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CONSTRUCTION DESIGN SYSTEMS FOR SUSTAINABLE FARM BUILDINGS. A CASE STUDY IN CALABRIA, ITALY

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ABSTRACT Recently in Italy the construction design systems applied to farm buildings have been required to improve their eco-compatibility, adaptability to the local environmental conditions, and functional/operational performance when answering the needs of the specific activities housed. This paper presents the results of a study carried out in Calabria (South Italy) and aimed at defining sustainable building systems for farm buildings. On the basis of previous studies conducted by the Authors in the same region and with regards to building types and layouts for animal housing based on local breeding systems, this paper is focussed on the construction design aspects to be applied to those buildings in regards of sustainable design. They are characterized by: local availability of raw materials, low cost, low energy demands, use of renewable resources, reduction of carbon dioxide emissions, ability of materials and components to be reused or recycled, aesthetic and visual integration with the regional landscape, valorisation of on site labour. In particular, three different construction design systems have been defined and applied: straw bales coupled with timber structural frame; timber frame and autoclaved aerated concrete-blocks; reinforced adobe.

Keywords: Straw bale, Earth bricks, Autoclaved aerated concrete, Sustainability, Calabria.

INTRODUCTION In recent years innovation in the building sector has been evermore oriented by the research of building techniques and materials able to match the new demands of sustainability. In EU countries the building industry absorbs about 40% non metalliferous minerary resources (natural stones, gravel, sand, clay), over 25% timber production and about 40% energy resources, for the construction and functioning of buildings, against a contribution of about 12% Gross Internal Product in the average (fonte: RICOS, 2007). In this context, in Italy a critical revision of the current and most widespread building systems (reinforced concrete, steel, bricks) has occurred and they have been encouraged the introduction and use of building components obtained from renewable natural resources, presenting good performance characteristics (thermal insulation, mechanical resistance, easy availability, durability, etc.), and offering a significant contribution towards the reduction of CO_2 emissions.

Analogous revision is needed also in the field of design methodology so as to improve the coherence of the whole building design with the specific site and the architectural functional theme (Pereira, 2009); in view of indoor-microclimate passive control, for example, all the relevant building choices must interact and converge towards effective solutions, from appropriate siting and orientation to overall spatial design and technical choices (building volumes, envelope thermal characteristics, openings and natural ventilation systems, etc.). The previous tendency towards homologation today appears as contested by the return to a differentiation of the architectural building design according to the various factors characterizing distinct regional contexts (climate, lifestyles, resource availability, etc.). In order to reduce the consumption of natural resources and the need for transport it is opportune to promote the use of local materials and building systems, as well as the use of agricultural by-products, thus also recovering the value they still contain.

In the present work attention is focussed on agricultural buildings. In time their importance has ever grown. While in the past they were often considered as mere "shelters" housing the production activities, today they must be seen as proper "tools" for the achievement of the production goals (Mumma, 2002). New approaches to the design of agricultural buildings are required and research and innovation not only concentrate on those building systems helping reduce the construction cost, but also on prefabricated systems allowing for easy assembling and disassembling of the building parts so as to valorize farmers' capacity as self-builders (Fichera et al., 1997; Barbari et al., 2003). Some aspects of sustainability imply also the reversibility of the construction process, in a sense that buildings should allow for an easy dismantlement and, at the end of their functional life, "disintegrate and dissolve" leaving as less traces as possible in terms of wastes, emissions, soil consumption, etc.

In this paper it is presented a modern interpretation of building materials, components and constructional systems which are characteristic of the traditional rural architecture and have recently been rediscovered and valorised by researchers. Application is proposed in Calabria, a region in South Italy where building traditions are still alive and recognizable in vernacular and self-built examples of rural architecture. In the following paragraphs they are described the main building systems defined in the research for a wide application in Calabria. Reference is made reference to the farm buidlings, mainly animal houses, of a sample area (Mt. Poro region) typical of the region under study.

MAIN SECTIONS The main building requisites demanded by the project-theme were flexibility, adaptability, coherence with the local context, low environmental impact, building suitability for potential future conversion and reuse/recycle of its components and materials. The three main constructional systems proposed, and here presented, as sustainable alternative to those today in use, all have a timber structural frame coupled with external walls respectively made of: straw bales; timber frame and autoclaved aerated concrete-blocks; raw earth bricks.

For each system a series of demonstrational technical cards have been produced, emphasising their characteristic features and suggesting their optimal field of application in relation to the advantages and disadvantages which can follow. The preference given to timber as a structure material in all the three systems is due to the following advantages it offers: low global energy cost in the various phases of growth, extraction,

production and disposal; possibility to produce structural elements with very high specific resistance (strength/weight ratio); low thermal and electric conductivity; high electromagnetic permeability; electrostatic neutrality; easy assemblability and disassemblability; derivation from natural renewable resource; easy reusability and non polluting disposability. Moreover timber, in comparison with other building materials commonly in use, has relatively low embodied energy; in large part, at the end of the service-life of the components, this can be liberated and regained through combustion. The use of protective treatments natural (i.e.: boron salt or water vapour) rather than synthetic, facilitates the environmental compatibility of the final disposal. The need for such treatments can be reduced if timber is chosen from among the species most suitable for the specific functional utilization (i.e.: resinous timber for externally exposed components). Local species are to be preferred, not only to reduce transport cost and emissions, but also because they have adapted to the climatic environmental conditions of the specific region and are more reliable, in that they can grant the required performance more durable and effectively (Davoli, 2001). Some timber species widespread in Calabria, such as *Abies alba, Pinus nigra, Castanea sativa, Pseudotsuga menziesii, Fagus sylvatica* show characteristics and offer performances making them well suitable for farm buildings.

In the use of building subsystems strongly characterized by timber components, when researching architectural sustainability the functional needs related to users' environmental comfort should be carefully translated into specific building requirements. If not, also the timber building systems might be uncritically applied on the basis of hypotheses taken from handbooks and referred to abstract conditions (i.e. regions characterized by cold climate), which often are very different from those of the specific building context. The region examined is in the average characterized by a mild climate, but with significant thermal excursion during the day in winter and summer. During the summer, moreover, temperature often is over 30 °C, resulting particularly stressing for the animals housed in farm buildings. In the region, therefore, rather than timber buildings descending from a global technologic option associated to a specific technologic style of intervention, they should be preferred constructional models allowing to manage well a correct technological mix, and design actions able to control complexity. For this reasons they have been preferred ventilated timber roofing-systems; structural timber framework easy to assemble; enclosure walls of high thermal mass made of straw bales, aerated auto-claved concrete blocks, raw earth bricks.

This way, timber is valorised in the structural framework, so taking advantage of its mechanical properties which make it suitable for seismic areas, while the envelope walls work as a thermal flywheel, so making the internal microclimate more stable and less dependent from the great variation of the external conditions. Timber frame building structures are in the constructional tradition of Calabria. Here, because of the high seismicity they were diffusely employed until 1950s and are still present in rural areas. The proposals which follow intend to match environmental and socio-cultural sustainability while respecting the local identity as expressed in the procedural, constructional and compositional aspects.

Ready-to-assemble building system with bearing timber-frame and autoclaved aerated concrete blocks. Autoclaved aerated concrete (AAC) is a relatively recent construction material, introduced in the building industry between late 19th and early 20th

century. It is used, with a consolidated tradition, for the production of solid or hollow blocks for wall systems. Recently AAC has been valorised in view of sustainability, thanks to: low environmental impact; economic competitiveness; process innovation. This last involves not only the material and component production, but also an integrated approach considering the product as a part of the system of relations which characterize its life-cycle. This approach implies greater attention towards the maintenance conditions and recycling; achieves greater building flexibility and adaptability in relation to the change of design or occupancy condition; turns into projects informed by criteria of modularity and design integration; makes the organisation of the construction site easy and clean.

The technical card in fig.1 shows the application of AAC blocks in a free-stall cattle barn corresponding to the breeding systems traditionally used in the region under study and for which suitable housing systems and building plans were defined in previous research (Cilona et al., 2004). Due to the high seismic risk of the region and in consideration of the related building codes, it has been preferred to attribute the load bearing function to a timber *post and beam* frame, not to the AAC walls. For these last they have been used blocks commonly in commerce, easily available and produced not far from the sample area; they size 0,625 m (length), 0,200 m (width), 0,250 m (height), are finger-joint shaped to allow dry assembling and have side lifting-handles and a central hole. The raw components for the production of AAC are locally available in the region: sand with high siliceous content, cement, lime, gypsum and water. The block assemblage is carried out by simple superimposition and mutual framing, not needing specialized skills or craftsmanship. This way, a walling panel reinforced by an incorporated timber frame is realized. At the end of its service cycle, it can be disassembled in a non destructive way, and the component blocks reused. The inner timber elements have mainly a stiffening function, give the wall some resistance to horizontal loads and work as a guide-rail for the positioning of the blocks. This way the building assumes a certain distributional versatility, in that the solutions presented, if applied according to a modular compositional grid based on the dimensions of the AAC blocks, can be easily modified not wasting material but simply shifting the timber vertical and cladding elements.

The foundation is a continuous system of reinforced-concrete strip-footing beams; their upper surface, bedding the first row of blocks, is elevated about 0,40 m from the natural ground level and presents seat holes for the positioning of the timber-frame vertical elements. Before laying the first row of blocks the bedding surface and the seat holes should be waterproofed and sealed (i.e. by hydro repellent membrane of bentonite or textile fibres, either oil-impregnated or waxed), so as to have an effective barrier to water capillary ascension from the ground. Elastic joints should be interposed between the AAC walls and the timber posts and beams of the load-bearing structure.

AAC can be easily worked and shaped, has low thermal conductivity (λ = 0,148 W/m°C), good water vapour permeability (μ = $32x10^{-9}$ g/msPa), high compression and bending resistance (characteristic compression resistance of test samples is 3,7 N/mm^2). The AAC walls don't require surface finishing treatements; plaster can anyway be used as a wear surface applied on a fibreglass mesh to prevent cracks deriving from settling shifts between the blocks. In absence of plaster, building chromatic appearance can be improved by the use of pigmented blocks, available in a wide range of colours (fig.2).

Building system with straw-bales and load-bearing timber frame. In this case particular reference is made to those categories of buildings where great advantage can be taken from the high insulating properties of straw, such as dairy barns, pig houses or those agro-food facilities (i.e.: wineries and olive oil mills), where indoor thermal control is important for the production process and the storage of products. The average thermal transmittance of a 0.48 m thick straw-bale wall is 0.13 W/m^2K, much lower than in the case of the most commonly used walls (0.30 m thick, made of brick/concrete-blocks, with mineral fibre insulation) where thermal transmittance is 0.44 W/m^2K in the average.

The first straw-bale buildings were built in Nebraska (USA) in early 20th century, following the introduction of mechanical balers, in areas where the lack of timber suggested the farmers to assemble the bales so as to form thick load bearing walls (US DoE, 1995). Recently, in view of sustainable building, the vernacular constructional methods of straw-bale building have been reconsidered, improved and divulgated worldwide with application to a varied range of building types (Corum, 2005). In the case of farm buildings, particularly when sited in cereal farms, the straw bale building system shows some apparent advantages. The easy availability of the raw material and the light weight of the bales determine a low cost of transport to the building site. Therefore, straw can be considered as a cheap building material with a very low embodied energy (EE). In literature its EE value is estimated in the range 0.13÷0.25 MJ/kg. Straw, if not used for buildings or as a bedding material in animal houses, would be otherwise considered as a waste material to burn, this way contributing to air pollution (Li et al., 2008). Because of this consideration some authors attribute straw, considered as a building material, a negative EE value (Wooley and Kimmins, 2005).

Wheat straw bales are well suitable for building construction. In Calabria wheat is the most widespread cereal crop and the harvester-baler machines there commonly in use produce small two-string bales sizing approximately 0.46×0.36×0.90 m, and weighing about 23 kg. Traditionally in some areas of the region the external walls of farm buildings resulted from the assembling of bricks made of earth and straw, materials with which the local farmers are still familiar. The *adobe* walling technique was often coupled with a structural timber frame made of round logs and either reinforcing the wall or having a load bearing specific function. Therefore, the constructional systems most appropriate for application in the region are those where the straw-bale walls have only a space-enclosure function (thus fully exploiting their excellent thermal insulation properties) while the load bearing role is played by a structural post and beam timber frame (fig. 5). Indeed, straw bales have proved satisfactory also when used in load bearing walls of short-span single-storey buildings. In our case this solution doesn't seem viable, either because of the large width of the most common farm buildings and because in the region considered seismic building-codes make no reference to straw-bale load-bearing walls.

Thermal properties of straw bales depend on their density and improve as the moisture content lowers. Moisture content less than 15% is to be preferred (Wooley and Kimmins, 2005). In order to prevent rapid decay caused by the growth of micro-organisms, moisture should be carefully measured and monitored so as to ensure it never exceeds 25% dry basis (Lawrence et al., 2009; Summers et al., 2003). The straw bale is therefore covered with a breathing plaster made of clay applied on fibreglass mesh. Protection from rain is assured by the roof overhang (0.60 m minimum). The wall lays on a reinforced concrete foundation beam, from which it is separated by a layer of bentonite or wax-

impregnated textile fibre working as a moisture barrier. This way, protected by clay plaster and kept dry, the wall has also sufficient protection to prevent fire from either externally- or self-generated combustion. The fire resistance achievable with this system is better than in the case of conventional concrete-block and brick walls (Theis, 2003).

Building system with raw-earth brick walls and load-bearing timber frame. In Calabria raw earth, as well as timber and stone, is a building material in use since ancient times. Its revival is today generally motivated by many advantages it offers in view of environmental sustainability (Bollini, 2002): easy and low-cost wining, not needing complex machinery; local availability, with low or no cost for transport and energy consumption; easy workability by non specialised workers; independence from the building market; independence from non renewable energy sources; assembling neither requires complex treatments nor produces polluting wastes or emissions; the building components are easily reusable and the materials recyclable; plaster, mortar and bricks can all be recovered. Walls, when damaged, can be easily repaired or demolished and rebuilt; aged earth bricks by re-humidification reacquire plasticity and can therefore be reused.

In the region investigated, dating from 1950s, earth bricks have known progressive technical and cultural obsolescence, partly because of the widespread application of new building systems (i.e. reinforced concrete and steel), and partly because of an unjustified social prejudice considering raw earth bricks as a sign of poverty to be removed even from memory. The present research intended to promote the use of raw earth bricks in farm buildings through innovation and performance improvement. These building components, relatively cheap and easy to assemble, help achieving a better visual integration between buildings and the landascape, and match also technical needs such as suitability for mechanization, animal welfare, hygiene, work safety. Moreover, good acoustic insulation and indoor hygrothermal conditions can be obtained, these last thanks to the transpirability of the material (Scudo et al., 2001)

The type building projects proposed in this work use “adobe” walls as envelope elements. Raw earth bricks can be hand made on farm by craftsmen or industrially produced with mechanized processes by specialized concerns. The modular grid governing the compositional and design choises is based on the characteristic dimensions of traditional earth bricks, sizing in the average 0,85 x 0,18 x 0,37. The structural role is exclusively attributed, as in the previous examples, to a timber frame with elements presenting a rectangular section. Roof eaves are wider than in the previous cases and overhang 1,5 m so as to protect the facade both from direct and indirect exposition to rainwater (figg.3,4).

CONCLUSION The building systems proposed allow for the appropriate use/reuse of agriculture and forestry products and by products easily available in Calabria and in most Italian regions. Low production cost and excellent thermal insulation performance make these constructional systems excellent for use in farm buildings. Moreover the technologic and projectual innovation presented, while actualizing the main criteria which characterize building sustainability, tend to match the local conditions in a wide sense. In fact the idea of sustainability has been fully applied, not only on the environmental side, often overemphasyzed, but also on the socio-cultural and economic ones, often forgotten or underestimated. Appropriateness has been researched in terms of building solutions’ suitability for- and adherence to- the specific needs of farmers and

farming activities, in such a way rural people can share and understand according to their cultural horizon and lifestyles. The main aspects of the proposed solutions which converge towards the realization of the fore mentioned aims were: valorization of farmers' self-build capacity; building easy assemblability and maintainability, flexibility and adaptability; ease of assembling and maintenance; reusability and recyclability of building components and materials.

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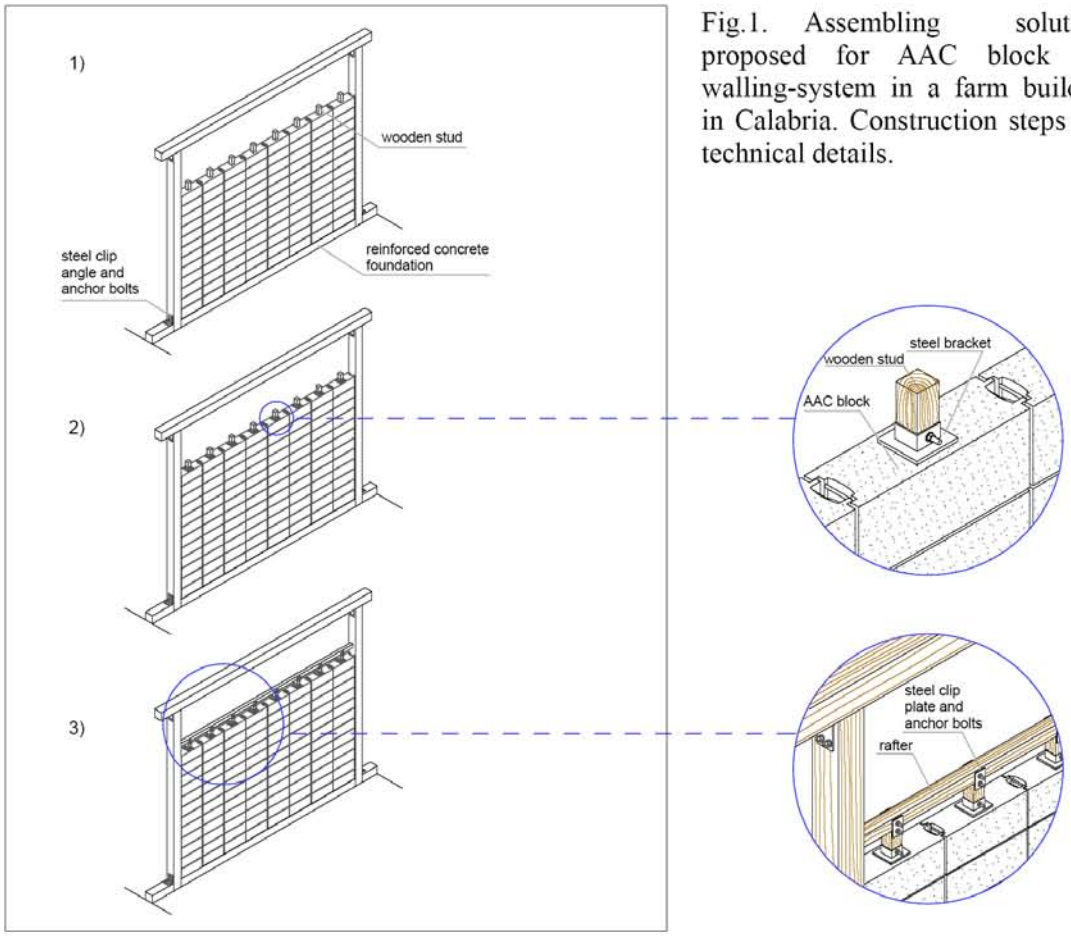


Fig.1. Assembling solutions proposed for AAC block dry walling-system in a farm building in Calabria. Construction steps and technical details.

Fig.2. Photo-rendering for the control of the aesthetic and compositional results obtained in a dairy barn with the AAC construction system shown in fig.1.

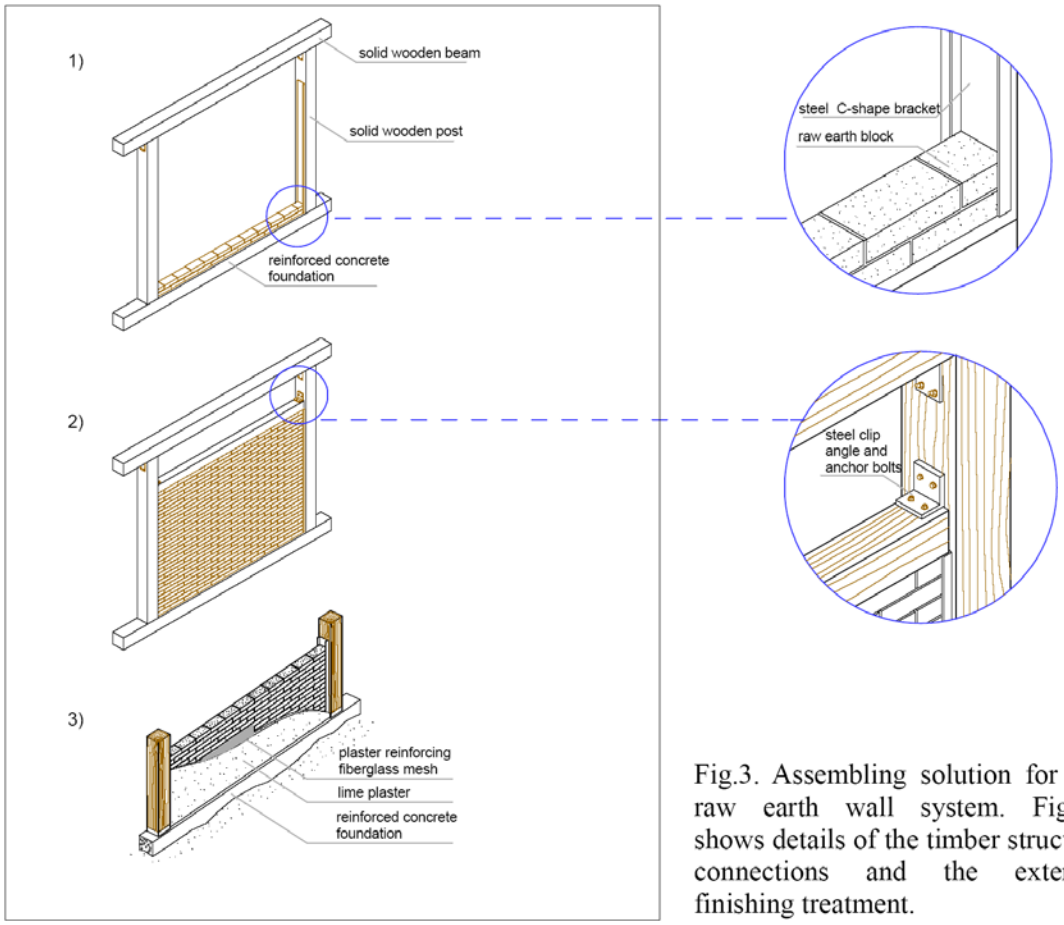


Fig.3. Assembling solution for the raw earth wall system. Figure shows details of the timber structure connections and the external finishing treatment.

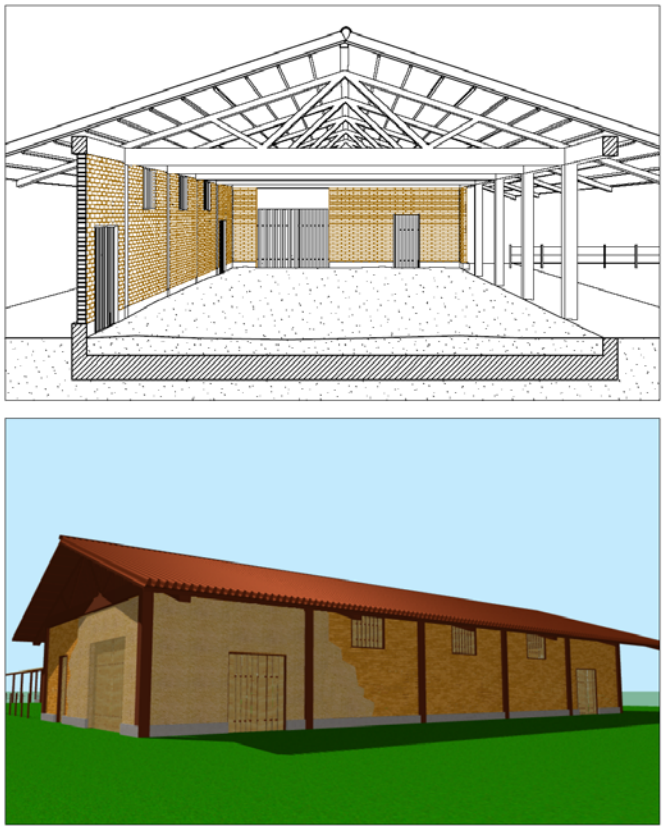
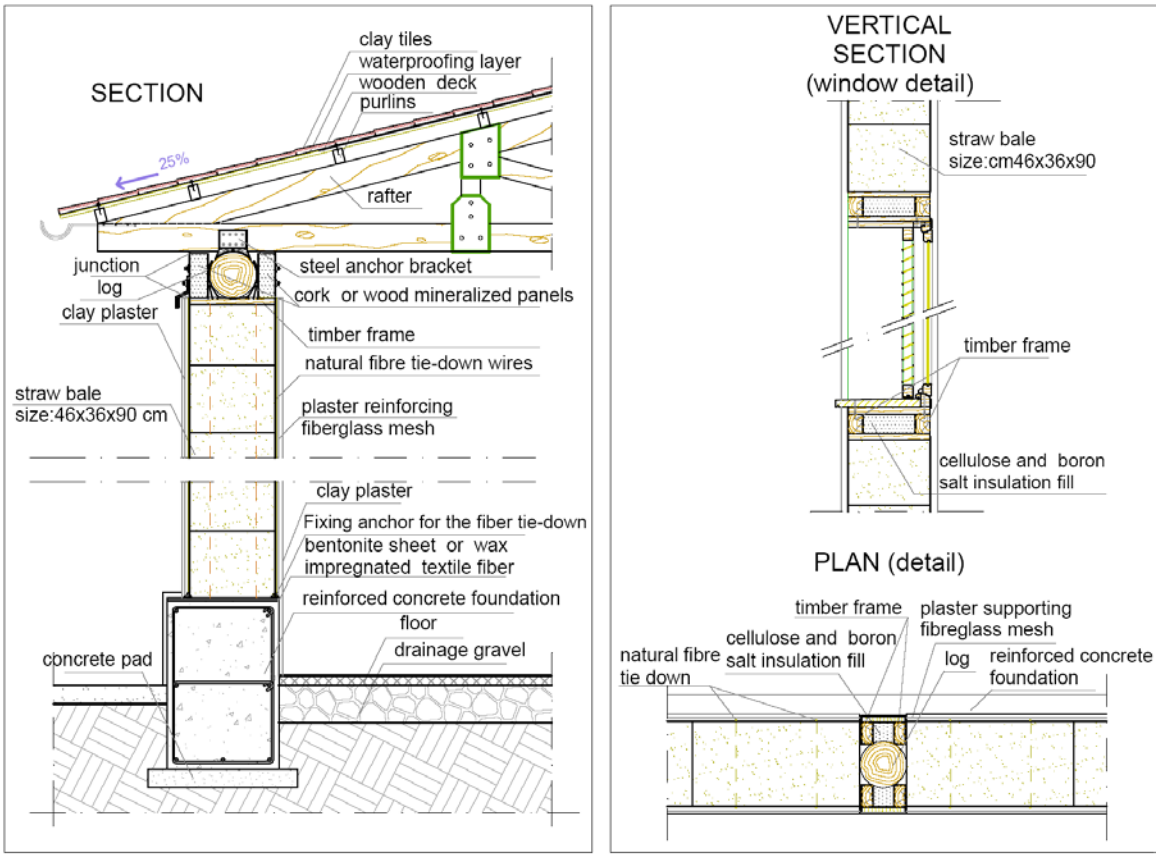


Fig.4. Perspective cross-section and photo-rendering of a barn using the building system shown in fig.3.



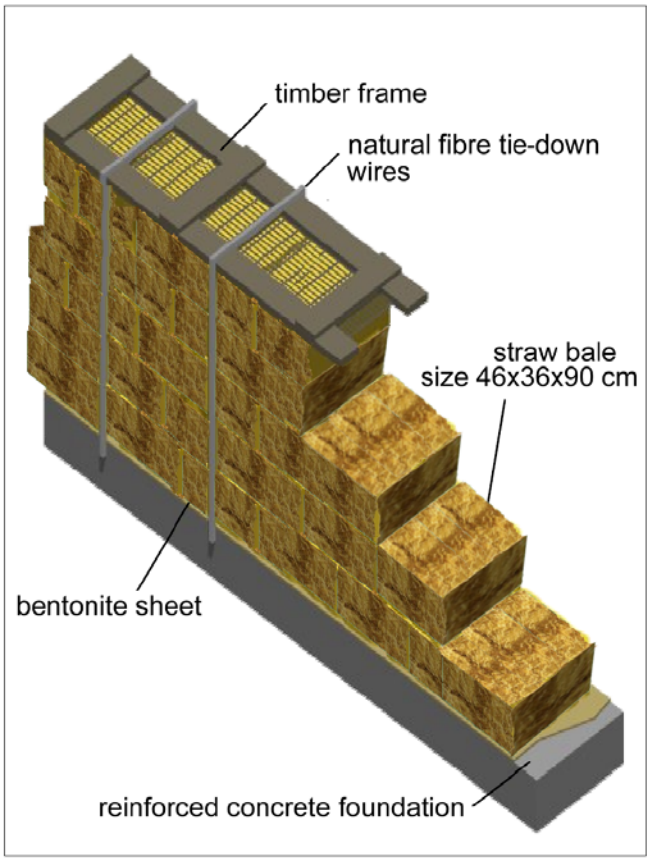


Fig.5. Vertical and plan cross-sections, axonometric view with photo-rendering showing the technical details of the straw bale construction system proposed for application in farm buildings.