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The Expert System Approach in Dairy Farm Design

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ABSTRACT
Ensuring animal welfare, labor efficiency, and sustainable productivity in dairy farms requires barn and facility designs that are compatible with herd structure and animal behaviour. The aim of this study is to present the development of an expert system called the Architectural Designing of Dairy Farms (ADDF), designed to automate and support the architectural planning process of dairy cattle operations. The system is based on ten modules encompassing herd size estimation, group management, and architectural layout of pens and service structures. Each module operates with clearly defined input-output relationships, and the system was implemented as a desktop application using Visual Basic 6.0. User-defined parameters, including the number of mature cows and milking shift length, allow for dynamic scenario analysis across different herd sizes and farm management strategies. A hypothetical case involving 250 dairy cows and a 3-hour milking shift was used to validate the model, and architectural plans were generated using AutoCAD. The results demonstrate that ADDF significantly reduces design time, improves decision-making in herd housing and infrastructure planning, and supports animal welfare-focused design principles. The system offers a flexible and practical tool to improve the efficiency of dairy farm design processes, with potential for integration into future smart farming systems.

Keywords: Dairy cattle, Animal welfare, Farm designing, Information technologies

1. Introduction

The main factors affecting the yield in animal production are: genetic structure, nutrition, housing and environmental conditions. Providing suitable barn design and environmental conditions for sustainable dairy farming is an obligation of equal importance for each animal. The design goals of animal barns in dairy farms are to provide healthy environmental conditions, to reduce initial investment costs while increasing labor efficiency and to optimize calf growth. In this context, the most important design goals for animals are: minimizing stress, providing clean, dry and comfortable resting areas, providing continuous and easy access to adequate food and water, and protecting especially young animals from the effects of adverse weather conditions. The main design goals for the caregiver are; minimizing the use of labor in feeding, cleaning, manure management and animal care, facilitating the observation and management of animals, providing adequate lighting and worker safety.

However, it is known that most of the investments in dairy farms are allocated to construction of structures. It is very difficult to reverse the mistakes made during the project preparation and construction phase of animal production structures; furthermore, such situations will increase the cost of the project and construction, and will greatly reduce the production amount and quality. A properly designed and managed barn will make it easier for animals to adapt to current management strategies, while a poorly or incorrectly designed barn will increase the risk of injury and disease. However, young animals raised in unsuitable environmental conditions do not reach their genetic milk production potential. It is stated that every design can have a concession, that is, there cannot be a single design that can be described as the "best". For this reason, design objectives should be prioritized in order to determine the business features that will meet the management plan. Before starting the construction of barns and other service structures in order to provide the expected economic benefit from the farms, factors such as the number of animals accommodated in the farm, production planning, physiological requirements, quantity and technical characteristics of the necessary equipment, and the geographical and climatic conditions of the environment should be thoroughly reviewed (Holmes et al. 2013; Berckmans 2017; Kaur et al. 2023).

In addition to the barns, a dairy farm consists of components such as a milking unit, feed and fertilizer storages. Change in one component of the farm affects others, and these interactions can affect business performance, environmental impact and profitability. These effects may not be obvious and easily understood. Calculating and comparing the benefits and costs of alternative designs, technologies and management strategies of the farm is not an easy process. However, such activities are

very difficult and costly (Karmakar et al. 2007; Rotz et al. 2011). Therefore, it is necessary to develop expert systems that will speed up analysis and ease decision-making (Samer 2008).

This study aims to develop and demonstrate an expert system "Architectural Designing of Dairy Farms" (ADDF) (Alkan 2017). It is expected that the developed model will make a significant contribution to the efficient and sustainable production of such farms by ensuring that the architectural plans of the newly established farms are prepared properly, allowing an appropriate herd management, and the existing farms are improved or restructured as efficient and modern enterprises.

2. Material and Methods

The project began with the creation of a database, employing scientific and technical principles to encompass all stages and principles of architectural design for dairy cattle farms. Subsequently, algorithms and flowcharts were developed for each module using the MS Excel program. The expert system was then converted into a computer program comprising 15 interfaces based on 10 modules, utilizing Visual Basic 6.0, an object-based programming language. The program takes inputs such as the total number of mature cows and milking shift length, and produces outputs including herd size and composition, management plans, and architectural designs for barns and other service buildings. To validate the system, an example operation was simulated involving 250 dairy animals and a 3-hour milking duration. The results were used to create a design using AutoCAD 2017, demonstrating the practical application of the program.

2.1. Developing expert system modules

The expert system comprises 10 modules with well-defined input-output relations, including: 1. Herd Size and Makeup, 2. Herd Management, 3. Calf and Heifer Pens Designing, 4. Lactating Cows Pens Designing, 5. Special Pens Designing, 6. Barn Systems Designing, 7. Milking System Designing, 8. Manure Storage Designing, 9. Feed Storages Designing, and 10. Farmstead Layout. This study specifically concentrates on detailing the Herd Management and Lactating Cows Pens Designing modules.

2.1.1. Herd Management module

In the expert system, the herd management plan was created separately for “calves and heifers”, “lactating cows” and “special need cows”, considering the number of animals determined for each group (Holmes et al. 2013). The total herd size was calculated based on the number of lactating cows and milking shift duration as primary inputs. Additional general assumptions include uniform calving throughout the year, a 12-month calving interval, first calving at 24 months of age, a 2–3% mortality rate, a 305-day lactation length, and a stable herd size. The steps followed and the principles taken into account in the creation of this module are as follows;

Herd management plan for calves and heifers: In the module, young animals were categorized into three groups based on their age, and a suitable barn type was determined for each group. It was decided that baby calves (0-2 months) should be housed in individual calf hutches, while transition calves (3-5 months) should be accommodated in bedded group pens, with a maximum of 10 animals per pen. Calves and heifers (6-24 months) were planned to be housed in freestall pens, with a maximum of 60 animals per pen (Pettersson et al. 2001). The calculations for the number of hutches needed for baby calves, the number of pens needed for transition calves, calves, and heifers, as well as the number of animals to be housed in each pen, were performed using equations 1 to 7.

$$CHN = BCN \quad \text{(Eq. 1)}$$

$$TCPN = \frac{TCN}{10} \quad \text{(Eq. 2)}$$

$$TCPN = Z^{+} \text{ (values are rounded to the next highest whole number)} \quad \text{(Eq. 3)}$$

$$TCPAN = \frac{TCN}{TCPN} \quad \text{(Eq. 4)}$$

$$HPN = \frac{HN}{60} \quad \text{(Eq. 5)}$$

$$HPN = Z^{+} \text{ (values are rounded to the next highest whole number)} \quad \text{(Eq. 6)}$$

$$HPAN = \frac{HN}{HPN} \quad \text{(Eq. 7)}$$

CHN; Number of calf hutches (number), BCN; Number of baby calves (head), TCPN; Number of transition calf pens (number), TCN; Number of transition calves (head), TCPAN; Animal number in each transition calf pen (head), HPN; Number of heifer pens (number), HN; Number of heifers (head) and HPAN; Animal number in each heifer pen (head).

Herd management plan for lactating cows: The module forecasts that milking cows will be housed in freestall pens planned according to their age and weight. The number of pens for the milking group is based on the milking group size, which is calculated by the milking shift length input by the expert system user, not exceeding 6.5 hours (Cook & Nordlund 2004; Nordlund et al. 2006). The module determines the number of milking cow pens and the number of animals housed in each pen using equations 8 to 11 based on the milking group size. However, the module also forecasts that the number of animals housed in one pen should not exceed 100 head.

$$CPH=\frac{MCN}{MSL} \quad \text{(Eq. 8)}$$

$$MGS=GMTxCPH \quad \text{(Eq. 9)}$$

$$MCPN=\frac{MCN}{MGS} \quad \text{(Eq. 10)}$$

$$MCPAN=MGS \quad \text{(Eq. 11)}$$

CPH; Cows milked per hour (head), MCN; Number of milking cows (head), MSL; milking shift length (hour), MGS; Milking group size (head), GMT; Group milking time (hour), MCPN; Number of milking cow pens (number), MCPAN; Number of animals in each milking cows pen (head)

Herd management plan for special needs cows: In the module, it is forecasted that dry cows will be housed in freestall pens to be planned in line with their age and needs. In order to monitor the cows from the dry period to the breeding period, and to manage feeding and reproduction, far off dry cows pen, close up cows pen, maternity pen, post-fresh non-saleable milk pen, post-fresh monitoring pen, sick cow pen, heifer pen and mature cow pens are planned (Graves et al. 2006). Movements of animals between these pens (herd management organization) are shown in Figure 1 and the number of animals in each management group was determined based on the values in Table 1.

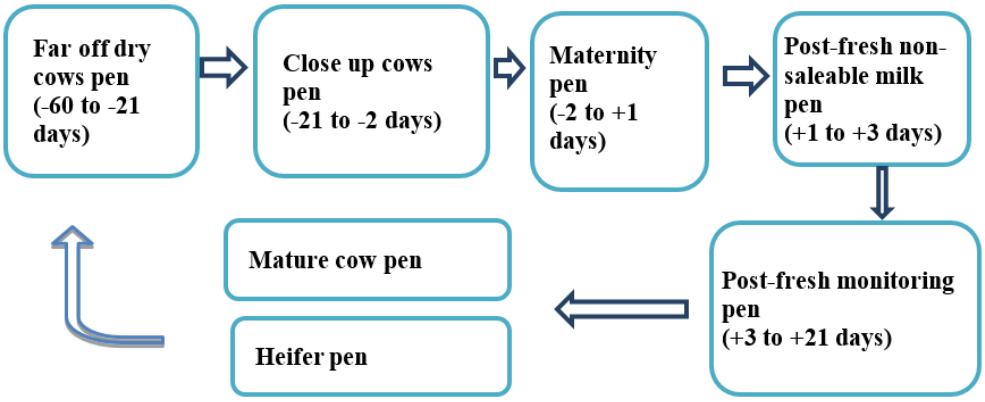


Figure 1- Grouping system used in the expert system to facilitate cow management (Holmes et al. 2013)

Table 1- Transition Cow Group Design Guidelines and Baseline values for the expert system

Transition Cow Group (Holmes et al. 2013)	*Duration of Stay in Group (Holmes et al. 2013)*	*100 Total Cows*				
		MWPS (1997)	*Cook and Nordlund (2004) Smith et al. (2001)*	*AgSource Cooperative Services (2006)*	*Graves et al, (2006)*	*Base value for the Expert system*
		Number of Cows in each group Average ***(Design Value @ 130% of Average)****				
Far-off Dry Cow Group	-60 to 21 days prepartum	12 (16)*	11 (15)*	12 (16)*	12 (15)*	16
Close-up Dry Cow Group	21 days prepartum	5 (7)*	6 (8)*	5 (7)*	6 (8)*	8
Close up Heifer Group	21 days prepartum	-	3 (4)*	3 (4)*	-	4
Total Close up Cow Group	21 days prepartum	-	9 (12)*	8 (11)*	-	12
Total Dry Cows Group	60 days prepartum	17 (23)*	17 (23)*	17 (23)*	18 (23)*	23
Maternity Cow Group	3 days during calving	1 (1)*	1 (1)*	1 (1)*	-	1
Maternity Heifer Group	3 days during calving	1 (1)*	1 (1)*	1 (1)*	-	1
Total Maternity Cow Group	3 days during calving	2 (2)*	2 (2)*	2 (2)*	-	4
Fresh Cow Group	21 days postpartum	5 (7)*	6 (8)*	5 (7)*	6 (8)*	8
Fresh Heifer Group	21 days postpartum	-	3 (4)*	3 (4)*	-	4
Total Fresh Cow Group	21 days postpartum	8 (11)*	9 (12)*	8 (11)*	9 (12)*	12
Treated Cows	10 days	-	(3)*	-	-	3
Lame Cows	21 days	-	(3)*	-	-	3
Cull Cows	28 days	-	(3)*	(3)*	-	3

2.1.2. Lactating and Dry cows housing module

The architectural design stages of the pens and the principles taken into account for the number of milking cows determined in the herd management plan in the expert system are presented below (Bewley et al. 2001; Holmes et al. 2013).

Sizing of the pens: In the expert system, it is forecasted that the milking cows will be housed in a two-row head to head freestall pen and loose bedded stall platforms will be used in the pens. Also one feed and stall alley and one stall alley are planned in each pen (Figure 2). A freestall is forecasted for each cow in these pens and a cross alley is planned between each stall block of 25 (with a maximum stall block width of 30 m) in order to facilitate the transition between service alleys (Brouk et al. 2003; Cook & Nordlund 2004; Nordlund et al. 2006; Cook 2009; Cook & Nordlund 2009). The dimensions of the milking cow pens in the module were determined with the equations from 12 to 21.

AN=Even Number⇨ FSN=AN (Eq. 12)

AN=Odd Number ⇨ FSN=AN+1 (Eq. 13)

AN≤ 100 (Eq. 14)

FSN ≤ 50 ⇨ CAN = 2 (Eq. 15)

FSN > 50 ⇨ CAN = 3 (Eq. 16)

$PL=(\frac{FSN}{2})$ x FSW+(CAN x CAW) (Eq. 17)

CFW=FSAW+FSPW+ SAW (Eq. 18)

PELA=AN x AELA (Eq. 19)

$$PELW=\frac{PELA}{PL} \quad \text{(Eq. 20)}$$

$$PW=CFW+PELW+TAW \quad \text{(Eq. 21)}$$

AN; Animal number in each pen (head), FSN; Freestall number in each pen (number), CAW; Cross alley width (cm), CAN; Cross alley number (number), PL; Pen length (cm), FSW; Freestall width (cm), CFW; Concrete floor width (cm), FSAW; Feed and stall alley width (cm), FSPW; freestall platform width (Outside curb to outside curb distance for head-to-head freestall platform) (cm), SAW; Stall alley width (cm), BGA PELA; Pen exercise lot area (Needed exercise lot for pen) (cm^2), AELA; Animal exercise lot area (Needed exercise lot per animal) (cm^2), PELW; Pen exercise lot width (cm), TAW; Transfer alley width (cm), PW; Pen width (cm)

Concrete Floor Width, Platform Alignment and Pen Length: To ensure continuous mechanized manure removal and avoid platform discontinuities, the compartment concrete floor width (CFW) is not fixed to a value. For each barn row, CFW is computed using the largest head-to-head freestall platform width among the adjacent pens (FSPW_max) to maintain a common platform alignment along the length of the barn. Differences in stall body space (stall length) between pens are achieved by adjusting brisket board and neck-rail positions rather than changing platform width, thereby preserving alignment for mechanization (scraper/loader envelopes and safety clearances) while meeting animal-scale design requirements. On the other hand, pen lengths were calculated independently by two criteria: (i) the total depth imposed by stall rows plus cross-over alley widths, and (ii) the feed bunk length required per animal. The greater of the two values was adopted to guarantee the minimum feed space per cow under all design scenarios.

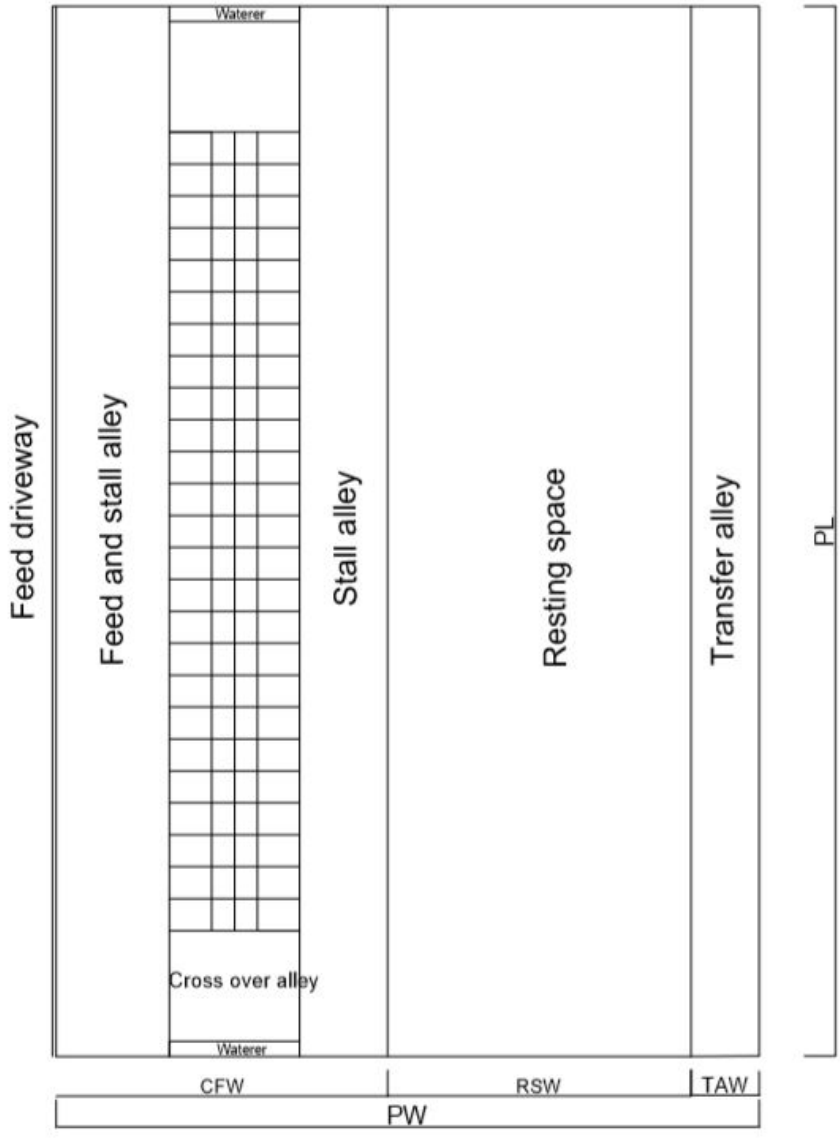


Figure 2- Architectural design of freestall pens

2.2. Developing an expert system program

The expert system has been converted into a program (ADDF) consisting of 15 interfaces using Visual Basic 6.0. Apart from the fixed values predicted for each module (accepted norms in the herd flow and management plan, the architectural details and dimensions of the barn and other service structures), the data requested from the user (number of milking animals, milking unit type and milking shift length) can be transferred to the algorithms developed for these modules.

The prototype of the ADDF expert system was implemented using Visual Basic 6.0 due to its compatibility with early-stage algorithmic modeling and rapid interface development. However, recognizing the long-term limitations of VB6, future iterations of ADDF are planned to be redeveloped using VB.NET, C#, or Python. This transition will ensure cross-platform functionality, enhanced security, and integration with web-based and cloud-based agricultural management systems.

3. Results

An expert system program called ADDF has been developed for the purpose of designing the barn and other service structures in a dairy farm, in accordance with the correct herd flow and herd management plans, to meet animal welfare criteria, to be compatible with climatic conditions and to increase workforce efficiency.

First, algorithms for the modules were created. Then, 15 interfaces were prepared, providing access to the modules of the expert system program.

3.1. Module algorithms

Algorithms and flowcharts have been developed in line with the principles and equations specified in the methods section for each module. The flowchart of the herd management module algorithm is given in Figure 3 and the flowchart of the lactating and dry cows pens designing module algorithm is given in Figure 4.

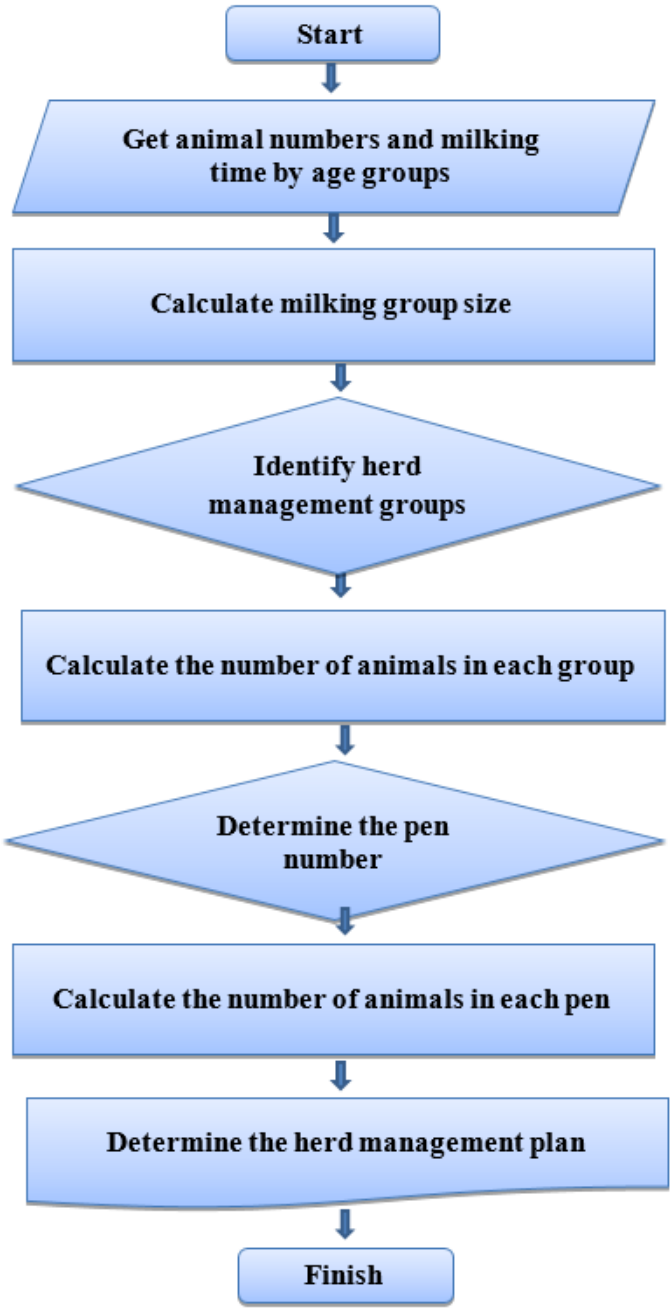


Figure 3- Flowchart of herd management module algorithm

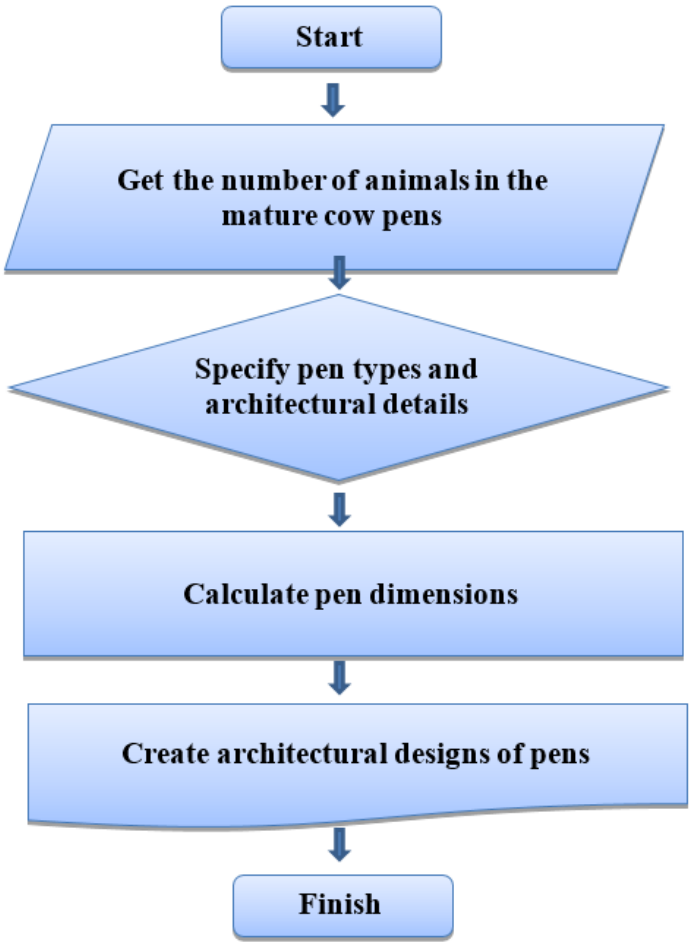


Figure 4- Flowchart of the lactating and dry cow pens designing module algorithm

3.2 System Interfaces and generated design outputs

The expert system consists of 15 interfaces. This study presents only the main menu of the expert system, whereas the herd management and lactating/dry cow pen design details generated by the program are summarized. The main menu provides access to modules. It consists of cells that allow the user to enter data on the number of milking animals and milking shift length, the calculate button and the cells showing the "group size" and the "total herd size" as an output of the program run by pressing the calculate button (Figure 5). Then there are tabs providing access to the administrative design interfaces (herd size and makeup, feeding ration, herd management). In these interfaces, data used in the design of barns and other structures on the farm are obtained. And then, there are tabs providing access to structural design interfaces (Calf pens designing, heifer pens designing, lactating and dry cow pens designing, special pens designing, barn systems designing, manure storage designing, parallel/ fishbone milking system designing, rotary milking system designing, horizontal concrete silos designing, feed storage designing and farmstead layout). In this section, the architectural designs of the barns and other service structures and the outputs of the farmstead layout are obtained by using the data obtained from the administrative design section. ADDF was run using the values of 250 milking cows and 3-hour milking shift length for a sample dairy farm. Thus, in the first part of the main menu, outputs are as follows: milking group size 63 heads and total herd size 791 heads (Figure 5).

The herd management plan is summarized in Table 2. In this table, the management groups foreseen in the herd management plan module (mature and dry cows groups according to the age group and special needs of the animals) are determined. Therefore, the number of animals in each management group, the number of pens and the number of animals in each pen are calculated using the data determined in the previous interfaces by ADDF. These values are used as input in all other modules.

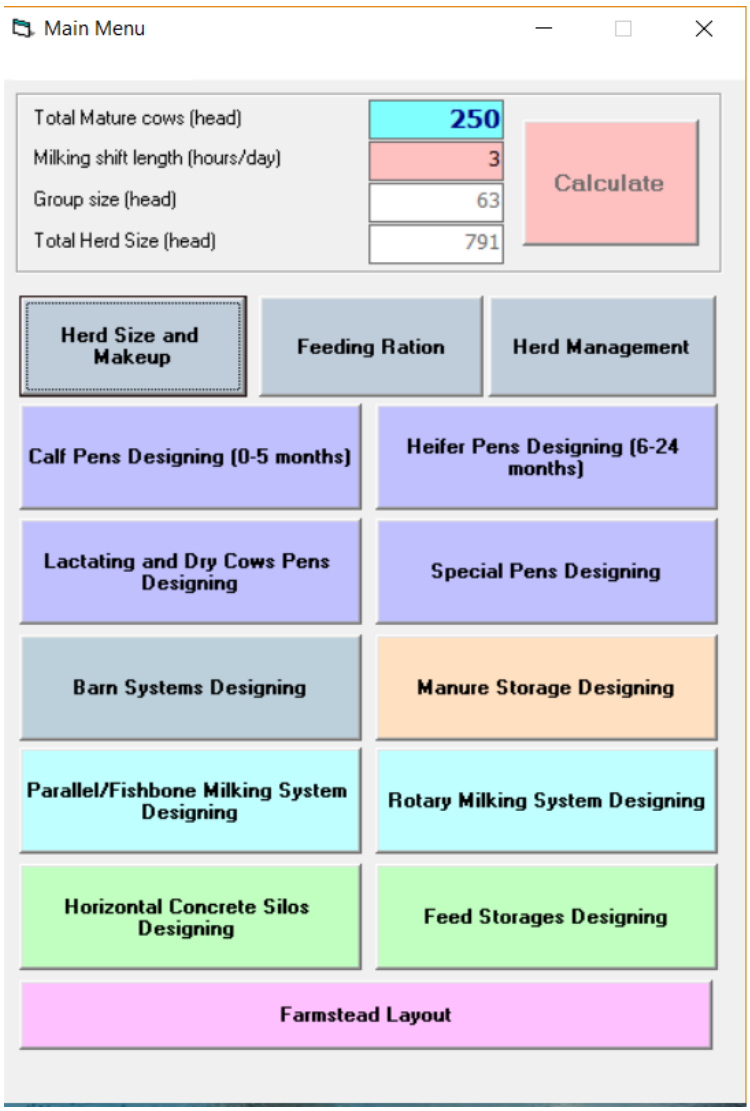


Figure 5- Main menu of the expert system

Table 2- Aggregate design parameters generated by ADDF for different management groups

Parameter	*Far-off Dry Cows (-60 to -21)**	*Close-up Dry Cows (-21 to -2)**	*Post-fresh (1 to 3)***	*Post-fresh-monitoring pen (3 to 21)***	*First-lactation heifers (21 to 305)*	*Late-lactation cows (21 to 305)*
Animal size (head)	40	30	30	30	75	145
Pen size (number)	2	1	1	1	2	3
Animals per pen (head)	20	30	30	30	38	49
Freestalls per pen (no.)	20	30	30	30	38	50
Cross-over alleys (no.)	2	2	2	2	2	2
Stall width (cm)	137	137	127	127	122	127
Cross-over alley width (cm) (366–500)	500	500	500	500	500	500
Head-to-head freestall platform width (cm)	518	518	518	518	518	518
Stall body space length (cm)	178	178	178	178	173	178
Feed and stall alley width (cm) (396–457)	450	450	450	450	450	450
Stall alley width (cm) (305–366)	350	350	350	350	350	350
Concrete floor width of pen (cm)	1318	1318	1318	1318	1318	1318
Resting space width (cm)	759	884	929	929	1031	1056
Transfer alley width (cm)	270	270	270	270	270	270
Pen width (cm)	2347	1588	2517	2517	2619	2644
Pen Length (cm)	2370	3055	2905	2905	3318	4175

The architectural design parameters for the lactating and dry cow pens are summarized in Table 2. In this module, the dimensions of the alleys, the number and dimensions of the freestalls, the size of the resting space and the dimensions of the pens were determined separately for each management group. The lactating and dry cow management groups determined in the herd management plan module and the number of animals in the pens belonging to these groups are used as inputs.

In this module, the user is provided with the opportunity to make changes only to the limit values specified next to these cells; alleys, feed line and transfer alley width values. Additionally, it is allowed to change the head-to-head stall platform and stall width values and stall body space length values depending on the dimensions recommended for the live weight of the animals. The "calculate" button on the interface is inactive if there is no change in these cell values, but it activates if there is any change. The dimensions of the architectural design of the pens planned for the milking and dry cows according to the number of 250 milking animals and 3 hours of milking shift length for the sample farm were determined for each management group of animals at the interface (Table 2). ADDF calculated the number of cross alleys for each pen belonging to 6 different herd management groups in the interface as 2, as one cross alley for every 25 stalls. It is determined that the number of freestalls in the pen, according to the number of animals in each management group, is an even number. The program found the width of the resting area for each management group which values are calculated to provide sufficient resting space for the pens. In practice, it is foreseen to use the largest width in the adjacent pens along the length of the barn. In order to ensure compliance with the use of mechanization in manure cleaning, the program determined the concrete floor width of the pens as 1318 cm in all management group pens. In addition, the program calculated the pen length values.

4. Discussion

Efficient planning of herd management and the architectural design of dairy farms is critical for achieving sustainability, productivity, and animal welfare. The expert system developed in this study (ADDF) integrates the environmental needs of animals with structural requirements, aligning with the principles of precision livestock farming (PLF), which emphasize the role of decision-support systems in optimizing animal-based operations (Berckmans 2017; Kaur et al. 2023).

In recent years, large-capacity dairy farms have increasingly adopted high-yielding breeds to maximize milk production. However, sustaining this potential requires well-designed barns and service structures that support the animals' genetic and physiological needs. Inadequate environmental conditions can adversely affect milk yield, reproductive performance, and welfare (Bewley et al. 2001; Cook & Nordlund 2004; Holmes et al. 2013; Olgun 2016). Beyond the simulated 250-cow scenario, ADDF was also evaluated using real farm data from three commercial dairy farms in Menemen, Türkiye, demonstrating applicability under field conditions. Field results further indicate that—even in modern farms—design non-conformities persist, particularly in grouping strategy, access to feed/water, and freestall dimensions; ADDF systematically surfaces these issues for corrective action (Alkan & Akyüz 2024). Accordingly, modern dairy facilities should be designed using integrative strategies that consider animal behavior, climate control, and labor efficiency rather than traditional layouts.

One of the strongest aspects of the ADDF system is its emphasis on understanding and responding to herd makeup, particularly for physiologically or behaviorally distinct groups such as calves, heifers, dry cows, fresh cows, and lame individuals. Scientifically grounded algorithms are employed to address the special needs of each group through tailored pen layouts, housing configurations, and transition zones. Numerous studies have emphasized that group-specific housing is essential for improving animal comfort, controlling disease, enhancing reproductive success, and supporting behavioral well-being—especially during calving and transition periods (Bewley et al. 2001; Pettersson et al. 2001; Cook & Nordlund 2004; Graves et al. 2006; Kammel & Graves 2007; Tucker et al. 2021; EFSA 2023). By embedding these principles into its modular design logic, the ADDF enables proactive welfare management and infrastructure-based risk mitigation.

Compared to previous systems that focused primarily on environmental or nutrient planning (Samer 2008; Rotz et al. 2011), the ADDF provides a comprehensive and adaptable planning tool. User-defined inputs, such as herd size and milking shift duration, allow the system to dynamically adjust to diverse farm scales and management strategies. This level of flexibility is crucial in high-capacity operations, where production intensity and herd composition frequently vary (De Vries 2020).

Moreover, recent research has confirmed that housing design and management practices substantially affect key welfare indicators such as lameness prevalence and somatic cell counts (Gieseke et al. 2022). Addressing these concerns, the ADDF incorporates spatially optimized modules for each subgroup, ensuring that space allocation and pen configurations meet biological standards and welfare requirements.

Despite its contributions, the ADDF has areas for potential enhancement. Currently, it lacks integration with economic evaluation modules. Incorporating real-time environmental data (e.g., temperature, humidity) and cost-estimation tools could strengthen the system's predictive utility and operational feasibility. As highlighted by Berckmans (2017) and supported by recent developments (Arulmozhi et al. 2024), the integration of expert systems with precision livestock farming and digital modeling technologies is an emerging priority in modern livestock facility design.

In summary, the ADDF represents a scientifically grounded and innovative approach to dairy farm planning. By integrating biological, architectural, and managerial variables, it offers a robust platform to enhance productivity, sustainability, and animal welfare in dairy production systems.

5. Conclusions

This study presents the development of an expert system named ADDF, designed to support the planning and design of modern dairy farm facilities. By integrating scientifically grounded herd management strategies with structural design principles, the system enables farm-specific solutions that align with animal welfare, production efficiency, and environmental adaptability.

Through its modular structure and user-defined inputs—such as herd size and milking shift length—the ADDF system offers flexibility to accommodate various farm management scenarios. The ability to generate customized architectural layouts based on biological and operational parameters positions the system as a valuable tool in both new farm development and the restructuring of existing operations.

The system's focus on group-specific planning (e.g., for calves, lactating cows, and transition groups) reflects a deep understanding of behavioral and physiological needs, which are critical for productivity and welfare. The implementation of this system has the potential to significantly reduce design errors, lower investment risks, and improve labor efficiency.
Although the current version of ADDF successfully demonstrates a functional and welfare-oriented expert system for dairy farm design, certain limitations remain. Quantitative performance indicators such as design time reduction and efficiency metrics were not evaluated within the scope of this study. Additionally, economic evaluation components, including cost–benefit analysis, have yet to be integrated. Future research will address these aspects by conducting comparative assessments between manual and ADDF-assisted design processes and by developing an economic evaluation module to complement the system’s technical framework.

While the current version demonstrates substantial utility, future developments should aim to incorporate real-time environmental data, economic feasibility assessments, and web-based accessibility. With these improvements, the ADDF expert system could serve as a comprehensive digital platform contributing to the broader adoption of precision livestock farming practices.

Author Declarations

Authors' contributions: Concept: İ.A., Design: İ.A., Data collection: İ.A., Analysis: İ.A., H.B.Ü., Writing: İ.A., H.B.Ü.

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