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Criteria of design for deconstruction applied to dairy cows housing: a case study in Italy

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Abstract. This work aims at presenting the design process of a new barn for dairy cows. Project embraces several concepts that are rather new to the dairy industry and will deeply affect its environmental, economic and social sustainability. The barn will be built on a green field site located in Cervasca (CN) in the region of Piedmont. Building has been designed applying the emerging principle of "design for deconstruction" extensively. A series of constructive solutions was developed allowing for complete end-of-life disassembly and reuse of building materials. Structural system will consist of locally sourced timber connected by steel joints. Foundations will be realized by means of chestnut wood piles driven into the ground. The employment of an alternative housing system for dairy cows based entirely on cultivated pack will allow limiting the use of cast-in-place concrete, which is largely employed in conventional dairy barns. The cultivated pack needs a large space per cow leading the building to be particularly extended. The large covered area combined with the high snow load of the building site posed several challenges. Accumulation of snow on the roof would increase dramatically the structural load and therefore construction costs. Therefore, the building will consist of several 12m-large modules with 4m free space between them. Given the unusual shape of the barn and the limited use of concrete for flooring, the development of efficient systems for livestock management required the study of dedicated solutions. A first module, already realized to collect useful information for final design, is described.

Key words: design for deconstruction, sustainable building, cattle housing, cultivated pack barns, compost dairy barns.

INTRODUCTION

Housing can play a major role in determining environmental, economic and social sustainability of dairy farming. The construction and materials used for buildings can influence together with technological equipment the microclimatic conditions inside the cowsheds (Kic, 2017). Over the last decades, free stall barns have established as the standard housing system for dairy cattle worldwide. Such solution allowed achieving substantial improvements in labour requirement and cow cleanliness (Bewley et al., 2017). However, recent research highlighted this system may have several shortcomings, especially with respect to animal welfare and waste management (EFSA, 2009). Conventional building design and extensive use of concrete, typical in free stall barns, may also have a negative impact on the sustainability of cattle housing.

Cultivated pack barns (CPB), also known as compost bedded pack barns, are an alternative housing systems for dairy cows, which showed potential to improve animal welfare (Barberg, 2007a; Leso et al., 2013). In CPB, cows are provided with an open bedded pack area for resting and walking rather than individual stalls and concrete alleys. The bedded pack, which is a mixture of bedding material and animal excreta, is cultivated daily to foster the evaporation of water and maintain adequate hygienic conditions for the cows. Such housing system was developed in recent years mainly to improve the welfare of cows.

Scientific research showed that cows housed in compost barns have healthier claws and legs likely due to the reduced concrete surfaces and less injury-causing obstacles in the barn compared with the conventional free stall housing system (Fulwider et al., 2007; Kester et al., 2014). Although some authors expressed concerns about cow cleanliness and udder health, recent findings showed that, if properly managed, this housing would allow maintaining adequate udder health and milk quality (Black et al., 2014). Other advantages of CPB regard cows longevity and improved behaviour (Enders & Barberg, 2007; Leso et al., 2014). Better welfare may result in improved productivity, lower production costs and reduced use of medicines and antibiotics (von Keyserlingk et al. 2009).

Compared with free stalls, employing CPB would also allow producing higher quantities of solid effluents while reducing the amount of liquid wastes. Solid manure can be easily stocked and demonstrated to produce less odour compared with slurry. Recent research also showed this material is a valuable fertilizer, especially due to the very high content of organic matter, which improves soil structure over the long term (de Boer, 2014). Furthermore, employing CPB could reduce the use of (cast-in-place) concrete, especially for paving, in the areas dedicated to the animals.

Construction waste management has become extremely important due to stricter disposal and landfill regulations, and a lesser number of available landfills (Rios et al., 2015). Design for Deconstruction (DfD) is a concept in building science, which has the potential to improve the management of construction waste and thus contributes reducing the environmental impact of a building.

Design for Deconstruction is a concept in building science based on the use of recyclable, renewable, locally available and environmentally friendly raw materials, with low environmental and economic impact according to six main principles for sustainable construction: to minimise resource consumption; to maximise resource reuse; to use renewable and recyclable resources; to protect the natural environment; to create a healthy and non-toxic environment; to pursue quality in creating the built environment (Miyatake, 1996).

These topics are a priority for authors, who over the years have carried out several projects regarding the sustainable development of agricultural buildings (Barbari et al., 2003; Barbari et al., 2012; Conti et al., 2016). The deconstructable anthropization should be considered for reversible changes of the places, in order to increase the temporary business needs of farming without compromising the original conditions of the territory. In fact, buildings that can be destroyed and eliminated at the end of their functional and planning life, using no additional resources and disposed causing no environmental pollution, can be considered deconstructable. The purpose of DfD consists in 'increase resource and economic efficiency and reduce pollution impacts in the adaptation of and eventual removal of buildings, and to recover components and materials for reuse, re-manufacturing and recycling' (Pulasky et al., 2003).

To achieve these objectives, it is necessary to make coherent choices in all phases of the design process. In particular, it is important to consider an integrated design connected to the choice of natural and locally available building materials, of suitable building technologies and to the analysis of economic and environmental costs for the potential decommissioning of the sustainable building. The main criteria of the building systems adopted are based on the disassembly of each element in parts conveniently transportable, storable, and reusable without heavy reconditioning interventions. These criteria seem to find practical applications in the 7th Environment Action Programme, which will address European environment policy until 2020 (EAP, 2016).

To date, concepts of DfD have been poorly implemented in the design of cattle housing. The present work aims at describing and discussing the design process of a new barn for dairy cows. The project embraces several concepts that are rather new to the dairy industry, including CBD and DfD, which can improve its sustainability. The design process started in 2013 and is still on-going. However, main building solutions and general layout of the barn have been identified. A first module, already realized to collect useful information for final design, is also described.

MATERIALS AND METHODS

Case study

The case study presented in this paper resulted from the collaboration between the Department of Agricultural, Food and Forestry Systems (GESAAF) of the University of Firenze and Cascina Bianca, a certified organic dairy farm located in Piedmont, Italy. Cascina Bianca already owns housing facilities for about 70 lactating cows (Fleckvieh breed), delivering about 1,400 kg of milk per day, but the farm aims at expanding the milk production to 7,000 kg day^{-1}. Therefore, one of the main objectives of the project was to build a new barn capable of housing the number of animals required to achieve the target daily milk production. Recent evidence shows that environmental concerns and societal perception of farming are becoming urgently important (Boogaard et al., 2011). Since Cascina Bianca processes and markets directly organic dairy products, developing a project that meets the fast changing needs of consumers was crucial. Hence, the department GESAAF was asked to help identify solutions to improve sustainability of the new housing facility. Besides improving productivity, project was expected to reduce environmental footprint and ensure high levels of animal welfare as well as being economically sound.

Construction site and context

The barn will be built on a green field site located in Cervasca (CN), Piedmont, Italy (44.405583, 7.500528). The area is in the south-western edge of the Po plain, at the foot of the Western Alps. The construction site is mostly flat and approximately rectangular in shape, with the main length lying on the North-South direction. Soil is loam with high presence of gravel. In the area, climate is continental temperate, with cool to cold winters and warm summers. Mean month temperatures range between 1.5 °C in January to 20.5 °C in July (Arpa, 2011). Maximum temperatures can be particularly high (> 30 °C) in summer, potentially causing sever heat stress conditions for dairy cattle (West, 2003). Prevailing wind flow from South-West while average annual precipitation is 1028 mm (Frattiani et al., 2007). Proximity with the Alps makes the area prone to high snowfall during the winter. Italian law sets a minimum design snow load of 240 kg m^{-2} for this particular area (D.M. 14 Gennaio 2008, Italian Government). Besides agriculture, forestry is very well developed in the area, particularly due to the wide availability of chestnut (*Castanea sativa*).

Project constrains

As already noted, project was expected to deliver a high level of sustainability. In particular, the main constrains set by Cascina Bianca were:

- building has to be designed according to the principles of DfD as the entire facility will have to be completely removed (and most materials recycled) when obsolete (expected life time 20 years);
- building has to be pleasant, consumers friendly, provide unobstructed views of the internal spaces and realized mainly with natural and locally sourced materials;
- cows have to be provided with high level of animal welfare, with special focus on limiting risk for painful diseases and fostering natural cattle behaviour;
- production of liquid effluents has to be limited as much as possible while high quality solid effluents are strongly desired.

Prototype building and test

In 2014, Cascina Bianca built a prototype building in order to test the feasibility of the project and measure effects on animal welfare (Fig. 1). The prototype building has been realized employing the same techniques and materials described below and can therefore provide useful indications about the performance of the housing system. The prototype building was 10 m wide and 40 m long with a total covered area of 400 m^2, of which 340 m^2 were bedded.

Figure 1. External view of the prototype building used for test.

RESULTS AND DISCUSSION

One of the first steps in the design process was identifying the housing system for the cows. Several solutions have been investigated and compared. Conventional systems like straw yards (SY) and free stalls (FS) have been quickly discarded due to the need of large volumes of concrete, which would have limited the deconstructability of the building (Salama, 2017). Also, both SY and FS may pose some limitations to animal welfare. Free stall housing showed to increase risk of foot and leg disorders, which represent a major welfare problem for dairy cattle (Kester et al., 2014). On the other hand, SY may result in poor udder health, especially due to high exposure to environmental mastitis-causing bacteria (Fregonesi & Leaver, 2001).

A housing system based on CPB was selected primarily because of the documented benefits regarding animal welfare (Bewley et al., 2017), which was one of the main focus of the project. Besides that, CPB would result in a very simple housing facility, with a unique large open area for the animals. Compared with FS, a CPB requires less steelwork and potentially less concrete. This allows applying extensively the concepts of DfD and has the potential to reduce construction costs. Moreover, employing CPB would limit the amount of liquid effluents produced while increase solid manure.

Normally, CPB consist of two separate areas for resting and for feeding. Resting area is bedded and pack thickness can vary from few cm to more than 1m depending on management (Klaas & Bjerg, 2011). Depending on the country and begging management, the floor beneath the bedded pack can be paved or not. In most cases CPB in Italy have a cast-in-place concrete floor in the resting area (Leso et al., 2013). Barberg et al. (2007b) reported that CPB in Minnesota are commonly bedded upon a clay base. Other research found that most CPB in the Netherlands have a concrete floor, while just one Dutch CPB was provided with a plastic foil under the bedding (Galama et al., 2011). In CPB, 30 to 50% of the total cow excreta are produced in the feeding area (Janni et al., 2007). For this reason, the floor of the feeding area is generally not bedded and made up of concrete (close or slatted) to facilitate frequent removal of manure.

To reduce as much as possible the use of concrete and steelwork, the housing system for the new barn of Cascina Bianca will consist of a unique continuous bedded area on which the cows will rest, walk and eat. Therefore, there will be no distinctions between the resting and the feeding areas. To ensure homogenous distribution of excreta over the bedded area, cows will be fed with movable feed troughs (Fig. 2). The troughs will be filled with fresh feed and moved on a new spot every day. Bedding will be 0.8 to 1.0 m-deep and the floor beneath will be realized with a plastic foil. A layer of sand will be placed above the foil to protect it even though the pack stirring operations, which will be carried out once or twice a day, will occur at a maximum depth of 0.25–0.3 m. Previous experiences in CPB with deep bedding suggest that just the upper part of the bedded pack needs to be removed and substituted periodically (normally once a year) with new material, while the lower layer

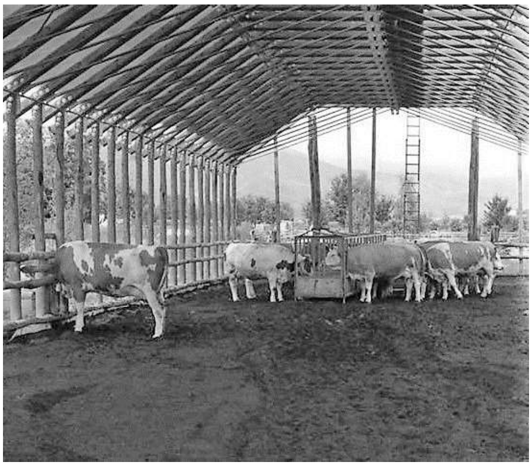

Figure 2. The movable feeding trough system allows spreading the manure over the entire area of the bedded pack, without the need of a concrete alley.

can be left in place (Galama et al., 2011). This management guarantees the plastic foil is not damaged by machines and makes concrete paving beneath bedding unnecessary.

In compost barns throughout the world, several kinds of bedding have been employed, based on climate, local availability and market price. Most common seem to be sawdust and woodchips (Klaas & Bjerg, 2011). However, the price of wood-based materials has increased in recent years mainly due to the use as alternative energy sources. Cascina Bianca will adopt green waste compost sourced from a local composting plant as bedding. Besides being environmentally friendly, this material resulted to be particularly cheap on the local market. Besides reducing costs associated with bedding, employing compost allows shortening the loop of organic wastes within the local economy and can contribute generating a positive perception of the farm. The employment of compost bedding coupled with the movable feeding system will result in the production of a single type of effluent. Such material, being relatively dry and solid, can be easily stocked and managed. Recent research also showed this material is an excellent fertilizer, especially due to the very high content of organic matter, which improves soil structure over the long term (de Boer, 2014). This aspect makes it very well suited to organic farming systems.

Although this kind of CPB housing would allow a high level of animal welfare, as the cows are not exposed to concrete flooring, the cultivated pack needs a large area, leading the building to be particularly extended. First aim of Cascina Bianca is building an housing facility to increase production of milk up to 7,000 kg day^{-1}. Considering a milk yield per animal of 25 kg day^{-1} (which is the actual milk production level at Cascina Bianca), the new barn will need to house 280 lactating cows. Space for 40 dry cows and 40 pregnant heifers will also need to be provided, leading to a total capacity of 360 dairy cattle. Previous research indicates 30m^2 cow^{-1} can be an adequate animal density in CPB systems that are not provided with scraped feeding area (Klaas & Bjerg, 2011). The barn will therefore have a covered area of 10,800 m^2, excluding the milking facility.

Cows will be milked twice a day in a 20+20 herringbone parlour. A dedicated building will accommodate the parlour and other necessary facilities including the milk and equipment rooms, the holding pen and the cows treatment area. Such building will be constructed using the same techniques and materials employed for the superstructure of cattle housing. However, the whole building will be paved with concrete to facilitate cleaning operations. Conventional building solutions (concrete and bricks) will also be used to create the internal and external walls of the milking centre. Effluents generated in this area will be collected in a dedicated tank, and will represent the only liquid waste produced.

Building layout and structure

Structural system consists of locally sourced timber connected by steel joints and supporting truss work in wood. The bearing structure is composed of pillars in solid chestnut wood (diameter 0.15 m, nominal length 6.25 m), the roof has a nominal span of 12 m, and overall height is 8.25 m. The anchor joints with pillars are simply placed flat on a wood beam under the roof truss. Foundations are realized with chestnut wood pillars driven into the underground to a depth of 2.4 m.

The very large covered area combined with the high snow load of the building site (240 kg m^{-2}) posed several challenges. The snow accumulated on the roof increases dramatically the structural load and therefore construction costs. Therefore, it is necessary to adopt a solution that consists to build a simple structure with a moderate clear span of 12 m for a total length of 180 m. This kind of buildings will be replicated throughout 4 modules of building separated between them with a distance of 4 m (Fig. 3).

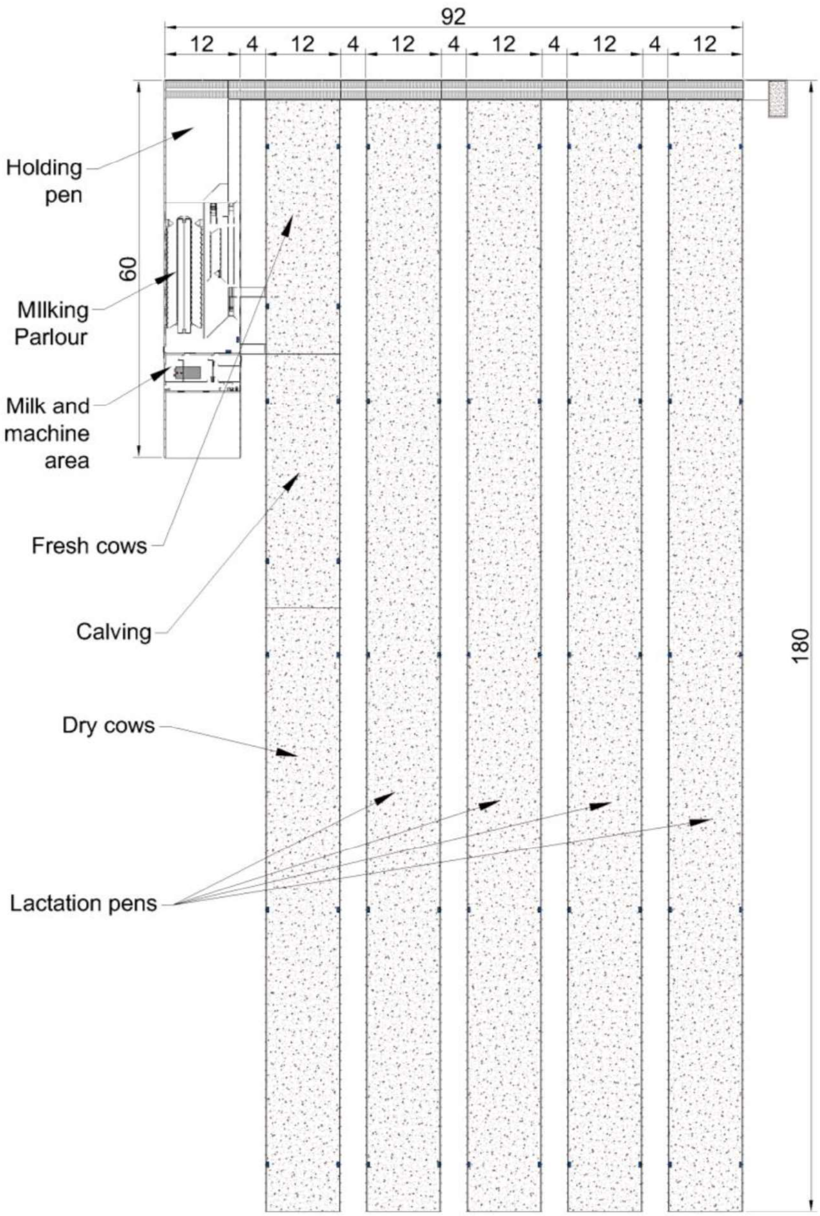

Figure 3. Plan view of the building.

All structures, including the milking centre will be covered with a transparent PVC foil, derived from the greenhouse sector. The transparent covering is recyclable and will help creating bright and pleasant interiors as well as contributing to maintain the bedded pack dry and comfortable for the cows. To avoid excessive heat load, a plastic shading net will be installed over the transparent covering during summer months. Moreover, a row of trees will be planted between each module with the aim of fostering natural shading of the structure as well as creating a more natural-looking environment (Leso et al., 2017). A cross section of one of the building modules is reported in Fig. 4.

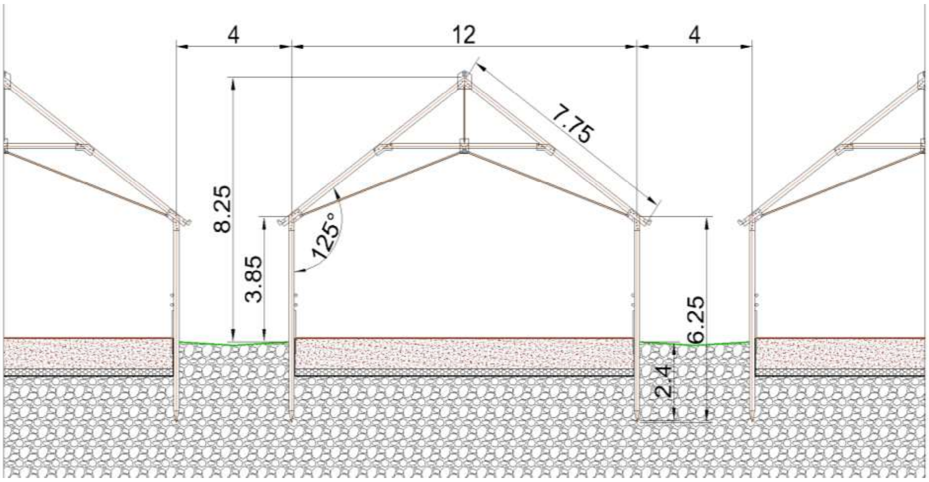

Figure 4. Cross section representing one of the building modules.

Building materials

In the context of building removal, some materials are better suited to recycling, some to reuse. Metals, for example, are well suited to recycling. Steel can be roughly treated (bent, torn apart and otherwise) and still retain a relatively high value. Even if it is intermixed with other materials, metal can be separated (magnetically) for recycling (Falk, 2002). As regards to the selection of building materials for the design of the sustainable cattle housing, the technical features are shown here:

– Chestnut timber: if solid lumber is mistreated and broken up, it is impractical to separate it from other building materials and any value is vastly reduced (Falk, 2002). In order to respect this point only local round chestnut has been used.

– Steel plate joints: simple and standardized structural connections can enhance the assembly and disassembly process. For example, modular connections, such as the new rigid key-type joint or an older modular connection called Saxe clips for structural steel, allow steel members to be easily disassembled and reused. These modular connections require as little as one bolt and no welding for installation, resulting in a simplified construction process and contributing to a shorter construction schedule. Attention to connection details is critical for future reusability of structural elements. Complex and unique connections increase installation time and complicate the deconstruction process. Fewer connections and consolidation of the types and sizes of connectors will reduce the need for multiple tools during deconstruction (Guy & Shell, 2002). Simple and standard connections that facilitate the ease of disassembly and full recovery of reusable materials are necessary to close the loop on material reuse (Pulaski et al., 2003). Metallic joints mainly made of galvanized steel (hot-dip galvanizing or electrogalvanized) are recyclable. Recycling consists of separating steel from zinc, in order to obtain materials with the same initial physical and chemical properties.

– Plastic film: cheap, durable and versatile, plastics bring us multiple benefits. But these materials can also pose problems when plastics end up in the environment, with impacts on nature, the climate and human health. To make recycling easier, plastic manufacturers have implemented a numeric resin identification. DfD must respect this code system in order to simplify reuse and to promote the use of recycle plastic.

Livestock housing and handling solutions

Given the unusual shape of the barn and the limited use of concrete for flooring, the development of efficient systems for livestock feeding and management required the study of dedicated solutions. Housing for cows will be organized in 5 distinct modules (Fig. 3). One of them (the closest to the milking parlour) will accommodate 3 pens for different production stages: 1) dry cows, 2) calving pen, 3) freshly calved and special attention cows. The remaining modules will house all lactating cows, offering flexibility to create up to 4 groups of animals. This allows providing different rations tailored to the nutritional requirement of each group. Also, lactating cows can be separated based on their parity. A sorting gate placed at the exit of the milking parlour will allow separating individual cows that need to be examined, treated or inseminated. A dedicated treatment area, provided with insemination and treatment chutes, will facilitate animal husbandry operations.

Results obtained with the prototype building

The prototype building realized in 2014 allowed Cascina Bianca to assess the feasibility of the project and evaluate construction methods and building materials. After more than four years from construction, the structure and in particular the wooden posts driven into the ground showed no apparent signs of deterioration indicating the building techniques employed can be sustainable over the mid- to long-term.

Furthermore, to assess effects on animal welfare and performance, a trial was organized in cooperation with the University of Turin, Department of Veterinary Science (Bellino, 2014). Twenty two primiparous cows (Fleckvieh breed) were randomly divided in two groups. The first group was housed in a conventional free stall barn while the second was housed in the prototype building with CPB housing system. The 11 cows in the group CPB-TRTM were allocated 30.9 m^2 $animal^{-1}$. All cows were fed the same TMR ration and milked 2 times a day in a 5+5 herringbone parlour. Experiment lasted 8 months (from February 2014 to October 2014), during which the animals were constantly monitored to determine milk production and quality. Animal behaviour was monitored by direct observations carried out by a trained operator. Air temperature and temperature of the bedding in the prototype building were also monitored during the course of the study.

Results of the trial carried out in the prototype building indicated cows housed in CPB were healthier and produced higher quality milk compared with those in the conventional free stalls system (Bellino, 2014). In particular, cows in CPB-TRTM showed lower locomotion score, lower somatic cells count, lower total bacteria count, and higher milk fat content. No differences were detected in milk yield and body conditions score among the two groups. Furthermore, compared with FS-TRTM, cows in CPB-TRTM showed less agonistic behaviours among herd mates and better interactions with humans. During the course of the study, temperature of the bedding was significantly higher than air temperature, indicating that the material was actively composting.

CONCLUSIONS

The concept of DfD has the potential to limit the environmental impact of construction by supporting end-of-life disassembly and reuse of building materials. To date, such concept has been poorly implemented in the design of livestock housing and research in this specific field is still very sparse. The case study described in this paper demonstrates applying DfD extensively to dairy cows housing is feasible. However, novel and dedicated solutions need to be identified during early phases of the design process. Cultivated pack barns seem to be better suited to DfD compared with conventional housing systems, such as FS. Further research is strongly needed to develop viable DfD-oriented building solutions for livestock housing.

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