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Criteria for assessing dairy farm types

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Abstract In Galicia and in the rest of Spain, dairy barns are going through a transition to implement the latest technologies, improve labour efficiency, and increase size. Barns with capacity for more cows are required due to the new market demands. Such barns must be perfectly defined, so that the construction of new buildings may entail reduced investment and operating costs. A wrong decision in the design phase can lead to serious financial trouble, even to the extent of making the farm economically non-viable.

This study focuses in determining the factors that most strongly affect the construction costs of dairy housing, based on the most common barn designs in Galicia. Such factors are determined by implementing different indices that analyse the shape of the building.

The implemented indices concern the design of the building –mainly its shape– and consider in all cases the relation of the design to the total cost and cost per item of the different constructions. Among these indices, the ‘ratio of area to perimeter squared’ or shape index (dimensionless), and elongation (ratio between the length and the width of the building), enable the determination of the shapes that are more convenient from the economic perspective. The cost of the building envelope per square meter varies as the barn area increases. The relation between the variation in the cost of the building envelope and both indices is studied for the different design options considered.

With the data obtained, some guidelines are suggested in order to help project designers find the most appropriate result for their design work.

Keywords Dairy housing; Engineering design; Galicia.

Resumen Las estabulaciones de vacas de leche en Galicia, y en el resto de España, están pasando por una fase de transición, para adaptarse a nuevas tecnologías, mejorar la eficacia del trabajo y aumentar de tamaño. Las nuevas demandas del mercado ocasionan la necesidad de establos con mayor número de cabezas, los cuales deben de estar perfectamente definidos para que la construcción de nuevas edificaciones de como resultado un menor coste de inversión y explotación. Una decisión equivocada en la fase de diseño puede dar lugar a dificultades financieras serias, incluso hasta el punto de hacer la granja económicamente inviable.

El presente estudio se centra en la determinación, sobre las tipologías de estabulaciones de vacuno lechero más usuales en Galicia, de factores que inciden de manera más importante en los costes de construcción de la edificación, lo cual realizaremos a partir de la implementación de indicadores que analicen la forma del edificio.

Estos indicadores se refieren al diseño de la instalación, fundamentalmente a la forma de la misma, pero siempre teniendo en cuenta su relación con los costes totales y por partidas de las distintas construcciones. Destacan, por ejemplo, la “relación superficie perímetro al cuadrado”, o también denominado índice de forma (con carácter adimensional), y la elongación (relación entre el largo y el ancho de la edificación), que nos permiten determinar las formas más convenientes económicamente. Por último, se relacionan con los indicadores las variaciones del coste del cerramiento por metro cuadrado, para los distintos tipos de diseño, a medida que se incrementa la superficie del establo.

Todo ello se concretará en una serie de recomendaciones para ayudar al proyectista en la búsqueda del resultado más adecuado en su labor de diseño.

Palabras clave Alojamientos de vacuno lechero; Diseño en ingeniería; Galicia.

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Introduction And Background

Galicia is an autonomous community located in northwest Spain. The main economic activity of this region is the agricultural sector, with a particularly relevant livestock sub-sector. This sub-sector is traditionally characterized by the occurrence of small farms, especially as compared to the size of Spanish farms and to the size of the farms across the European Union (Fernández, 2003).

During the last few decades, the Galician livestock sub-sector, and in particular dairy production, has gone through a restructuring process with two main characteristics: first, the number of farms has decreased as a consequence of the accession of Spain to the European Union in 1986. After accession, many farms that were oriented to local markets and self-supply production, and managed by farmers of advanced age ceased activity. Second, the number of farms specialized in milk or meat production for the market has grown, and consequently, the size of the farms has increased.

Table 1 shows an increase in milk production, in spite of the dramatic reduction in the number of farms that affects mainly the first four size intervals. In addition, Table 1 reveals a reduction in the number of dairy cows. These two circumstances suggest a dynamism in the dairy sector that attempts to improve production and management systems, and the genetic and feed quality of livestock.

The changes underwent in this sector demand new buildings to house larger farms (the average number of cows per farm increased from 6.75 in 1993 to 13.50 in 2000). The increase in farm size derives from amalgamation or enlargement of non-profitable farms, association of several farms, or establishment of new enterprises. A few years ago, the Administration established a minimum barn size of 30 cows for a profitable farm. However, the current minimum herd size for a profitable farm is 60 cows (Maseda *et al.*, 2004). This process is expected to be continuous in the next few years due to competition in the agricultural markets of the European Union. Competition has become a particularly relevant issue after 2 May 2004, when the European Union was enlarged to 25 Member States. Some of the new Member States have livestock populations with an important potential for development.

The evolution of the livestock sub-sector in Galicia is reflected in the size of farms, and in farm design. In the new

competitive situation, farm design must find the best projects for the new facilities because optimum profitability requires appropriate investment and operating costs (Pereira, *et al.*, 2005). To obtain optimum profitability, the formulation of new buildings must be performed by applying design engineering techniques (Álvarez *et al.*, 1995).

The design phase of the project is an essentially creative phase that includes most of the technical aspects and attempts to solve previously identified problems. During this phase, decisions are constantly made, and the decision-making process is completed by determining the final construction costs (Trueba *et al.*, 1995).

A wrong decision in farm design can bring about serious financial trouble, to the extent of making the farm economically non-viable (Palmer, 1999). The project designer must focus on the factors that improve management and reduce investment and operation costs (Carreira, 1997).

As opposed to searching a unique and optimal design, different design options must be compared and, consequently, the functionality and investment costs of the design options considered must be compared. Many authors have approached the study of agricultural building designs, among whom Hives (1985), who analysed the variation in the cost of the building envelope according to the plan form of the building; and Pereira *et al.* (2003), who determined the most appropriate designs for dairy cattle farms in Galicia according to size (number of stalls) and total investment cost.

The problem of layout design applied to dairy housing has not been addressed in technical literature in a systematic manner (Bowell *et al.* 2003). Most authors have offered one or several layouts as examples, but such layouts were solutions to specific cases, i.e. solutions 'obtained for' and 'applied to' specific situations. Many authors have reported technical assessments on the dimensioning of the different elements that compose the design and on the materials that must be used. However, there are different opinions or even contradictions among authors (Bewley *et al.*, 2001).

Actually, these contradictions cannot be considered as such, because they arise from the specificity of the different models of free-stall dairy barns suggested, from the need to adapt the designs to local conditions, and from the fact that each author has based the research on his/her own experience (Fernández *et al.*, 2006).

Size	1993			2003		
	Number of farms	Dairy cows	Milk production (thousands of litres)	Number of farms	Dairy cows	Milk production (thousands of litres)
1-2	28,200	39,840	21,182	1.510	2.317	1.997,5
3-4	12,693	42,960	29,984	1.149	3.936	4.273,3
5-9	17,230	114,009	96,859	4.057	27.427	32.035,1
10-19	12,383	163,791	166,948	6.107	85.905	103.840,3
20-29	3204	74,527	81,533	3.653	86.585	117.756,7
30-49	1502	51,142	60,352	3.287	120.715	176.812,8
>50	193	15,352	21,155	1.136	81.467	130.968,8
Total	75,405	501,621	478,013	20.899	408.351	567.684,4

Table 1. - Distribution of dairy farms in Galicia in 1993 and 2003. Source: Galician Statistics Institute. Bovine survey. Year 2003 (Instituto Gallego de Estadística, 2004)

The conventional meaning of the term 'design' is not discussed here. It must be assumed that most authors have established fixed and determining 'design criteria' based on such meaning, and that such criteria have been generated from the experience of the authors, rather than from specific and systematic analyses of the layout problem (Balakrishnan & Cheng, 2000). According to Pérez et al. (2004), this situation derives from a simplistic and primitive consideration of layout design, which is currently considered as an essential starting point in the design process for any farm that intends to develop a production process.

Many research contributions have been made in the field of the application of layout design techniques to industrial facilities (Wu & Appleton, 2002), while the application of such techniques to farm housing has been very limited. However, some researchers have applied classical algorithms to dairy housing by using hybrid algorithms (Alvarez, 1994), while other authors have applied genetic algorithms to milk goat farms (Pérez et al., 2004).

Given the impossibility of considering all the options for barn construction, the six designs shown in Figure 1 were analysed in this study. The designs considered represent the most widely used designs in Galicia. In the analysis, common specifications for locations, materials, equipments and measurement units were assumed.

Dairy barns in Galicia occupy quadrangular sheds, in which the resting area, the loafing area and the other farm facilities are located. The building can be enlarged according to the number of cows in the farm.

Design T1 is the most widely used design option, with 66% representativeness in new constructions. Considering that design T2 –the second most representative design with 13% representativeness– consists of a double T1, the uniformity in the design and construction of new farms is even higher. Therefore, barn designs with stalls arranged head to head and an alley lateral to the row of stalls account for 79% of the total barns constructed in Galicia in the period 1988-2000. The rest of the designs are scarcely represented in new constructions.

At present, due to the need to increase farm size, discussion is focused on how to tackle the process, both in terms of the modification of existing buildings and of the design of new barns.

The objective of this study is to analyze the different design options of dairy farms in Galicia by applying two indices, the shape index and the elongation index, in an attempt to identify the most appropriate results, taking into consideration the shape and size of the design as a function of the number of stalls, and the relation of both

characteristics to civil construction costs. The research work consists in defining the mentioned indices and validating their usefulness by applying them to the different design options.

The principal aim is draw conclusions, criteria for assessing, that enable farmers and engineers responsible for project planning (new construction or modification) to have more information about the design and further development of the barn project.

Materials And Methods

Previous studies carried out by this research team (Pereira, 2002; Díaz, 1998) provided initial information to estimate the costs of the projects. A database for budgeting dairy barn projects was used. This database was compiled in the year 2000 as a reference material to estimate costs within the autonomous community of Galicia, Spain (I.T.G., 2000), and has been used and tested mainly in barn projects developed in this region.

By using the mentioned database, designs T1, T3 and T5 were developed and budgeted for 32, 60, 84, 108 and 120 dairy cows; designs T2 and T4 were developed and budgeted for 32, 60, 84, 108, 120 and 200 cows; and design T6 was developed and budgeted for 32 and 60 cows. All these designs were used as working material.

The first stage of the study focused on the definition of indices that determined the functionality of the design. Variations in the building costs according to the shape of the building were estimated theoretically (Hives, 1985). A hypothetical farm with an area of 1500 m², which corresponds to approximately 90 cows, was considered (Álvarez, 1994) and used to analyse variation in costs according to the plan form of the building.

In a first approach, it was considered that civil construction costs were estimated as a function of the surface area of the building (flooring, roofing, prefabricated structure, etc.). This hypothesis was based on the presented barn design options and on the use of the database available. However, it became clear that the cost of the building envelope was strongly correlated to the shape of the building.

As shown in Table 2, the cost of the building envelope for a barn that measures 1500m² may vary by more than 25% for three different plan forms, one of them square and the other two rectangular (the first one at a ratio of 1:2, and the second one at a ratio of 1:3). Such variation cannot be neglected because the cost of the building envelope can account for up to 15% of the total cost of the barn.

Shape	Area (m ²)	Length of the exterior envelope (m)	Cost of the building envelope per m ² (Euros)
Square (1:1)	1500	154.92	9.29
Rectangular (1:2)	1500	164.32	9.86
Rectangular (1:3)	1500	178.92	10.73

3 m-high exterior wall. The cost/m² of the wall amounts 30 Euros.

Table 2.- Variation in the cost of the building envelope per m² for different plan forms

Figure 2 was generated by applying the information included in Table 2 to areas that ranged from 100 to 2000 m², which corresponded to barns for 6 to 120 cows (Álvarez, 1994). Figure 2 revealed a strong influence of the shape of the building on the cost of the exterior envelope. The costs for the different shapes decreased as the area of the building increased.

The estimation presented in Figure 2 confirms the hypothesis that square shapes involve the lowest costs of the building envelope (excluding circular shapes and regular, many-sided polygonal shapes due to difficulty of construction and problems for size evolution).

Because the aim of this study was to make the work of the project designer easier, two indices directly related to the plan form of the building were proposed. The designations given to the indices proposed were 'shape index' and 'elongation'.

$$SHAPE\ INDEX = \frac{Area\ (m^2)}{Perimeter^2\ (m^2)} = \frac{A}{P^2} \quad \text{Equation 1. Shape index}$$

$$ELONGATION = \frac{Width\ (m)}{Length\ (m)} = \frac{A}{B} \quad \text{Equation 2. Elongation}$$

The idea of this study was based on the largely relevant effect of shape on the cost of the building. Due to this effect, the project designer must find the shape that provides the best economic result.

The variables 'area' and 'perimeter' were analysed and applied to different polygonal shapes. By relating both variables, two utilization factors were obtained that were designated absolute utilization factor (A/P) and relative utilization factor (A/P²) (González, 2004). Graphs 2 and 3 show data for these factors.

Figure 3 shows the values obtained for the absolute utilization factor (area to perimeter ratio). The area per meter of perimeter is higher for square buildings.

The area of the barn does not show any influence on the relative utilization factor or shape index (A/P²) because this factor is a ratio between two comparable units and, therefore, a dimensionless unit is obtained. The values of the shape index characterise barns in terms of shape, independent of area.

The numerical value of the shape of a building increases as the building comes closer to a circumference, i.e. the value increases with compactness. Therefore, square buildings show higher values than rectangular buildings.

With regard to elongation, Figure 4 shows that the shape index reaches its maximum value when elongation equals 1, which means that the shape index reaches the peak value when A and B (sides of a polygon) are equal and, therefore, in square buildings. In rectangular buildings, the shape index decreases to a minimum of 0.02 for elongations higher than 11, which correspond to rectangular buildings with one side more than 11 times longer than the other side.

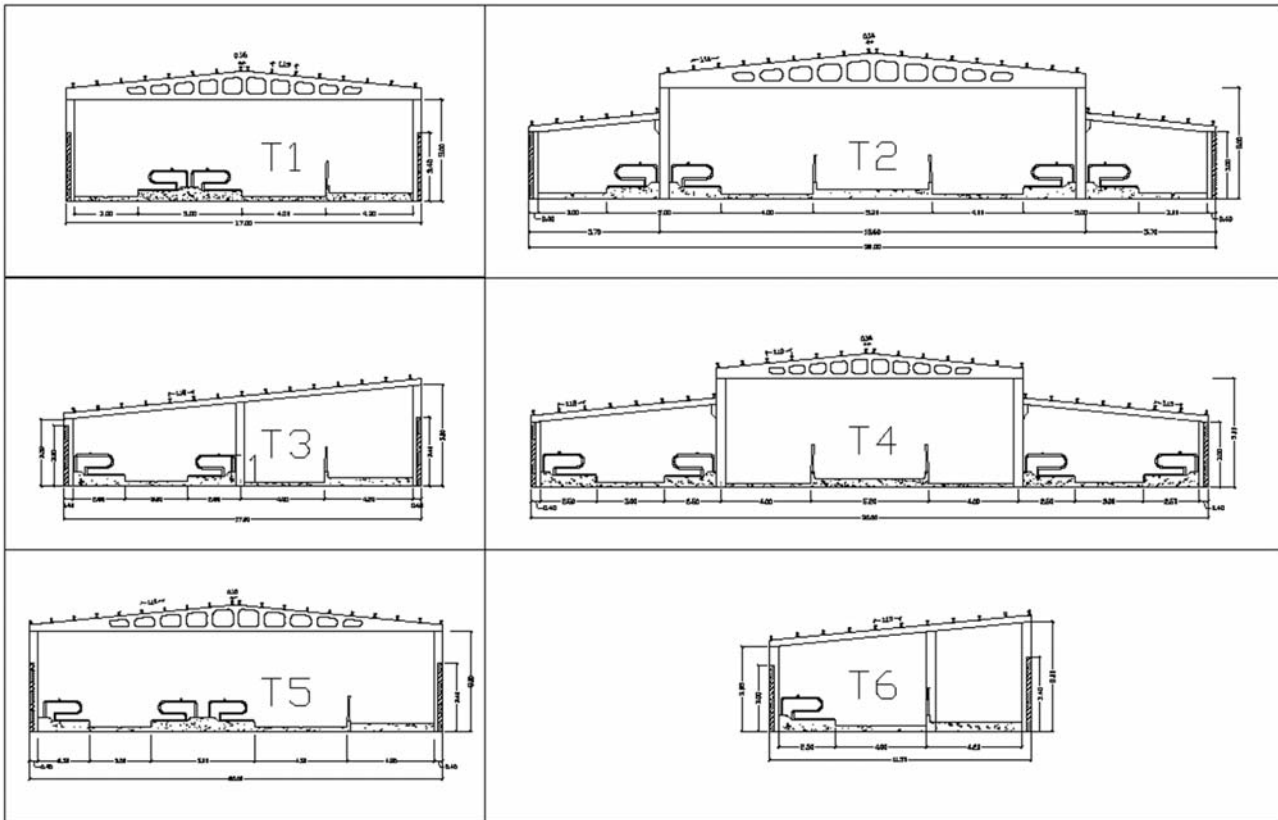


Figure 1.- The most widely used designs in Galicia

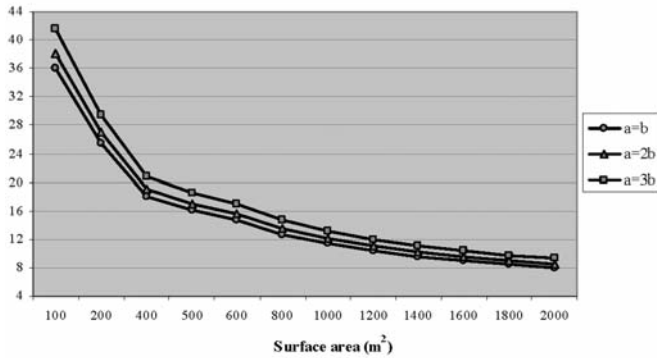


Figure 2.- Variation in the cost of the building envelope per square meter of surface area

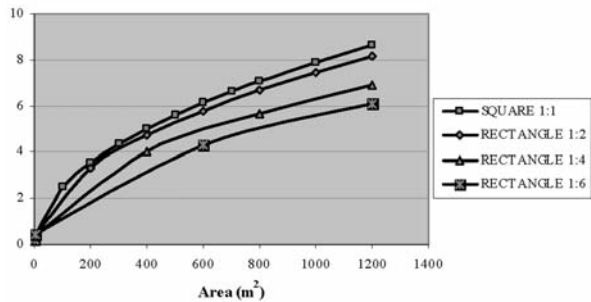


Figure 3.- Variation in the A/P ratio (absolute utilization factor) according to area

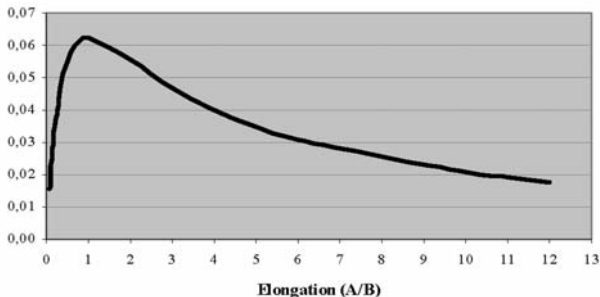


Figure 4.- Variation in elongation with shape index

In this work, the mentioned indices were applied to the six designs presented, for different numbers of stalls. This method enabled design validation based on the estimation of the investment costs required. In addition, different options for enlargement were considered, including not only the longitudinal growth of the different designs, but also transverse enlargement.

Results And Discussion

The preliminary analyses consisted in estimating the variation in the price of a building per square meter according to its surface area. Figure 5 shows that, in general, the cost of a building per square meter of surface area tends to be inversely proportional to the size of the building, which means that the cost per square meter of a small building is higher than the cost per square meter of a large building. Therefore, given the same area, it is better to construct one building than two buildings. This consideration

is particularly relevant because it suggests that enlarging the existing barn is preferable to adding a new building to the farm, independent of the type of design considered.

As in the case of total civil construction costs, the cost of the building envelope per square meter (Figure 6) decreases with increase in the barn area, independent of the design type. The lowest costs are observed for designs T2 and T4, which correspond to modular square-shaped designs. These results agree with the results reported by Hives.

With regard to variation in the cost of structures according to the surface area of the building, Figure 7 suggests the same situation as in the previous two cases, except for a leap increase in the size of the prefabricated elements at this point.

The design of the different barn types was carried out by increasing the length of the shed according to the number of stalls required on the farm. The increase in the number of stalls was studied by adding together two T1 buildings or two T2 buildings, either frontally (type A addition) or laterally (type B addition). Table 3 shows the results of exterior envelope costs considering both types of addition, and assuming 60 or 120 stalls for type A, and 60, 120 or 200 stalls for type B.

The results reported in Table 3 suggest that lateral addition of two structures (Type B) offers larger savings in exterior envelope costs than constructing two structures that are joined frontally. Conversely, for design T2, Type A addition is less expensive than lateral addition, except for designs with 100 stalls or more, which show the same behaviour as design T1. By adding together two T1 structures (initially rectangular) side to side, a square structure is obtained and, therefore the structure can house the same number of cows with a shorter wall perimeter. In the case of design T2, the structures obtained are more quadrangular if one of the buildings is added frontally to the other, except for barns with 100 or more stalls, for which square structures are obtained by joining the buildings side to side.

After studying the effect of shape on the construction costs, the indices proposed in this study were validated by applying them to the different designs considered.

	Type 1	Type 2
	Envelope costs (Euros)	Envelope costs (Euros)
2 structures of 30 stalls (type A)	4405.41	3300.21
2 structures of 30 stalls (type B)	3840.58	4463.2
2 structures of 60 stalls (type A)	7439.10	5061.47
2 structures of 60 stalls (type B)	5466.30	5839.63
2 structures of 100 stalls (type A)	-	7382.15
2 structures of 100 stalls (type B)	-	7293.98

Table 3.- Exterior envelope costs for the same number of stalls according to type of addition and design option

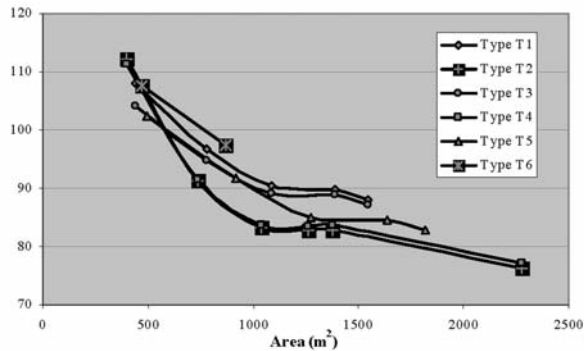


Figure 5.- Variation in the total cost of the building per m² according to surface area for the different design options considered

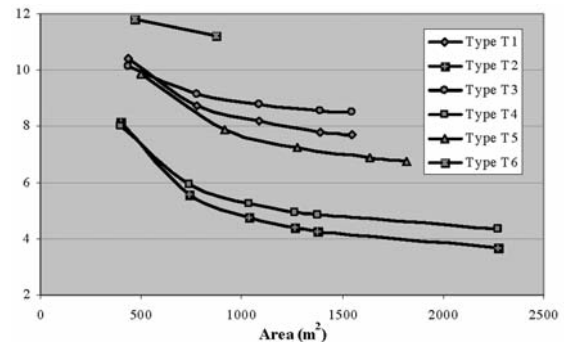


Figure 6.- Variation in cost of the building envelope per m² according to surface area for the different design options

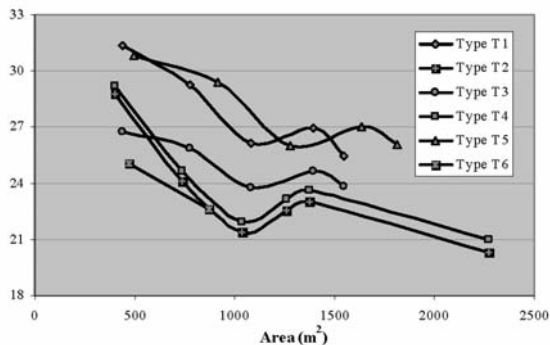


Figure 7.- Variation in the cost of structures per m² according to surface area for the different design options

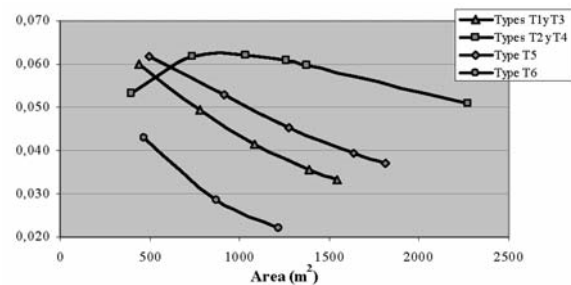


Figure 8.- Variation in the A/P² ratio according to surface area for the different design options

The application of the shape index (A/P_2) to the different design options reveals that the values of designs T2 and T4 are the closest values to 0.063 (ranging between 0.050 and 0.063), which means that these designs present the squarish shapes (Figure 8). The shapes of the rest of the designs are more quadrangular for small areas, and show a decrease in the value of the shape index with the increase in the surface area. This ratio suggests rectangular-shaped barns with a higher building envelope cost per square meter than the first two designs.

The same result can be observed in Figure 8, which represents variation in the elongation index (where A is the width and B is the length of the barn) as a function of the surface area. Elongation values decrease as the surface area increases. Such decrease occurs because the width of the buildings remains constant for all the designs while the surface area increases, which produces variation in the length of the buildings.

As shown in Figure 9, designs T2 and T4 show the highest elongation values in all cases because T2 and T4 are modular designs, with larger spans between columns and, proportionally, a larger side A (as compared to side B) than the rest of the designs.

Because the area assigned to individual stalls is different for each design, the number of stalls has been included in the horizontal axis of the previous two graphs. Figure 10 and 11 include this modification.

Figure 10 shows that the highest shape index is obtained with designs T2 and T4 for barns with more than 40 stalls.

Moreover, the mentioned designs show the highest elongation values for any number of stalls (Figure 10). Because shape index and elongation are two fully dependent variables (Figure 4), a value of 1 is obtained for elongation (structure in which both dimensions are equal) when the A/P_2 ratio equals 0.063, which is the maximum value.

After estimating the variation in shape index and elongation according to surface area or number of stalls, the relationship between variation in the analysed indices and construction costs (total civil construction costs and costs per cattle head) must be estimated to determine which design option involves the lowest investment in barn construction.

The results obtained for variation in the shape index according to total civil construction costs in euros (Figure 12) reveal that designs T2 and T4 are less expensive than T1 and T3 for buildings with the same number of stalls. This graph shows the influence of shape on total construction costs. The results suggest that the designs with a shape index near 0.063 (square shape) are the least expensive designs, except for barns with 40 or less stalls. In such case, designs T1 and T3 are more expensive but squarer than designs T2 and T4 with the same number of stalls. As the number of stalls increases, larger differences are observed in the shape index of T2 and T4 as compared to T1 and T3, and variation in the civil construction costs becomes more significant.

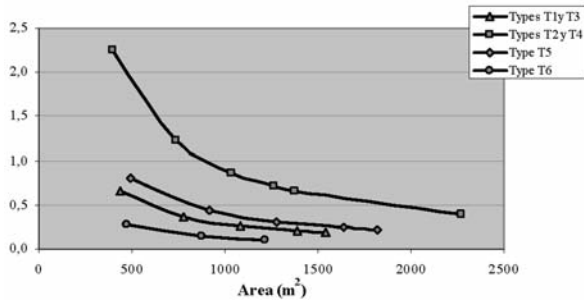


Figure 9.- Variation in elongation according to surface area for the different design options

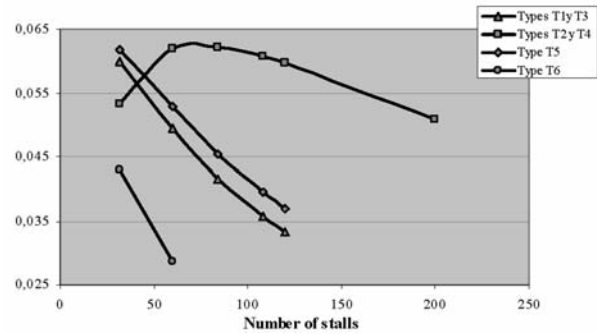


Figure 10.- Variation in the A/P² ratio according to number of stalls for the different design options

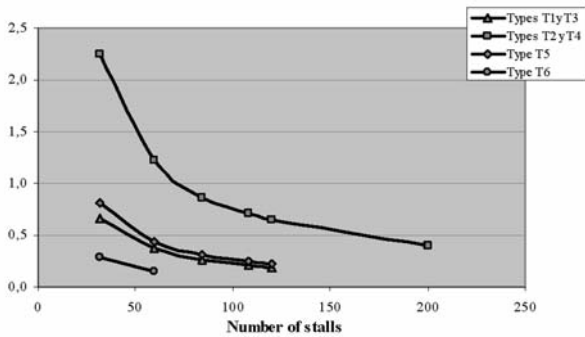


Figure 11.- Variation in elongation according to number of stalls for the different design options

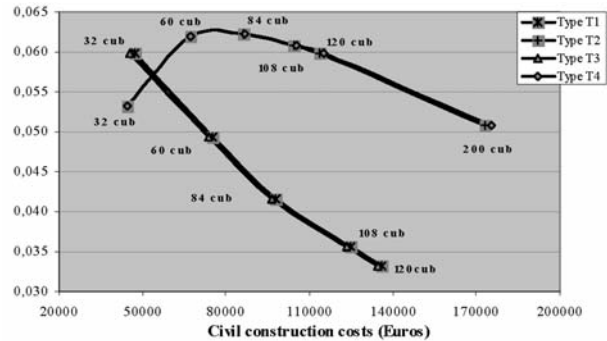


Figure 12.- Variation in the A/P² ratio according to civil construction costs for the different design options

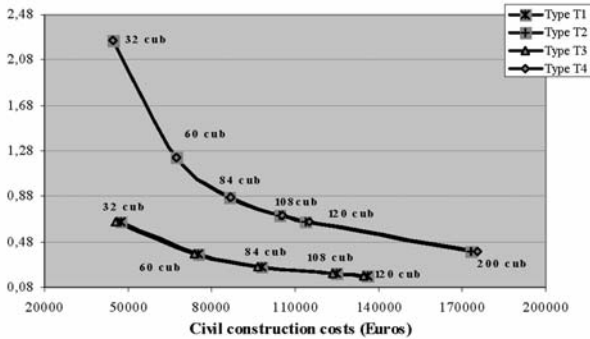


Figure 13.- Variation in elongation according to civil construction costs for the different stalls design options

less expensive than T1 and T3 for the same number of stalls in all cases. However, from among these designs, the least expensive options are square-shaped designs with more than 40 stalls. For 32 stalls, types T1 and T3 show A/P² index values closer to 0.063 than T2 and T4; while for more than 60 stalls, the values of the shape index are always higher in designs T2 and T4.

Conclusions

Before presenting the conclusions, some initial considerations derived from the results of this study are established.

First, the design options that can be chosen by engineers or owners are limited or restricted by two circumstances. The first circumstance is related to the production process, and considers that dairy cattle need a loafing area. The second circumstance is related to the use of prefabricated elements, which do not follow a continuous distribution in the dimensioning. These elements have pre-established measures, and allow only a limited number of combinations to provide solutions to the first restriction and to the whole production process.

Second, certain factors have not been considered in this study, among which the variability of the production systems (cleaning systems, milking parlours...) or changes in environmental legislation, which will require the development of new designs or the adaptation of the

The representation of variation in elongation according to civil construction costs for the different design options (Figure 13) reveals that large differences occur as the size of the structures decreases. Square shapes show elongation values near 1. For example, in the case of barns with 32 stalls, designs T2 and T4 are less compact than T1 and T3. Designs T1 and T3 show values closer to 1 and, therefore, are squarer. However, the cost of these designs is higher. In contrast with the observations for the shape index, the differences in the elongation index for the design groups studied decrease with the increase in the number of stalls. However, civil construction costs increase.

Figure 14 and 15 show the results for the civil construction costs per stall or per cattle head. These results coincide with the results represented in Figure 12. Designs T2 and T4 are

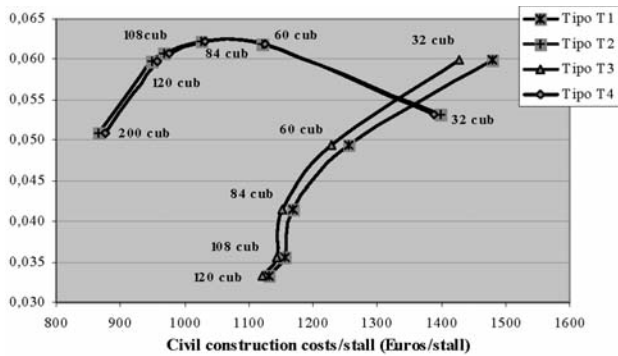


Figure 14.- Variation in the A/P^2 ratio according to civil construction costs per stall for the different design options

existing ones in order to comply with the standards and to be able to maintain the current objectives.

The most relevant conclusions drawn from the present study are presented below:

1- The costs of a building per square meter of surface area tend to be inversely proportional to the size of the building, which means that the cost per square meter of a small building is higher than the cost of a large building. Therefore, for the same surface area, constructing only one building is better than constructing two. This consideration is very relevant because it suggests the preferability of enlarging the existing barn to adding a new building to the farm.

2- Similarly, the cost of the building envelope and the cost of structures decrease as the area of the building increases. The decrease in the cost of structures is less continuous because a leap is observed between 1000 and 1700 m² due to the increase in the dimensions of the prefabricated elements.

3- The cost of the building envelope can vary by more than 25% for barns with the same area but different shape. This data cannot be neglected because the cost of the building envelope can account for up to 15% of the total costs of the barn.

4- Designs T2 and T4 are the least expensive designs in terms of total civil construction costs and in terms of the budget item for the building envelope. With regard to the cost of prefabricated structures, the least expensive design option is T6 (used only for small barns), while designs T2 and T4 show a lower structural cost for areas larger than 800 m² (about 70 stalls).

5- Square shapes entail the lowest cost of the building envelope because such shapes involve shorter perimeters for buildings with the same surface area. Circular shapes and regular many-sided polygonal shapes were not considered due to difficulty of construction and problems for size evolution.

6- Designs T2 and T4 are less expensive than T1 and T3 for buildings with the same number of stalls. The results suggest the influence of shape on total costs. The designs with a shape index near 0.063 (square shape) are the least expensive designs, except for barns with 40 or less stalls. In such case, designs T1 and T3 are more expensive but

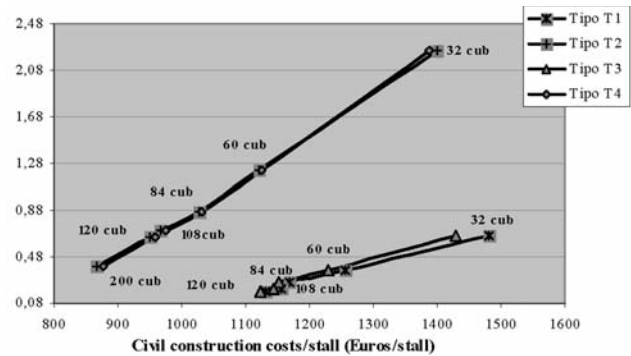


Figure 15.- Variation in elongation according to civil construction costs per stall for the different design options

squarer than designs T2 and T4 with the same number of stalls.

7- The analysis of the option of adding two designs T1 or two designs T2 together (either laterally or frontally), and the estimation of the cost of the building envelope in both cases reveal that the largest savings are obtained for lateral addition of design T1 and for lateral addition of design T2 with more than 100 stalls. In both cases, larger savings occur because square structures are obtained from addition. For T2 designs with less than 100 stalls, the investment in exterior walls is lower if the structures are joined frontally.

8- The shape and elongation indices reveal, as expected, that square shapes are more convenient than rectangular shapes for barn design.

Finally, these indices are useful for developing designs of agricultural facilities, particularly at layout level. This study lays the foundations for a future research line that develops new models of facilities for the Galician agricultural sector in order to obtain optimal designs according to the aims considered and the restrictions established.

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