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Self-build silos for storage of cereals in African rural villages

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Prototypes of silos for the storage of cereals were designed and built at the Department of Agricultural, Food and Forestry Systems of University of Firenze. The silos were planned specifically to be used in Tanzania, by individual farmers operating in the inland areas of the country. Nevertheless, with a capacity of 1 m^3 and 2 m^3, they can be considered suitable for several African areas. Except for some details that require local blacksmith workshops, the users can self-build the silos. The possibility to use materials and equipment normally available on site is included among the criteria to take into account during the design phase. For example, corrugated galvanized iron, employed by the local population as cover for houses, can be considered a suitable material, as well as raw-earth, traditionally used in African rural areas. To demonstrate the reliability of the design and the functionality of the adopted solutions, unskilled staff of the Department built the silo in the workshop, using only simple tools available almost anywhere. The paper gives suitable information to replicate the building of this kind of silos, where unskilled labor is available at the family and/or farm level.

Key words: Silos, self-building, raw-earth, rural villages, maize storage, Tanzania.

INTRODUCTION

Especially for the development of the agricultural sector, two main categories of interventions can be schematized in developing countries in support of the economy and social progress (Dixon et al., 2001; Barker, 2007; Hoffmann, 2011).

The first category includes interventions that can transfer on-site facilities and organization having a markedly industrial nature, similar to those present in the countries of origin. In these cases, to be effective and long lasting, the actions generally need to be set in an industrialized context, capable of providing the new body the contribution of complementary tools, continuity of energy supply and qualified technical and administrative workers, essential for operation. When these conditions do not occur, the intervention is likely to result in an ephemeral attempt, as not infrequently it has happened in the past. These interventions are characterized by a significant financial commitment and by limited needs

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related to the number and duration of the presence of qualified people provided by donors. Anyhow, this type of intervention has a low impact on the social-economic local environment, at least in the short and medium term,

since it involves only a small number of highly qualified local technicians (HSI, 2011).

The second category comprises the interventions that at first analyze local conditions, in particular taking into consideration the socio-economic situation and the traditional production means and techniques actually available on site. As a result, the introduction of few elements of scientific progress improves the agricultural and livestock productions thank to adoption of intervention strategies by local people, which do not seriously change traditional methods. This type of action is characterized by a limited financial commitment and, mainly in the initial stages, by a need for the presence of technical personnel on site. The social impact of these actions is generally very high since, in addition to technical personnel for the control and dissemination of knowledge, numerous local agricultural operators are directly involved. These interventions can result in extensive agro-livestock chains able to develop the socio-economic conditions of relatively large areas, in gradual but sustained and solid way (Kwa, 2001; Smalley, 2013).

The Department of Agricultural, Food and Forestry Systems of University of Firenze (GESAAF) has operated in various ways in the context of both types of interventions above described, also carrying out trainings in Italy and locally with the implementation of on-site pilot interventions.

The solution proposed in this work can be considered an intervention of the second type. Silos have been planned for the specific needs of a typical family in the area of Itigi, Singida Region, Tanzania that is a typical rural village of Africa, where GESAAF has been called to solve problems related to grains storage. Usually, farmers in this area owns an average of 1 to 2 ha of farmland, which has a typical yield of about 1.000 kg/ha of maize or other grains (FAO, 2013).

In this area, the rainy season starts in early November and ends in late March so the sowing is done in late October and the harvesting in early April (FAO, 2013). After about two weeks of outdoor drying, the maize reaches a water content of around 12 to 13%, and then it can be stored with a water content below 14%, level considered safe for maize storage (Golob, 2009; Wambugu et al., 2009; Yakubu et al., 2010). The crop must be able to be stored both for the next sowing, which occurs 6 months after harvest, and for food use until the next harvest, which occurs after 11 to 12 months.

Currently a significant portion of the grain stored is lost because of poor storage conditions (Proctor, 1994; Coulter and Schneider, 2004; Golob et al., 2009; Yakubu et al., 2010). The stored material can undergo direct attack by animals (insects, small mammals and birds), while the increase of moisture and temperature, in particular in the course of the rainy season, can cause the onset of mildew and microorganisms, and the germination of the seeds. GESAAF has designed containers able to reduce losses of food. Besides, the storage of maize, the designed silos can store other kind of cereals (wheat, barley) and other seeds (e.g. beans).

The total size of the silos depends on the presence of walls and empty spaces, planned to increase its insulation from the heat. Cereal grain can generate heat, but this process is generally negligible for small amounts, and in any case cannot be avoided unless ventilation is used. In this case, however, other, more severe, drawbacks have to be highlighted such as the increase of humidity (Wambugu et al., 2009).

MATERIALS AND METHODS

Two silos were designed, one of 1 m^3 and another of 2 m^3, constructed in corrugated galvanized iron and insulated with earthen walls, with materials and equipment existing in Itigi, Tanzania. The same equipment and materials are available in many other rural areas in African Countries. The container has been structurally designed according to the relevant Eurocodes (EN 1991-4, 2006; EN 1993-1-3, 2006; EN 1993-4-1, 2007). The drawing of the content must be made on a daily basis without the outside agents penetrate inside (Petrovskij, 1990; Proctor, 1994; Udoh et al., 2000; Coulter and Schneider, 2004), so silos should be impenetrable, airtight and able to maintain a temperature as low and constant as possible. It has to be accessible for cleaning and filling on a yearly basis.

For the construction of the silo the following materials are necessary: corrugated galvanized steel sheet, galvanized smooth sheet, angle section bars 30×30×3 mm, rivets 4 mm nominal diameter, strips of waxed fabric, e.g. truck tarpaulin, which can be formed both from organic or synthetic material, sturdy fabric, sturdy thread to sew the fabric, twine, bitumen, galvanized network, 20x20 mm mesh, clayey soil, coarse gravel, leafy branches, aluminum thin sheets, if available.

The tools needed for the construction are: hand shears (necessary to cut sheets), electric or hand driller and 4 mm diameter drill bits, hand riveter, welder, a small metal container to heat the bitumen, a brush to spread the bitumen, sturdy needle to sew the fabric. The silo consists of the following elements shown in Figure 1.

1. Bottom sheet: round edges allow adapting the container inside the perimeter wall (Figure 1:1).
2. Sidewall of the container cylinder: this part consists of three sheets joined together by rivets; the joints are sealed with outside applied bitumen (Figure 1:2).
3. Angle section bar frame: this structure has the task to strengthen the upper closure of the container, to allow a person to rest over in order to enter into the container (Figure 1:3).
4. Upper closure: the hole allows a person to enter into the container; round edges allow to adapt the container inside the perimeter wall and to eliminate the trouble of alignment with the bottom (Figure 1:4).
5. Lid: it must be affixed and sealed after filling; yearly it must be removed and repositioned (Figure 1:5).
6. Drawing device (Figure 2): it consists of an air lock chamber closed by a sluice valve; the length of the device is due to the need to reach the outside of the external walls (Figure 1:6).
7. Bag: to complete the emptying (Figure 1:7); the rear and the lateral parts of the bag are raised by means of the twines according to the scheme in Figure 3.

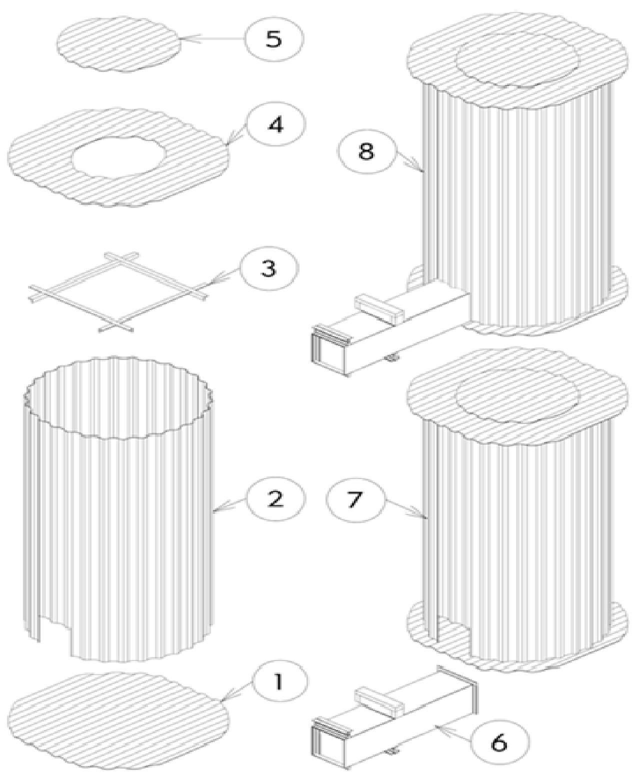

Figure 1. The silo and its components.

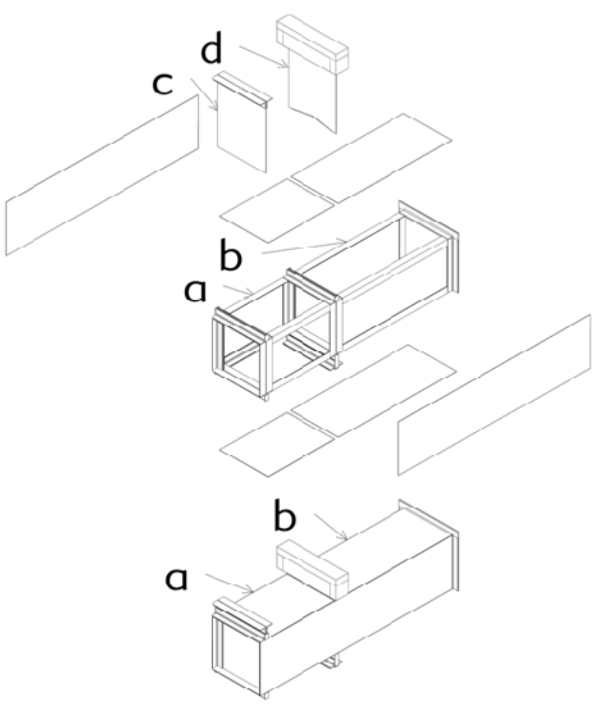

Figure 2. The drawing device and its components: a) drawing chamber b) extension outside of the wall to allow the actuation of the device d; c) outside guillotine for grains drawing; d) inside guillotine (valve) for closure during the drawing.

8. The container assembled is shown in Figure 1: 8.

The main container must be built with corrugated galvanized steel sheet, a thin sheet (0,4 mm) which is normally used by the local population as cover for houses. Also galvanized smooth sheets thicker (1-2 mm) are locally available, but because they are more expensive, they can be used only in small quantities for special applications. Due to the low thickness the sheets are not easily weldable. Therefore, the sheets should be joined each other and to the section bars by means of rivets.

For the construction of the container it is necessary to use a sturdy fabric, which can be formed either from vegetable or synthetic material. To seal the container, hot bitumen of the type used for asphalting roads is used. The bitumen is always coated on strips of waxed fabric, e.g., truck tarpaulin, which are arranged outside of the container, so that the bitumen is never in contact with the edible content.

The construction of raw earth brick walls ensures the thermal insulation of the container. In order to insulate it from the rainwater, from the moisture of the soil and from insects and other animals that burrow in the soil, a frustum of a pyramid constructed of a coarse gravel base supports the whole construction.

To avoid direct sunlight, a thick layer of leafy branches must cover the vertical walls and the roof of the construction. All these materials are available on site. The use of aluminum thin sheets to increase the thermal insulation from radiation heat transfer would be helpful. However, it is not certain that this material is available on site.

A test has been prepared in order to assess the ease of construction of the silo and to verify the functionality of the design solutions adopted. The workshop of the department was specifically arranged to create the same atmospheric conditions and the typical working situations of the Itigi village in Tanzania. In particular, the temperature and the humidity of the environment and the lack of resources and materials were taken into account. In this background, two unskilled workers built a prototype of the smaller silo using only the tools and the materials envisaged in the plan.

RESULTS AND DISCUSSION

The assembling of the silo, except the earth walls, required two days of work, during which several issues related with the construction and the use of materials were highlighted. Main considerations explaining some of the measures and decisions taken to improve the design of silo after the results stressed in the test are reported.

To ensure sealing of the container to external agents during the extraction of the grains, the silo is equipped with a slide valve. As illustrated in Figure 2, the ensiled material is present in part b, which is in direct communication with the interior of the container. Opening the guillotine d, the material enters the part a, which is closed by the guillotine c. Closing the guillotine, the gain to drawing chamber can be accessed and the contents can be drawn without external agents enter in b. The part b must be sufficiently long to allow the operation of the guillotine d, when the silo is inside the thermal insulation walls.

The above-said behavior happens until the ensiled material has reached the angle of repose, which is about 35° for maize and wheat (EN 1991-4, 2006). To allow the complete emptying of the silo, it is necessary that the grain is contained within a fabric bag which, reached the second phase (Figure 3), can be operated by means of

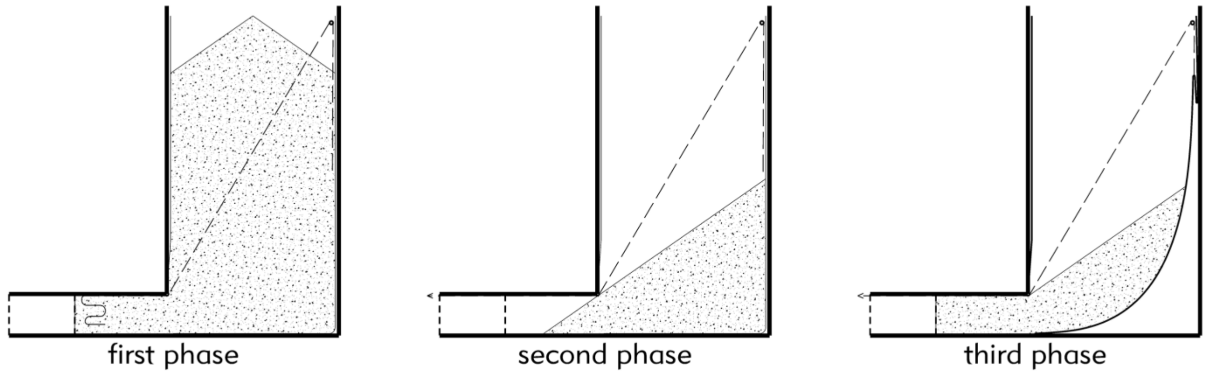

Figure 3. Phases of the container emptying.

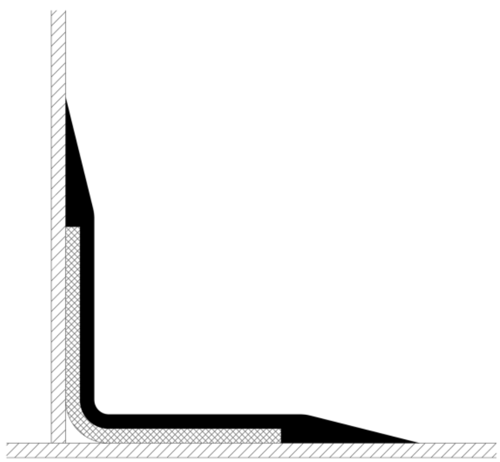

Figure 4. Joints ribbon-bitumen sealing.

Figure 5. The prototype under construction.

small ropes protruding from the outside of the mouth, so as to convey the content to the drawing device.

L-shaped elements, fastened with rivets to the two parts, made the joint between the vertical and horizontal sheets. By cutting and bending little pieces of sheet, it is also possible to create L-shaped elements. The cylindrical sidewall sustains the pressure of the content, so it slightly stresses the joint between the bottom sheet and the sidewall.

The joint between the vertical and horizontal sheets and between the lid and the upper closure must be sealed affixing a ribbon of waxed fabric on which the bitumen is spread, according to the scheme shown in Figure 4.

In this way, it is possible to seal the spaces corresponding to the corrugations of the sheets. Furthermore, in comparison to the direct sealing of the sheets, this constitutes a safer, less sensitive to the deformations of the support sheets joint. It is also less prone to contamination of the contents.

A prototype of the inside metal container has been made in the workshops of GESAAF by two unskilled people (Figure 5).

The silo should be placed on a foundation consisting of a loose coarse gravel embankment, resting on the ground level. In this way, it is insulated from moisture and meteoric water. Furthermore, it is hindered the access to the internal cavities by soil-borne insects and mammals. On the top of the foundation, a sheet of material impervious to moisture and animals should be placed.

In order to store up the grains in the most appropriate manner, it is very important to minimize the increase in their temperature caused by external factors. For this purpose, the container must be thermally insulated from the external environment. To obtain this goal in the designed silos, it was decided to use the raw earth for the external structure. The raw material is widely available on the same building site and most people may carry out its processing, as it requires no special skill or complex equipment.

Raw earth buildings, if properly executed, have considerable strength and, if properly maintained, can have a virtually unlimited life (Barbari et al., 2014a,b). Maintenance consists essentially in repair by plastering parts that might be damaged by weathering, performed using the same clay mortar. Raw earth has a high

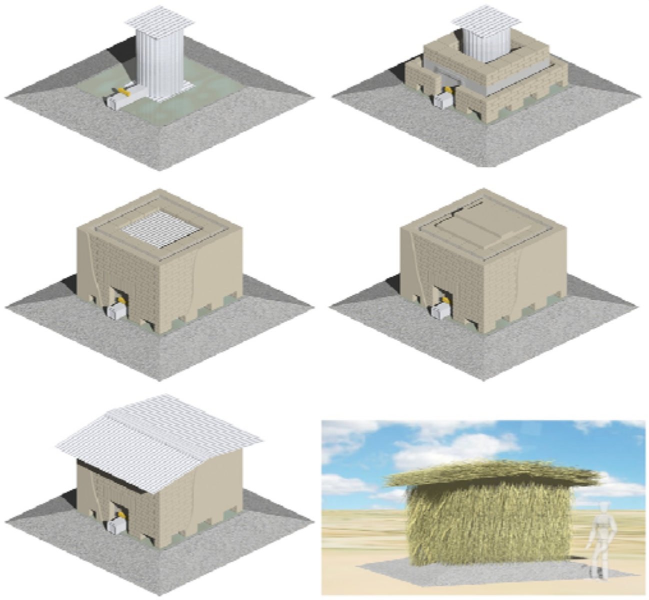

Figure 6. Phases of the silo completion (type A).

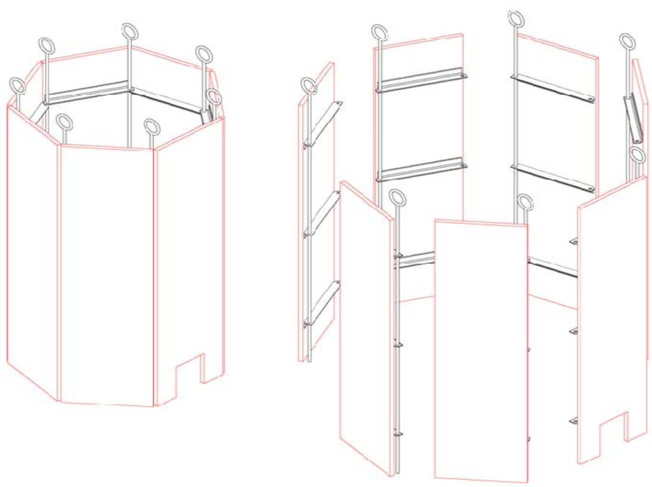

Figure 7. The dismantable internal formwork.

thermal inertia. Therefore, when a raw earth wall is heated on one face, it takes some time so that, while heating the mass of the wall, the temperature rises also on the opposite face. Since the temperature in the external environment has a sinusoidal trend in the 24 h, the temperature on the unheated face has not the time to reach the external value before night cooling, so it remains lower than outside. If the values of the thickness of the wall and of the day/night temperature swing are sufficiently high, the temperature rise of the inner face can be reduced to very small values or also to zero.

The daytime temperature rise of the outer face of the wall can be greatly limited if solar radiation does not reach it directly. This can be achieved with an effective shading that can be realized thereby charging to the outer surfaces a sufficiently thick layer of plant material, such as grasses, straw, reeds, brushwood and similar as well as with suitably arranged trees.

The temperature of the outer face of the wall can be maintained at a value very similar to outside air temperature realizing a ventilated wall that is built outside a second wall to form a cavity in which air can circulates for the chimney effect. It is possible to place on the outer face of the internal wall a layer of reflective material. In this way, the heat radiation from the outer wall is rejected and the thermal insulation increased.

For these reasons, to achieve the thermal insulation a building made of considerable thick raw earth walls with a significant thermal inertia enclosed the container. An effective thermal lag in heat transfer is achieved (Doat et al., 1991; NZS, 1998; Morton, 2008; Minke, 2009). The roof covering must be removable to allow the annual cleaning and filling. The upper opening is closed with corrugated sheets, on which several layers of unbaked bricks are placed in order to obtain the same effect of thermal inertia characteristics of the vertical walls. On these bricks, galvanized corrugated sheets are placed in turn covered by a thick layer of plant material.

In applying the above principles to the designed silos, two construction methods are proposed, which use: a) unbaked clay bricks (adobe), b) rammed earth monolithic walls.

a) Unbaked clay bricks

Outside the first wall, a second wall is built, forming a cavity wall with natural air circulation. If available, on the outer surface of the first wall a reflective aluminum thin sheet should be applied. Furthermore, the vertical walls and the roof of the construction must be covered with a thick layer of leafy branches to avoid direct sunlight.

This solution requires, for the 1 m^3 capacity silo, the construction of about 800 bricks, of various measures, which must be walled using as mortar the same mixture used for the bricks, but with a different degree of humidity. Finally, the exterior vertical surfaces of the building should be plastered (Figure 6).

b) Rammed earth monolithic walls

The rammed earth construction technique consists in laying raw earth in specially crafted formworks, and ramming it until the desired consistency is obtained. After removing the formwork, the result is a wall of considerable strength and durability.

In order to carry out the construction, two formworks are required: an internal formwork (Figure 7) and an external one (Figure 8). Both formworks must be able to be disassembled for their reuse. In order to favor carrying

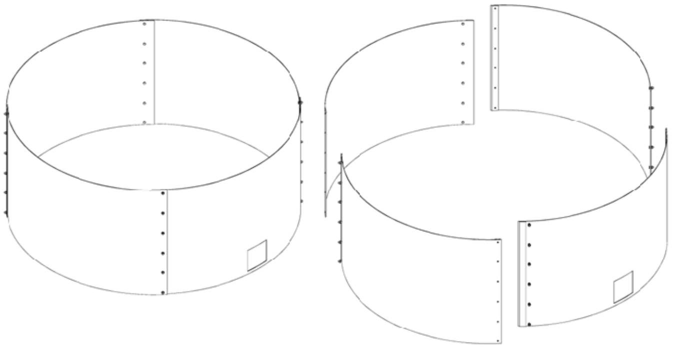

Figure 8. The dismantable external formwork.

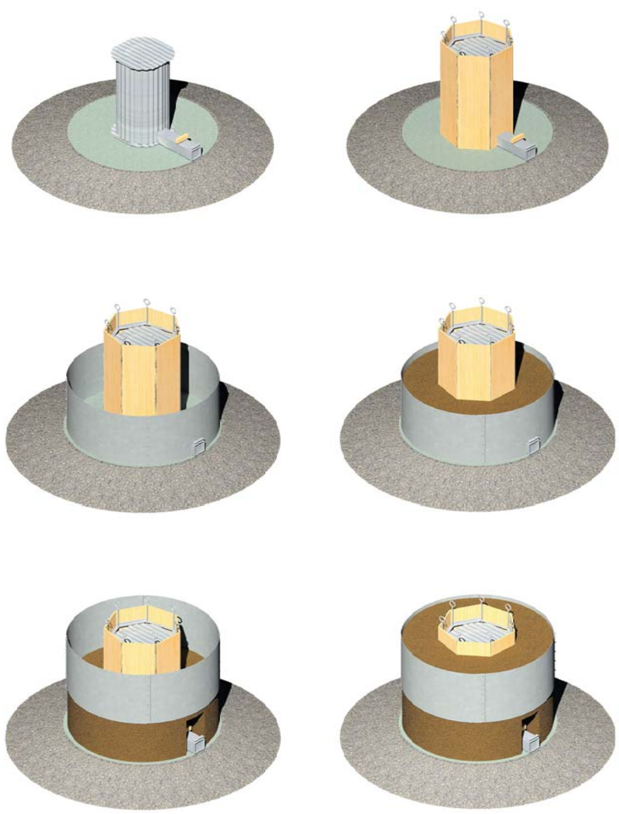

Figure 9. First phases of the silo completion (type B).

and moving, it is necessary to contain the weights of formworks. Therefore, the external formwork has been designed to perform the casting of the wall in two phases, moving it up (Figures 9 and 10).

Conclusions

The proposed silos can be a suitable solution to store cereals and other seeds in African rural villages, thanks

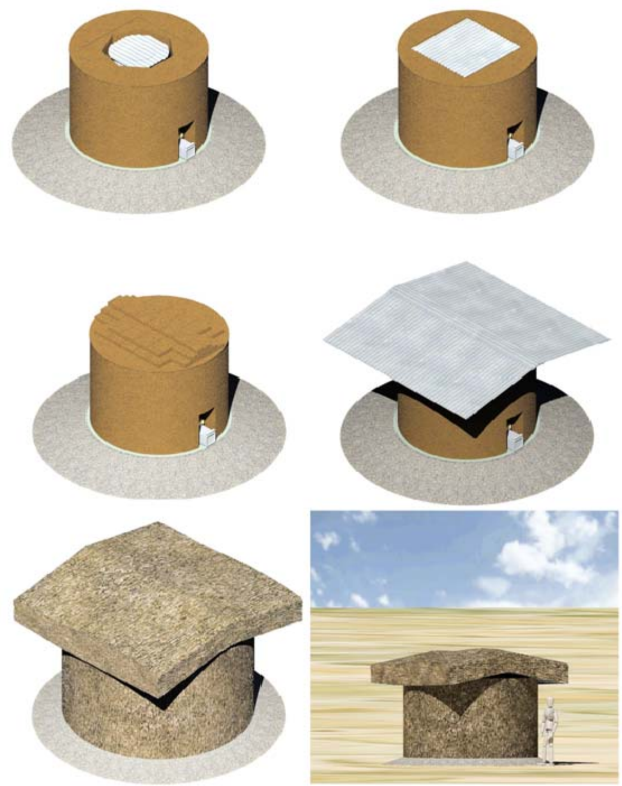

Figure 10. Second phases of the silo completion (type B).

to the low cost of realization and to the simplicity of building, turning to unskilled labor of farmer's family.

The container and brick walls of adobe were made in the workshops of GESAAF using only materials and equipment actually available in the area to which the project is intended. Furthermore, the staff who implemented the construction did not have professional skills. This allowed us to verify the actual possibility of implementing the project on site.

Several improvements were introduced in the design after the test phase, related with the construction and the use of materials. In particular, a better system of unloading and a proper way to provide thermal insulation were developed.

Next step of the research will be the construction of the silo in an area of use in order to record and evaluate operating parameters.

Conflict of Interests

The authors have not declared any conflict of interests.

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