Designing Human Powered Balers for Straw Bale Construction in Developing Countries: The Case of Haiti

Carlo Ferraresi, Walter Franco(✉), and Giuseppe Quaglia

Politecnico di Torino, Turin, Italy
walter.franco@polito.it

Abstract. Straw bale constructions are appropriate for the improvement of the housing conditions in developing Countries. The paper presents, starting from the analysis of the context to the fabrication of prototypes, the design process of several human powered balers useful for the production of straw bales for straw bale construction in poor Countries.

Keywords: Straw bale construction · Human powered baler · Hand-operated machine, humanitarian mechanical engineering

1 Introduction

In January 2016, thanks to the efforts of United Nations, Countries have adopted a new sustainable development agenda, with the aim to end poverty and hunger, to protect the planet from degradation, and that all human beings can enjoy prosperous and fulfilling lives [12]. The agenda is organized in seventeen goals; the eleventh goal provides to make cities and human settlements inclusive, safe, resilient and sustainable. Today, in the World, 828 million people live in slums and the number keeps rising; in addition one in five people in developing regions still live on less than \$1.25 a day [12]. How to ensure access for all to adequate, safe and affordable housing?

The problem is very complex. Typically the appropriate solutions provide the use of widespread, easily available and low cost construction materials, such compressed earth block, [4, 11], straw [6–8] or timber [1]. The solution, however, can only be found from a detailed analysis of the contexts. The present work concerns the development of straw presses for producing straw bale constructions aimed at mitigating the tremendous housing crisis in Haiti.

Haiti is one of the poorest countries of the world and the poorest in the Americas region, with corruption, poor infrastructure, lack of health care and lack of education. Fifty-four percent of the population lives with less than one dollar a day. The Human Development Index is equal to 0.48. In addition Haiti has had in recent years two significant emergencies: in 2010 the earthquake, with 230.000 victims, 600.000 evacuees, 250.000 homes destroyed; in 2016 the hurricane Matthew, with 20.000 evacuees, in particular in the Jéremie region. Both natural disasters have increased a strong housing emergency.

M.I.C. Dede et al. (eds.), *Mechanisms, Transmissions and Applications*,
Mechanisms and Machine Science 52, DOI 10.1007/978-3-319-60702-3_2

The question is: how to mitigate the housing emergency in this situation? Which construction techniques may be appropriate in this context? In 2011, ASF Piemonte, in an international cooperation project, has built a school centre using wood as construction material [1]. The experience has not proved effective: in Haiti, the wood is hard to find, expensive and of low quality. Haiti is quite completely deforested. The study of the context allowed identifying in the traditional rice cultivation the possible solution of the problem. In fact a by-product of the rice cultivation is the straw, which currently is considered a waste, and is burnt in the field at the end of the threshing. Every farmer, in an average plot of 0.25 ha, produces 1.6 tons of straw per year that can be used to realize one hundred fifty straw bales suitable for straw bale construction [2].

There are two basic styles of straw bale construction: the first is non-load-bearing, or post-and-beam, or infill style, in which bales are used as infill panels between or around a structural frame; the second one is load-bearing or Nebraska-style in which the bale wall carries vertical load.

The choice of the appropriate construction technique depends on the local situation. Infill constructions requires to build wood frames, which can be problematic when wood is scarce; on the other hand they have the advantage of being easily designable from the structural point of view; finally are sufficient medium density straw bales (90 kg m^{-3}). Load bearing constructions require higher density straw bales (120 kg m^{-3}), but they have the advantage of presenting high resistance to dynamic loads of earthquakes [3, 9, 10] and not require wood for the structures.

In all cases, it is necessary a suitable equipment for the production of the straw bales. At present, where do not exist balers for agricultural use, it is required to rigorously design appropriate presses, improved over the traditional local solutions. This paper presents several solutions designed by the authors, some of which have been realized and tested on the field.

First, the design specifications of this kind of balers are presented. Then is described the architecture of possible presses and actuation mechanisms are discussed. Concluding, the different solutions are compared.

2 Design Specifications of the Balers

The presses must be able to produce bales of defined and constant dimension (in the specific case the dimensions chosen were $0.30 \div 0.36 \times .45 \times .90$ m), with a density of between $90 \div 120$ kg m^{-3}, depending on the style construction.

The press must be able to operate also without fuels or electricity, in order to reduce the running cost and being available and usable in low-income communities. For this reason must be manually actuated.

Since one of the aims of the project was to involve local communities and to engage a self-constructing and sustainable technology process at a local level, the press has to be simple, ergonomic and easy to self-build; it has to be made using metal products and other materials that can be found directly on site.

Finally the presses must be manufactured using simple tools available locally: metal circular saw, angle grinder, welding machine, drill (Fig. 1).

Fig. 1. Simple tools locally available.

3 Concept Design of the Balers

To produce a 0.3 × 0.45 × 0.9 m straw bale, with final density ρ_f of 90 kg m^{-3}, it is required a mechanical compression work of about 2500 J [6]. The maximum work doable by a human operator, acting with a force F_{op} of about 200 N on an operating lever of 2 m length, rotating it of 90°, is approximately 600 J. A human powered press must then be able to produce a bale in more compression cycles.

Following, first some possible architecture and strategies for the production of the bales are described, and then some simple actuation mechanisms are presented.

3.1 Types of Presses

A first type of baler is characterized by a closed compression chamber (Fig. 2). A certain mass of straw m_c, with initial density ρ_o, is introduced in a closed compression chamber with section A and initial length l_o (Fig. 2a). The compression plate is moved reaching the stroke y_c, necessary to obtain the desired final density of the straw ρ_f (Fig. 2b). Afterwards, the compression plate is back in the initial position (Fig. 2c). Then the sliding-lockable end of the compression chamber is translated by a quantity l_f equal to the length of the compressed straw in the previous compression cycle, and a new compression cycle start (Fig. 2d). Once formed the whole bale in a congruous number of compression cycles, it must be tied and extracted from the compression chamber.

In a second type of baler, called with continuous production, a certain mass of straw m_c, with initial density ρ_o, is introduced in the compression chamber at each compression cycle (Fig. 3a). The being formed straw bale, whose final density ρ_f has been obtained during the precedent compression cycle, takes place in the final part of the compression chamber, and constitutes its end. After this, a complete formed bale is forced to pass through a vertically restricted opening, that crushes the bale. Moving the compression plate, in a first phase the bale already formed is in static friction condition, so it works by an end of the compression chamber, and the straw introduced in the current cycle is compressed (Fig. 3b), until reaching the desired final density ρ_f.

Adjusting the transverse crushing of the bale already formed, it is possible to regulate the friction force, and then, the density of the being formed straw bale. In fact, at the desired density ρ_f, the force applied by the compression plate reaches the

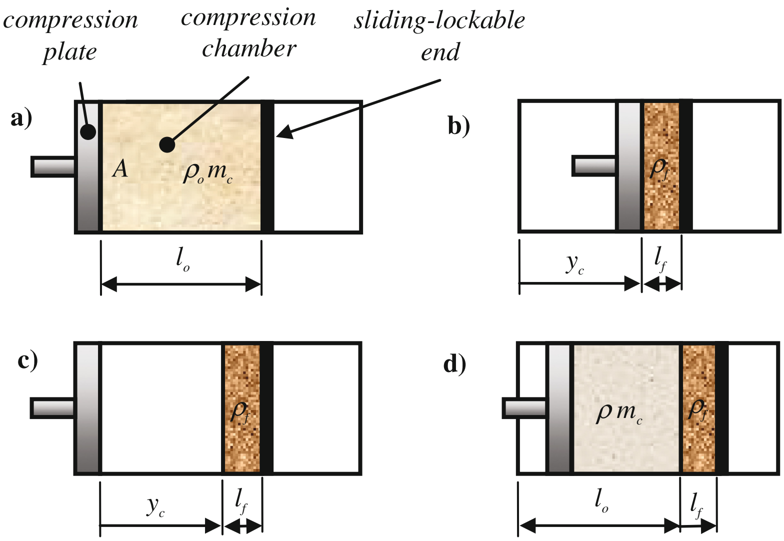

Fig. 2. Bale production storyboard: closed compression chamber press.

dynamic friction force and all the straw translates of y_b (Fig. 3c). The compression cycle is ended when the whole bale moved of l_f, i.e. the length of the straw mass m_c compressed ad the density ρ_f (Fig. 3d). At this point the compression plate is brought back and a new compression cycle is repeated. With this solution the formed bale is ejected gradually, and the bale production is continuous, with possibility to adjust the density.

3.2 Actuation Mechanisms

Apart from the type of press, the actuation mechanism that moves the compression plate should be simple. Considering that, in order to increase the straw density, it is necessary to increase the pressure on the piston surface (and the resultant force), it would be useful an actuation mechanism with variable transmission ratio, in order to require almost constant operating force, while exerting increasing force on the compression plate.

In all cases, for ergonomic reasons, it is considered appropriate an input actuation operated by a lever. The lever, in order to be easily grasped even in vertical position, must have a maximum length of 2 m; the operator, during a compression cycle, should rotate the lever to almost $\alpha_c = 90°$, from a vertical position to a horizontal one, optimizing the application of the force.

In the type synthesis of the actuation mechanism, it is taken into account, first of all, the specification of simplicity and constructability, rather than the requirement of optimization of the transmission ratio. For this reason, simple planar link mechanisms have been chosen instead of cam mechanisms.

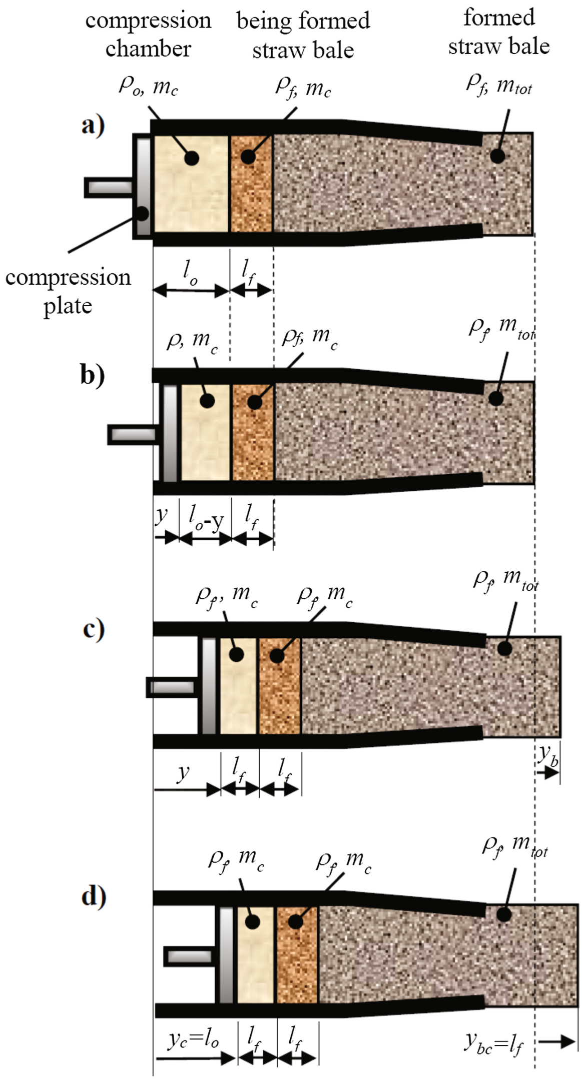

Fig. 3. Bale production storyboard: continuous production press with density control.

A first actuation system proposed is a centred slider crank mechanism (Fig. 4). The actuation lever is rigidly connected to the crank. Making the dimensional synthesis of the mechanism, as described in detail in [6, 7], it must be defined the proper length of the crank m, of the connecting rod b, and the optimum initial angle of the crank α_o, such that the compression plate can be moved of desired stroke y_c, minimizing the operating force F_{op}.

For example, Fig. 5 shows the trend of the operating force F_{op} versus the operating lever angular position α, in a closed compression chamber press, with a compression

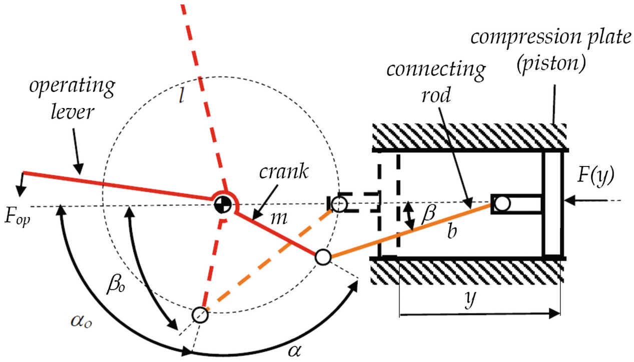

Fig. 4. Baler slider crank actuation mechanism.

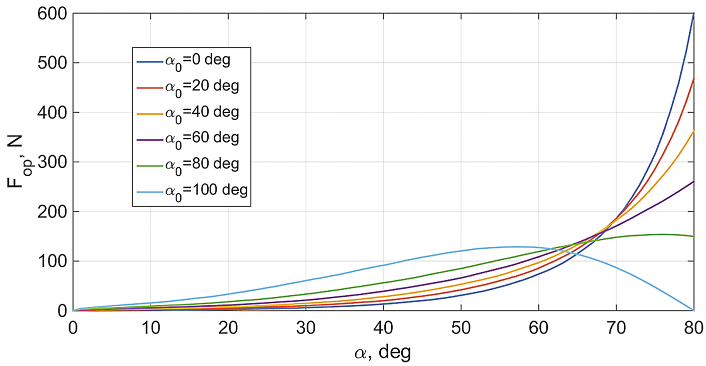

Fig. 5. Operating force F_{op} versus the rotation of the lever α in the case of a slider crank mechanism actuation ($\rho_o \approx 30$ kg m^{-3}; $\rho_f = 90$ kg m^{-3}; $\alpha_c = 80°$; $l = 2$ m; $m = 0.3$ m; $b = 0.7$ m).

plate stroke y_c of 0.31 m. The density of the rice straw is increased to a final value $\rho_f = 90$ kg m^{-3} starting from an initial value $\rho_o \approx 30$ kg m^{-3} [7].

Choosing an initial angle of the crank α_o of about 80÷100°, it is possible to reduce the maximum of the operating force. Unfortunately, the operating force changes significantly during the rotation of the lever. To overcome this drawback, a second actuation mechanism is proposed (Fig. 6). It uses a pantograph mechanism in series to a double slider crank mechanism. The operating lever is connected to the central link of the mechanism (in red in Fig. 6) of length equal to $2d$. Thanks to the higher number of design parameters, and the adjustable phase shift between the two mechanisms in series, it is possible to adapt the mechanism to the required performances, to have more regular operator force, and to avoid normal forces on the sliding plate, that introduces friction and lower efficiency of the press.

Designing the mechanism, the length of the members a, c, d, and the initial angle α_o of the member d must be defined, as discussed in [5]. Figure 7 shows the trend of the

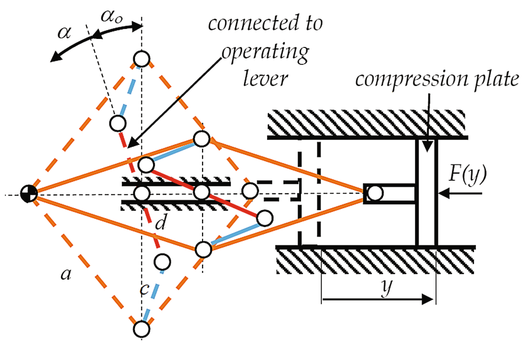

Fig. 6. Baler pantograph actuation mechanism.

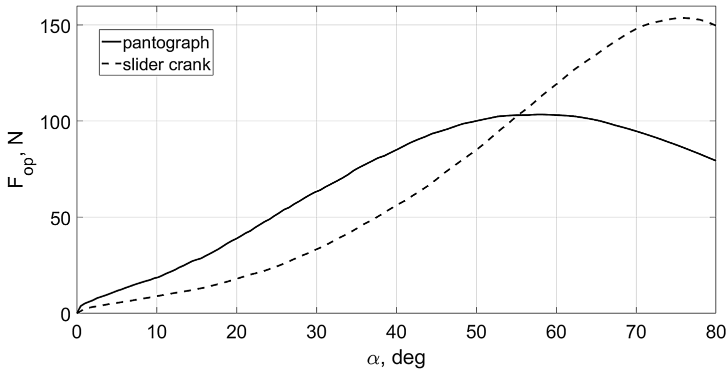

Fig. 7. Operating force F_{op} versus the lever rotation α in the case of a pantograph mechanism (a = 0.35 m, c = 0.2 m, d = 0.131 m, α_o = 30°) and a slider crank mechanism (α_o = 80°)

operating force F_{op} versus the rotation angle of the lever α in the case of a pantograph mechanism, compared to the slider crank mechanism with the same stroke y_c = 0.31 m. In both cases, the density of the rice straw, starting from an initial value $\rho_o \approx 30$ kg m^{-3}, is increased to the final value $\rho_f = 90$ kg m^{-3}.

4 Detailed Design of the Presses and Prototypes

Starting from the considerations presented in the previous sections, the detailed design of different balers have been developed, some of which have been realized.

A first press adopt a closed chamber solution, with a slider crank actuation mechanism (Fig. 8). The straw is charged into the loading chamber. The sliding/lockable end of the compression chamber must be moved cycle after cycle, in order to restore the chamber dimension. The bale formed must be extracted by the unload door.

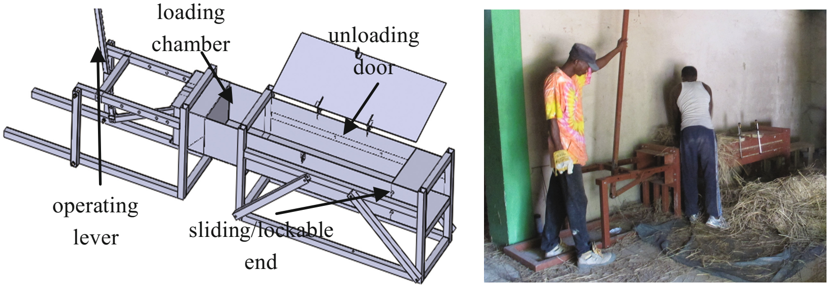

Fig. 8. Closed compression chamber baler with slider crank actuation mechanism: detailed design and prototype

A second kind of baler permit to produce bales continuously, with the adjustment of the density. The actuation transmission is still a centred slider crank mechanism (Fig. 9). The bale formed is progressively expulsed.

Fig. 9. Press with continuous bale production and slider crank actuation mechanism: detailed design and prototype

A last solution proposed (and not realised) is equipped with the continuous production system, and actuated by a pantograph mechanism (Fig. 10).

In all cases, the revolute joints and the prismatic joints of the compression plate are plain bearings. Very simple solutions, as shown in Fig. 11, have been adopted. In order to reduce the friction force, lubricating grease was used.

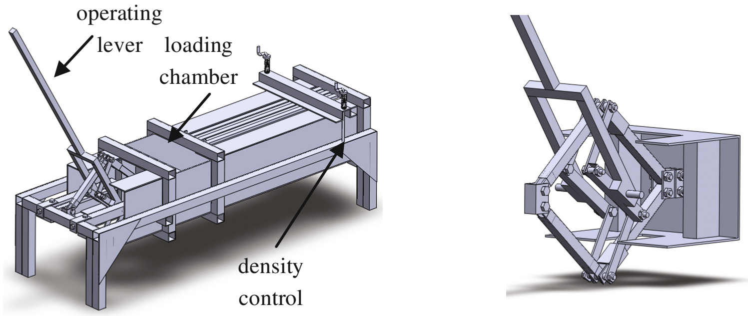

Fig. 10. Press with continuous bale production and pantograph actuation mechanism: detailed design and particular of the actuation mechanism

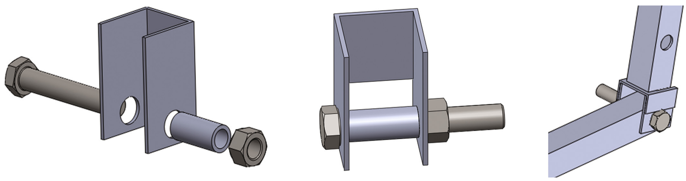

Fig. 11. Constructive solution of the revolute joints of the actuation mechanism.

5 Conclusions

Different solutions of human powered balers for production of bales for bale construction have been proposed. The presses differ both for the architectures and the bale production strategies (closed compression chamber, continuous production), both for the actuation mechanisms (slider crank or pantograph).

Regarding the *closed chamber presses*, they have the disadvantage of having to reposition, at each compression cycle, the sliding lockable-end; in addition the bale density adjustment can only be done by weighing the mass of straw inserted in the bale at each compression cycle; finally the extraction of the entire bale is difficult.

Regarding the *continuous production presses*, they have the significant advantage of being able to control the density of the straw, independently from the mass of straw inserted in the press at each compression cycle; in addition they have the convenience of having the progressive expulsion of the bale being formed. In this case a set up phase of the press at the beginning of straw bale production is required, regulating the friction on the bale adjusting the transverse crushing of the bale, in order to have the proper final density.

Regarding the *actuation mechanisms*, the *slider crank mechanism* is simple and easy to be realized, but has some limitations from the point of view of the optimization of the trend of the operating force. The *pantograph mechanism* is more complex, but it allows to optimize the trend of the operating force.

In general, the solutions proposed have proved to be appropriate for the production of bales for straw bale construction. In fact, two prototypes were constructed, and effectively used for the construction of an infill straw bale warehouse for a rice farmer cooperative of Haiti, and of a load bearing straw module at the Politecnico di Torino, as part of the Anpilpay 2.0 student workshop.

Acknowledgments. Our gratitude goes to eng. Federico Iarussi for the collaboration in the detailed design of the press Anpilpay 1.0; the Architettura Senza Frontiere Piemonte (ASF) association, in the person of Valeria Cottino, Annalisa Mosetto and Veronica Brugaletta for the realization of the Anpilpay1.0 prototype; the Politecnico di Torino student team Anpil Pay 2.0 for the detailed design of the second prototype of baler.

References

1. ASF Piemonte (2013) Haiti |1| Foyer d'accueil aux enfants démunis d'Haiti, III Congress of the University Network for Development Cooperation, CUCS Torino 2013, Torino, 19–21 September 2013, p 317
2. ASF Piemonte (2013) Haiti |2| Re-start from straw, III Congress of the University Network for Development Cooperation, CUCS Torino 2013, Torino, 19–21 September 2013, p 318
3. Bonoli A, Rizzo S, Chiavetta C (2015) Straw as construction material for sustainable buildings: life cycle assessment of a post-earthquake reconstruction. In: vernacular architecture: to-wards a sustainable future. CRC Press, pp 143–146
4. Ferraresi C, Franco W, Quaglia G (2011) Human powered press for raw earth blocks. In: ASME IMECE 2011 international mechanical engineering congress & exposition, Denver, USA, November 2011
5. Ferraresi C, Franco W, Quaglia G (2017) Synthesis of the actuation mechanisms of a human powered straw baler for straw bale constructions in developing countries. In: ASME IMECE 2017 international mechanical engineering congress & exposition, Tampa, USA, November 2017. Under review
6. Franco W, Iarussi F, Quaglia G (2016) Human powered press for producing straw bales for use in construction during post-emergency conditions. Biosys Eng 150:170–181
7. Franco W, Quaglia G, Ferraresi C (2017) Experimentally based design of a manually operated baler for straw bale construction. In: Proceedings of the 1st international conference of IFToMM ITALY, Vicenza, Italy, 1–2 December 2016. Mechanism and machine science, vol 47, pp 307–314
8. Franco W, Anastasio D, Ferraresi C, Gondino F, Quaglia G, Soprana L (under review) Anpilpay 2.0: a new human powered press for producing straw bales for load bearing constructions. Agric Eng Int CIGR J
9. King B (2006) Design of straw bale buildings: the state of art. Green Building Press, San Rafael
10. Pakistan Straw Bale and Appropriate Building. www.paksbab.org. Accessed 30 Dec 2016
11. Sassu M, Romanazzi A, Giresini L, Franco W, Ferraresi C, Quaglia G, Orefice E (under review) Mechanical characterization of compressed earth blocks (CEB) made by float ram 1.0 press. J Mater Civ Eng
12. United Nations. http://www.un.org/sustainabledevelopment/. Accessed 16 Dec 2016

http://www.springer.com/978-3-319-60701-6

Mechanisms, Transmissions and Applications
Proceedings of the Fourth MeTrApp Conference 2017
Dede, M.I.C.; Itik, M.; Lovasz, E.-C.; Kiper, G. (Eds.)
2018, XI, 288 p. 227 illus., Hardcover
ISBN: 978-3-319-60701-6