastal areas, inland, in the plains and in areas mountainous or hilly. A common factor is the use of earth taken under the fertile soil layer and therefore devoid of the organic fraction, composed of appropriate quantities of clay, which acts as a binder, silt and sand. The earth building technique has been successful due to the almost unlimited availability of the building material, its cost-effectiveness, the possibility of use on site without the costs of transport and transformation. The numerous and different earth construction techniques, developed in innumerable regions of the world according to local conditions, can be grouped into two macro-categories: *rammed earth or pisé* in which the wall is built compacting the earth directly in a box; *raw brick* in which the wall is realized using earth blocks.

In the field of self-construction, in recent decades the technique that uses raw bricks has been the subject of renewed interest as the blocks can be produced off-site reducing drying and installation times, and allowing assembly also by unskilled labor [9, 10]. Blocks can be made manually pressing the earth into an open timber frame (adobe) or produced using proper presses (compressed earth block CEB). The CEBs technique permits to improve the mechanical characteristic of the block, and to avoid erosion during rains, in particular when the soil is stabilized with a small percentage of Portland cement (about 6-10%) [9]. For all these reasons, the CEBs construction technique is appropriate to improve the housing conditions of poor people [11, 12].

To produce CEBs, hundreds of block presses have been developed since the first invented by the French architect François Cointeraux in 1789 [13]. The Belgian engineer E. Gossiaux in 1904 designed a machine, La Madelon, improved in the Super Madelon model, produced by different manufacturers with different names (Stabibloc, Fib-SM, Terstaram, Ceraman) and used until the 1990s. These models were bulky, heavy and expensive, with consequent limitation of dissemination. In order to overcome these issues, the Chilean engineer Raul Ramirez developed in 1952 a low-cost model, called Cinva-Ram, one of the best-known and most widely used block presses in the worl. One of the limits of Cinva-Ram is to perform unidirectional compression. Bi-directional presses can compress two sides of the block at the same time, improving its homogeneity. Among the bidirectional presses we mention the Altech Geo50. In [14], the authors underlined some disadvantages of the bidirectional presses currently available on the market: constructive complexity, high cost, difficult to use, poor ergonomics, non-constant actuation force required to the operator, low compaction pressure, safety issues. In [15] they presented the concept and the general design of a new press, called Float-Ram. In this paper, first the local context of the application of the technology, the Njombe region of Tanzania, is described, then the detailed design of the machine is presented, finally the kindergarten of Mkiu made in self-construction wit CEBs produced using the Float-Ram is shown.

2 Local needs and design requirements

2.1 Social conditions and traditional buildings in Tanzania

To assess whether a technology can have a positive impact in a specific context, it is necessary to start from the needs and criticalities of that community, and define the scenario, considering the specific living conditions. An example can be that of the Njombe region, Tanzania, where the rural population lives mainly on small agricultural activities and the very humble houses are built using fired clay bricks with rudimentary techniques (Fig 1a, 1b). The houses are not very durable, often unhealthy, and unsafe.

The workers, using their bare hands in the mud, fill moulds (Fig 2a) which are overturned on an open ground (Fig 2b) to allow drying in the sun. Subsequently, the bricks are fired creating small mounds under which the fire is kept burning for several days (Fig 2c). This technology has numerous drawbacks: it generates deforestation and a significant environmental impact in the areas where it is used; the bricks produced are very inhomogeneous, brittle, fractured and irregular (Fig 2d). Given the very irregular shape it is necessary to use a lot of mortar and therefore a lot of concrete between one brick course and the other, to build regular-looking walls, and a certain skill is required to make reasonably flat walls.

Fig. 1. Traditional buildings in fired clay bricks, Tanzania

Fig. 2. Production techniques of fired clay bricks in Tanzania

In this context, the local needs generate a request for appropriate technologies which is an indispensable condition for the implementation of successful projects. Appropriate technologies may have an impact not only on the aforementioned SDG11, but produce a social development, such as that desired in SDG1, and in particular in the targets 1.4, "ensure that all men and women, in particular the poor and the vulnerable, have access to appropriate new technology" and 1.5 "build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events"

Construction techniques with CEB are a valid alternative, particularly suitable in poor countries with a rural economy, to provide a better quality of life and housing.

2.2 Design requirements

Requirements related to CEB and production process

The authors chose to design a novel press, named Float-Ram, able to produce the CEB named "Blocco Mattone", whose geometry and dimensions are shown in Fig. 3. The geometry defined by prof. Roberto Mattone, of Politecnico di Torino, is effective for easy wall construction thanks to overhangs and holes, and guarantees high wall robustness [16, 17].

The earth must be compressed bi-directionally in order to increase the CEB quality, up to 60% of the initial volume, applying a compression pressure of 1÷2 MPa [9].

Regardless of the type of press, the production process of a CEB must carry out seven phases summarized in Table 1.

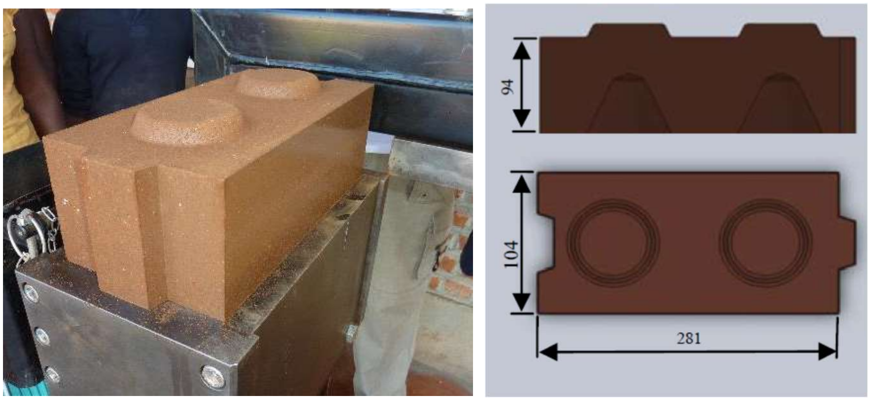

Fig. 3. "Mattone" Compressed Earth Block

Table 1. . CEB production cycle.

Operation	Phase
1. Mould filling	P1. press arrangement to earth filling
	P2. earth metering and mould filling
2 Block forming	P3. press reconfiguration for block pressing
	P4. block pressing
3. Block extraction	P5. press reconfiguration for block expulsion
	P6. block expulsion from mould
	P7. block removal

User oriented design

The design process is focused on the users, their needs and requirements.

In the conception of the press, the following project objectives were therefore set: safety, simplicity of use, effectiveness and efficiency. sustainability, human wellbeing, ergonomy and performance. Furthermore, the environmental and social context makes manual operation preferable since the costs deriving from hydraulically operated presses would not be sustainable and in general the supply of energy in poor regions is often difficult or impossible.

Operational requirements

Other requirements derive from the conditions of use: The press must be easily transportable on the construction site, loadable on a pick-up vehicle, must have a "closed" configuration very compact in a parallelepiped volume in order to be easily shipped to different countries, must be equipped with wheels for small mobility in the operational context, and must have the lowest possible construction cost, compatibly with high performance and reliability.

Mechanical synthesis requirements

A design challenge was to conceive a machine that could carry out the aforementioned seven phases basing all the movements on a single main kinematic element, as part of all the necessary kinematic pairs, with the general aim of reducing the press production costs and of making the press easily buildable and maintainable.

3 Functional design

3.1 Mechanical architecture

Starting from design requirements, the mechanical architecture of the machine was conceived (Fig. 4):

- a single lever, operated by the worker, is used to manage both the reconfigurations of the press and the compression and ejection phases of the block;
- bidirectional compression is obtained in an innovative way by moving only the lower plate and leaving free the translation of the mould walls;
- motion transmission occurs through a transformation of the rotation of the lever into a translation of the lower plate, thanks to a cam system; the synthesis of the variable transmission ratio mechanism allows the design of a system capable of exerting increasing pressure on the block, while requiring an almost constant force exerted from the operator;
- a single cylindrical kinematic element serves for the realization of all the kinematic pairs necessary for operations, reducing costs and complexity of the press and increasing its precision and repeatability.

The production cycle is presented in Fig. 4. First the mould must be positioned in the configuration of Fig 4a, to start the production of the block (phase P1). The metering box must be completely filled by the operator with a mixture of earth, cement and water necessary for the creation of the block. Since each type of soil has specific properties, the volume of earth necessary for the creation of the single block varies and for this purpose a process set-up phase is necessary. By adjusting the position of the movable bottom of the metering box, the volume of soil that will be poured into the mould at each cycle is defined, allowing a regularity of the production process and a constancy of the mechanical properties of the bricks produced. To fill the mould (P2) the metering box is rotated quickly, pouring its contents into the mould.

The mould, together with the entire motion transmission system, is brought inside the pressing portal simply by dragging the lever in rotation, A, with respect to a vertical axis coinciding with the shaft (P3), Fig 4b. During this operation, which takes place thanks to the presence of an axial support bearing on the shaft, the operator does not perceive significant forces since no part of the machine is raised or lowered.

The compression of the block (P4) occurs by rotating the lever downwards and thus activating the cam system, Fig 4c. It is necessary to point out that there are two different cams, integral with each other and operated by the same lever. The pressing cam is designed in such a way as to optimize the compression phase; the expulsion cam to carry out the subsequent phase of ejection of the block. Contrary to usual schemes, the cam axis is free to translate and rotate, while the roller has a rotation axis in a fixed position with respect to the frame. The rotation of the cam is then transformed into a translation in the vertical direction of its axis, guided by the cylindrical kinematic pair consisting of the vertical shaft and the substructure that supports the lower plate of the press. In this way the soil compression process is accomplished. In the same phase it should be emphasized that the floating mould is free to translate in the vertical direction, and this expedient allows a bidirectional compaction of the earth.

By performing an inverse rotation B (Fig. 4b) with respect to phase P3, the mould is brought back out of the portal frame, thus carrying out phase P5, press reconfiguration for block expulsion. Finally, in Fig 4d the phase P6, block expulsion from mould, is represented. In this phase the expulsion cam is active and the rotation of the cam is transformed into a wider translation of the lower plate, necessary for the complete expulsion of the block from the mould, and to allow the operator to take the block (P7), in ergonomic conditions (it is not necessary to bow down) simply by placing the hands on the side walls of the block.

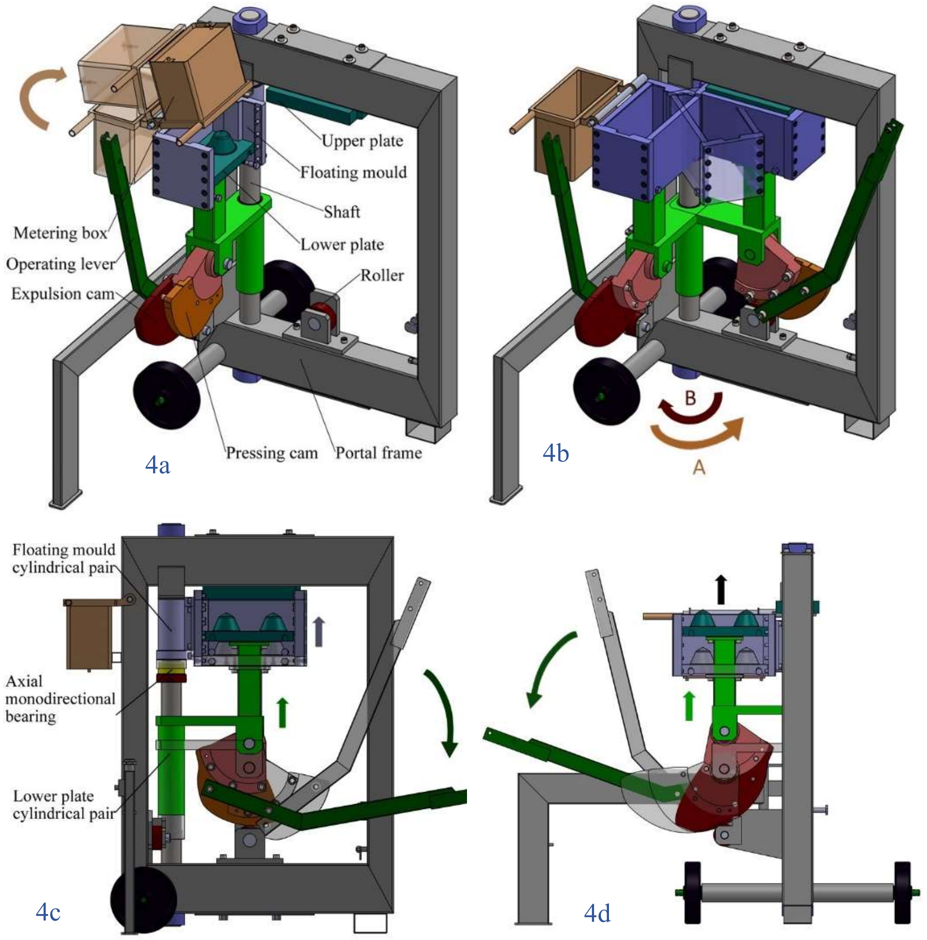

Fig. 4. Float-Ram mechanical architecture and operating phases

Some further details are evident in Figure 5, in which the press is seen in shipping conditions (closed, Fig. 5a) and in working conditions (open 5b).

The closed configuration allows for easy packaging and shipping anywhere in the world. The open condition is obtained with two simple actions: reassembling the folded operating lever in extended configuration, and rotating the lateral support foot 90 degrees, which is used to prevent overturning during the expulsion phase.

Finally, it should be noted the presence of two wheels that facilitate the small movements on site and the loading and unloading operations. The press total mass is about 260 kg and for proper operation cleaning and lubrication of cylindrical pair are required.

Productivity can be close to 100 blocks/hour, but it is strongly affected from the process of raw earth mixing and feeding.

Fig. 5. Float-Ram transport configuration 800x830x1260 mm(a) and operative configuration(b)

3.2 Transmission system design

The design of the cam system is a fundamental element to ensure ergonomic conditions for the operator. The cam profile was created starting from an experimental identification of the pressure trend during the compression of the block. Following an experimental campaign, example in Fig.6a, the parameters K_1 and K_2 of an exponential model of the compression curve of the blocks, $p(y) = K_1 \cdot e^{K_2 \cdot y}$ were identified, where p is the pressure exerted on the block surface A, and y is the compression stroke.

The efficiency of the cam transmission system η is equal to the ratio between the compression work W_F of the block and the work W_C provided by the operator, Eq. (1), indicating with F the force on the compression plate, and C the operating torque on the lever.

From Eq. 1 it is possible to express the instantaneous transmission ratio, *y'*, having the target to keep the requested torque as constant as possible (Eq. 2). After integration of Eq. 2, y(α) used in the typical synthesis algorithms of cam transmissions is obtained.

Figure 6b shows the profile of the compression cam. The synthesis of the profile also requires some further details regarding the initial clearance recovery phase and the final phase of resetting the transmission ratio, not described for sake of brevity.

$$\eta = \frac{dW_F}{dW_C} = \frac{F \cdot dy}{C \cdot d\alpha} = \frac{p \cdot A \cdot dy}{C \cdot d\alpha} \tag{1}$$

$$y' = \frac{dy}{d\alpha} = \frac{C\ \cdot \eta}{p \cdot A} = \frac{C\ \cdot \eta}{K_1 \cdot e^{K_2 \cdot y} \cdot A} \tag{2}$$

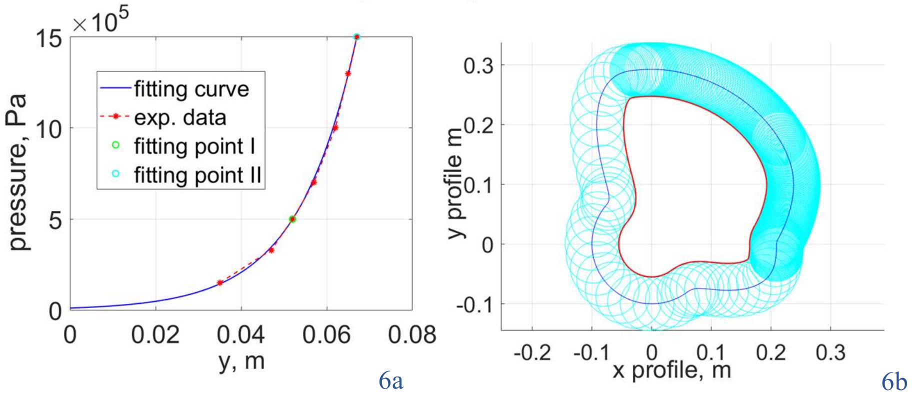

Fig. 6. Pressure experimental data and model (a) Compression cam profile (b)

4 Conclusions

Several examples of Float-Ram press have been used in numerous projects in Africa and South America. In addition to fully satisfactory operational functionality and the quality of the blocks and houses built, numerous positive impacts have been observed. Better and safer working conditions have been created and new professions have been born. Above all, local communities have been able to create conditions for a better future. In Fig. 7 the kindergarten of Mkiu is presented, made in self-construction with CEB "Blocco Mattone", using the Float-Ram press.

Fig. 7. Mkiu kindergarden, Tanzania

References

1. United Nations. Available from: https://sdgs.un.org/goals/goal11, last accessed 2021/05/12.
2. Habitat for Humanity. Available from: https://www.habitat.org/lc/lac/pdf/causes_of_inadequate_housing_in_lac.pdf, last accessed 2021/05/12
3. Foti, M. Tecnologie per tutti. Soluzioni semplice a basso costo per l'habitat. Scuola di specializzazione in tecnologia architettura e città nei Paesi in via di sviluppo, Politecnico di Torino. Internal report (2003).
4. Kean S. Rebuilding: from the bottom up, Science, 327 (5966), 638-639 (2010).
5. Franco, W., Iarussi F. and Quaglia G. Human powered press for producing straw bales for use in construction during post-emergency conditions, Biosystems Engineering, 150, pp. 170-181 (2016).
6. Franco W., Quaglia G., and Ferraresi C. Experimentally based design of a manually operated baler for straw bale construction, The 1st International Conference of IFToMM ITALY, Vicenza, Italy, December 1-2, 2016 in Mechanism and Machine Science, 47, pp. 307-314 (2017).
7. ASF Piemonte. Haiti |1| Foyer d'accueil aux enfants démunis d'Haiti, in III Congress of the University Network for Development Cooperation (CUCS Torino 2013), Torino, 19-21 September 2013, p.317 (2013).
8. G. Scudo, B. Narici, C. Talamo. Costruire con la terra. Tecniche costruttive, campi di utilizzo e prestazioni, Sistemi Editoriali Gruppo Editoriale Esselibri, Napoli, IT (2001).
9. CRAterre. Compressed earth block, Production equipments. Available from: http://craterre.org/, last accessed 2021/05/12.
10. Association Mattone su Mattone. Available from: http://www.mattonesumattone.eu, last accessed 2021/05/12.
11. Venkatarama Reddy B.V. "Design of a manual press for the production of compacted stabilized soil blocks", Current Science, 109 (9), pp. 1651-1659, (2015).
12. Guillaud, H., Houben, H. Earth construction: A comprehensive guide. London, Intermediate Technology (1994).
13. Mukerji, K. Soil Block Presses. German Appropriate Technology Exchange, GATE, (1988).
14. Ferraresi, C., Franco, W., and Quaglia, G. Human Powered Press For Raw Earth Blocks. Proc. ASME IMECE 2011 International Mechanical Engineering Congress & Exposition, ASME, Denver, pp. 579-588, (2011).
15. Ferraresi, C., Franco, W., and Quaglia, G. Concept and design of Float-Ram, a new human powered press for compressed earth blocks. Proceedings of the ASME 2017 International Mechanical Engineering Congress and Exposition, IMECE2017, November 3-9, 2017, Tampa, Florida, USA, (2017)
16. Melo, A. B., Barbosa, N. P., Lima, M. R. F., and Silva, E. P.: Structural performance for a masonry prototype built with blocks of stabilized raw earth. Ambiente Construído, 399 11(2), pp. 111-124. (2011)
17. Sassu, M., Romanazzi, A., Giresini, L., Franco, W., Ferraresi, C., Quaglia, G., Orefice, E. Production procedures and mechanical behaviour of interlocking stabilized compressed earth blocks (ISCEBs) manufactured using float ram 1.0 press. Engineering Solid Mechanics 6 (2), 89–104. https://doi.org/10.5267/j. (2018).