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RESEARCH ARTICLE

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Spain's national network of silos and granaries: architectural and technological change over time

Manuel V. Fernández-Fernández (Fernández-Fernández, MV)[1], Víctor Marcelo (Marcelo, V)[2], José B. Valenciano (Valenciano, JB)[2], F.-Javier López (López, FJ)[2] and Pablo Pastrana (Pastrana, P)[2]

[1]Junta de Castilla y León. Consejería de Agricultura y Ganadería. C/ Rigoberto Cortejoso 14, 47014 Valladolid. Spain. [2]Universidad de León, Dpto. Ingeniería y Ciencias Agrarias, Avda. Portugal 41, 24071 León. Spain.

Abstract

Aim of study: To analyse the 670 silos in Spain's NNSG (National Network of Silos and Granaries), along with the changes in typologies and degree of mechanisation taking place over time.

Area of study: Spain.

Material and methods: Research began in 2014, collecting NNSG grain storage data across Spain further to the methodology developed by the authors. In a first stage the information was gathered from the FEGA's general archives in Madrid and the archives of the departments of agriculture in the 13 regions where silos were built. In the second stage of the study, 665 silos were explored in situ. Photographs were taken and information was gathered on their characteristics (general features; architectural features; technological facilities).

Main results: This paper discusses the architectural and typological changes taking place over time, from the earliest small, local, richly adorned brick silos to larger, more modern and austere reinforced concrete structures. The machinery with which they are fitted is also addressed, with the progression from basic grain storage to more sophisticated equipment designed to clean, refrigerate or disinfect the grain. Some facilities were used exclusively to select and condition seed for subsequent sowing. The most modern structures, known as macrosilos, are highly mechanised affairs.

Research highlights: Spain's national network of silos and granaries was 41 years in the building. The inventory of the 665 existing silos identified 20 types or subtypes. Early richly adorned units gradually gave way to more austere, functional structures. The machinery in place in silos varied with type/purpose and period of construction.

Additional key words: storage unit; wheat; rural architecture; industrial architecture; industrial heritage.

Abbreviations used: FEGA (*Fondo Español de Garantía Agraria*, Agricultural Guarantee Fund); HSU (horizontal storage unit); NNSG (National Network of Silos and Granaries); SENPA (*Servicio Nacional de Productos Agrarios*, National Agricultural Product Service); SNC (*Servicio Nacional de Cereales*, National Grain Service); SNT (*Servicio Nacional del Trigo*, National Wheat Service); VSU (vertical storage unit).

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Correspondence should be addressed to Víctor Marcelo: v.marcelo@unileon.es

Introduction

Grain, wheat in particular, has been a staple in the human diet and the primary ingredient in bread since ancient times and its storage of cardinal importance since prehistory. Time of course has brought enormous change in storage, especially in recent history with the invention of the grain elevator at Buffalo, New York in 1843. After that date, the storage of large amounts of grain took a dramatic turn the world over, for traditional horizontal structures or granaries began to be replaced by vertical storage units (VSU) or silos (Salido, 2011; Fernández-Fernández, 2016).

Wheat output declined substantially in Spain during the country's Civil War (1936-39) (SNT, 1958), prompting the Government to guarantee supply by decreeing and enforcing interventionist legislation that created the national wheat service (Spanish initials, SNT) (BOE, 1937; Tortella, 1994; Valls *et al.*, 2015) and established a

monopolistic grain market. The need for a territorial system of silos to store grain (García, 2016) informed the design, around 1941, of the General Plan for the National Network of Silos and Granaries (NNSG). The plan initially called for 437 VSUs and 631 horizontal storage units (HSUs) or granaries, but was subsequently amended to build many more silos and many fewer granaries than initially envisaged (SNT, 1947, 1950, 1959; SENPA, 1978, 1994). The NNSG's responsibilities included wheat purchase (from farmers who had to sell their entire production to the service for a set price), storage and speedy distribution, as well as the maintenance of strategic reserves and the set-aside of grain selected and treated to extract seed for future crops.

Most of the storage units built in the late nineteen forties were silos. The first network VSUs were erected in 1949 at Valladolid, Villada (Palencia province) and Alcalá de Henares (Madrid province), although the network itself was not officially inaugurated until 1951 with the completion of the silo at Córdoba (Azcárate, 2009; García, 2016). Those silos were designed by agricultural engineers affiliated with the SNT who sought aesthetic counsel from Ignacio Fiter. That Spanish architect was essentially immune to the trends introduced by his European colleagues Le Corbusier, Gropius, Mendelsohn or Soviet counterpart El Lissitzky, who used vertical grain storage buildings as an example of a new kind of industrial architecture (Bergòs, 1965; Gil & Morales, 1993; Azcárate, 2002; García, 2016). The silos were initially built to the principles of 'utility, simplicity and economy' prevailing in the SNT at the time.

Until 1968 when it was superseded by the National Grain Service (Spanish initials SNC), the SNT was the developer and driver of NNSG construction. While paring back on interventionist policies, the SNC continued to build silos (Fernández-Fernández, 2016). Under the National Agricultural Product Service (Spanish initials, SENPA) created in 1971, wheat trade was regulated much more lightly than under its predecessors (BOE, 1971). The SENPA propelled macrosilo (>10,000 t) construction beginning in 1975, just as the country embarked on its political transition. Although the wheat monopoly disappeared in 1984 (BOE, 1984), silo construction went forward until 1990, when the last network facility was commissioned at Valchillón, Córdoba.

After 1986 when Spain joined what was then the European Economic Community, network use declined significantly, with the last usage dating from 2002. Since that date, nearly all are vacant. In 2014 control of the silos previously devolved to the regions reverted to the Agricultural Guarantee Fund (Spanish initials, FEGA) to auction off the buildings that remained in disuse (BOE, 2014). The outcome has been deterioration. The most modern and largest silos are auctioned from time to time, although such auctions often attract no bidders. Some of the older and smaller buildings have been assigned to municipalities and local associations of all kinds that have afforded them a new life, whilst others have been converted into multi-purpose warehouses and a few are now community centres or other specialised facilities.

Silos nonetheless form as much a part of the skyline of Spanish towns and cities as castles and churches (Mateo, 2011; Garrido-Cifuentes *et al.*, 2017) and like other agro-industrial assets, contribute to the country's cultural heritage. They should consequently be inventoried and documented to vindicate their importance and prevent their disappearance (Benito, 2002; Cano, 2007; Mateo, 2011; FEGA, 2012; Fuentes *et al.*, 2011; Florido, 2013), for they constitute a unique worldwide legacy (Salamanca-Cascos *et al.*, 2012). In some cases these silos have been repurposed (Fernández-Fernández *et al.*, 2017) to prevent their disappearance (Benito, 2002; Mateo, 2011) and afford them new value in light of their significance as industrial heritage assets.

Silo network construction went on for over 40 years. During that period, construction and architectural trends evolved from the early small, local units (made with materials available in the area and equipped with only basic machinery) to the latest unadorned, reinforced concrete, highly mechanised macrosilos in which all processes were automated.

The aim of the present 4-year (2014-2018) study was to analyse the 670 silos in Spain's NNSG, along with the changes in typologies and degree of mechanisation taking place over time.

Material and methods

Research began in 2014, collecting NNSG grain storage data across Spain further to the methodology developed by the authors and described in Fernández-Fernández *et al.* (2017).

In a first stage the information was gathered from the FEGA's general archives in Madrid and the archives of the departments of agriculture in the 13 regions where silos were built (Andalucía, Aragón, Castilla y León; Castilla-La Mancha, Cataluña, Comunidad Valenciana, Extremadura, Islas Canarias, La Rioja, Madrid, Murcia, Navarra, País Vasco). That documentary research identified 952 national silo and granary network SUs built in Spain from 1949 to 1990 ad more specifically 670 VSUs or silos and 282 HSUs or granaries (Azcárate, 2009; Fernández-Fernández *et al.*, 2017).

In the second stage of the study, conducted from 2015 to 2018, 665 silos were explored in situ. As a result of that campaign, three of the SG (initials for 'Secado de Grano', grain drying) type silos initially identified were disregarded because their shape and outer appearance were more like granaries; and one of the C type silos (at Calera y Chozas in the province of Toledo) and a 1800 t type D silo

planned for Roda in Albacete were found to be non-existent, for although the designs were on file with FEGA, they were never built.

Photographs were taken of the 665 silos and information was gathered on their characteristics; which were grouped as follows:

- General features: region, province, village, geolocation, year of construction.
- Architectural features: typology; capacity (t); ground plan and roof shape; tower position (Fig. 1); number of cell rows; number of cells; shape of cells; cell material; cell row position relative to the ground.
- Technological facilities: including existence of: railway; dust suction system; seed cleaning and selection machinery; thermometric sensors; gas dosage and refrigeration facilities; and information on; machinery capacity (t/h); No. elevators; No. upper storey horizontal conveyors.

In addition, to supplement the information silo managers, auditors and others involved in building upkeep were interviewed as described by Fuentes *et al.* (2015).

Results and discussion

Architectural and typological development

Although varying widely in typology, the silos can be listed under four major groups or categories based on main purpose or location: receipt, transition and reserve, port and seed selection. For the intents and purposes of classification, the types within the receipt group (with three exceptions) are labelled with a single initial in alphabetical order, the transition and reserve facilities with a T followed by a second initial, the seed selection units with an S and a second letter and the two port silos with a P. The resulting 20 typologies may be subdivided in some cases and labelled with subscripts (SENPA, 1973). The 665 NNSG silos are listed by type and region in Table 1 and the most prominent architectural and technological features by silo typology in Table 2.

Silos are often attached or adjacent to other types of horizontal buildings, normally bays used to store machinery or other equipment or even to select seeds or house weighing scales, transformer stations, silo manager or guard quarters, toilets and so on. The architectural value of those structures is negligible and their volume all but eclipsed by silo verticality. The results of all analysis are listed in Table S1 [suppl].

Receipt silos

This group comprises 11 types (A, B, C, D, E, F, GV, H, J, MC and MR) (see Table 1):

— The A type, the first reception silos designed and built by the SNT, are characterised by their small size (750 t to 1100 t) and location near grain-growing areas. All were built between 1949 and 1959. The features they share with most of the other types of silos built by the SNT and later the SNC include their structure based on reinforced concrete columns positioned at the corners of the cells or vertical deposits where the grain is stored. Cell

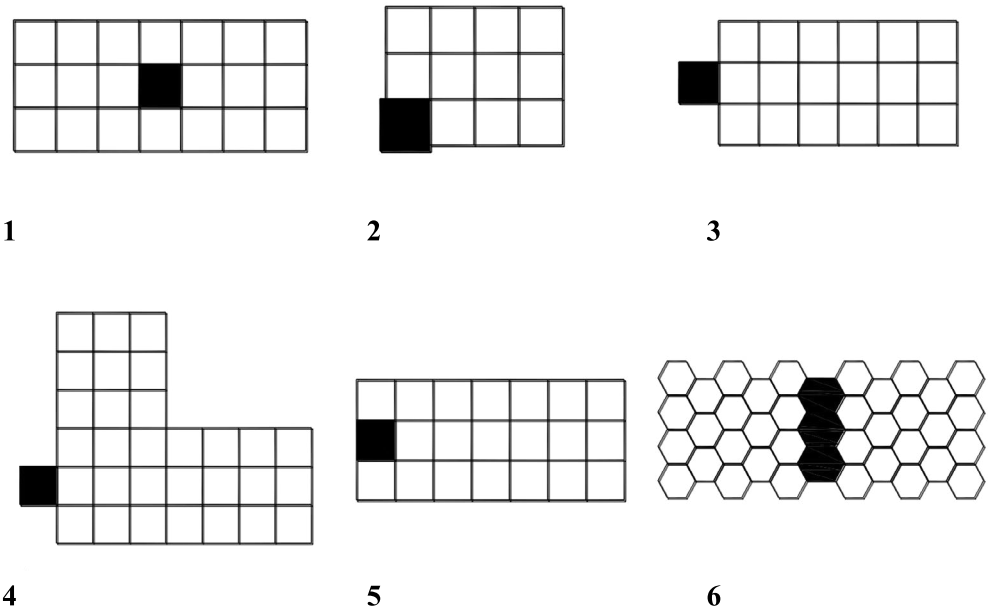

Figure 1. Tower position: 1) IT: interior tower; 2) CT: corner tower; 3) FT: front tower; 4) ST: side tower; 5) FTBC: front tower between two cells; 6) CET: central tower.

Table 1. Number of National Network of Silos and Granaries (NNSG) silos in Spain by type and region. *Source*: SNT, 1950; SENPA, 1971; FEGA, 2003; Fernández-Fernández *et al.*, 2017)

Typology[1]		Region													
		Castilla y León	Castilla-La Mancha	Andalucía	Aragón	Extremadura	Navarra	Cataluña	País Vasco	La Rioja	Madrid	C. Valenciana	Murcia	Canary Islands	Spain
Receipt															
A	A_{1000}	2	2	2		1			1						8
	A_{2000}	2		1		1			1						5
	A_{3000}	1	1	1	3										6
	A_{3500}	1		1		1									3
B	B	9	2	4	2	4	1	2							24
	B_{7500}	3	2	1	2	2	1	3							14
C		12	10												22
D	D_1	36	20	25	19	8	4	4		1	2	1			120
	D_2	4			2										6
	D_3	1													1
	D_4	30	19	23	14	19	11	4	3		1				124
	D_5	27	29	27	19	14	9	4	2	2	1	1	3		138
E		10	10	6	6	5	1			3					41
F		2		1	1			1		1					6
GV		1	3	2	4	2	1		1						14
H		5	3	3		1			1						13
J		2	1		2										5
MC		7	8	8	2	1	1	6	1	1	2				37
MR		2	7	7	4	4	3	1		1		1			30
Transition and reserve															
TR	TR_1										1				1
	TR_2			1											1
	TR_3					1									1
	TR_4			1	1										2
	TR_5	2						1							3
	TR_6	2													2
TC		1	1			1									3
TE		1	1	1	1										4
TH		1	1	2											4
TV		5	1	2	1	1	1				1				12
TF				1											1
Port															
P				1										1	2
Seed selection															
SV		2	4	2	1	1									10
SA		1	1												2
Total		**172**	**123**	**124**	**83**	**67**	**33**	**26**	**10**	**9**	**8**	**3**	**3**	**1**	**665**

[1] See text for abbreviations

walls consist in reinforced brick, a material that like adobe was commonly used in rural Spain (Azcárate, 2009; García, 2016). These silos have three rows known as *crujías* consisting in four square cells each, while the tower is sited inside one of the cells in the central bay, rising from that interior position above the body of the silo (Fig. 2.1).

Table 2. Most prominent architectural and technological features by NNSG silo typology. *Source*: Azcárate, 2009; SNT, 1950; SENPA, 1971; FEGA, 2003; Fernández-Fernández *et al.*, 2017.

Typology[1]		Main features												
		Year first construction	Ground plan [2]	Roof shape [3]	Tower position [4]	No. of cells rows	Shape of cells [5]	Cell construction material [6]	Position rows cell [7]	No. elevators	No. upper storey horizontal conveyors	Dust suction system [8]	Seed cleaning and selection machinery	Thermometric sensors, gas dosage and refrigeration facilities [9]
Receipt														
A	A_{1000}	1949	S	4	IT	3	S	RB	R	2	-	-	1	-
	A_{2000}	1950	S	2, 4	IT	3	S	RB	R	2	1	-	1	-
	A_{3000}	1949	T	4	IT	3	S	RB	R	2	2	Y	1	-
	A_{3500}	1950	+	4	IT	3	S	RB	R	2	3	Y	1	-
B	B	1952	S	F, F-2	CT	3	S	RB	R	3	-	-	1	-
	B_{7500}	1964	L	F, F-2	CT	3	S	RB	R	3	2	Y	1	-
C		1952	S	2	IT	2	CI	CB	C	1	2	-	-	-
D	D_1	1954	S	2	FT	3	S	RB	C-R-C	1	1	-	-	-
	D_2	1954	L	2	ST	3	S	RB	C-R-C	1	2	-	-	-
	D_3	1957	S	2	FT	1	S	RB	C-R-C	1	1	-	-	-
	D_4	1957	S	F	FT	3	S	RB	C-R-C	2	1	Y	1	-
	D_5	1957	S	F, 2	FTBC	3	S	RB	C-R-C	2	1	Y	1	-
E		1958	S	F	FT	5	S	RB	C-R-C-R-C	2	2	Y	2	-
F		1959	+	2	IT	3	S	RB	R	3	2	Y	1	-
GV		1962	S	F	CET	2	S	RB	R-C	1	-	-	-	-
H		1965	S	F, 2	IT	3	S	RB	C-R-C	2	2	Y	1	-
J		1981	S	F, 2	FT	3	S	RC	C-R-C	2	2	Y	1	-
MC		1960	S	2	FTBC	2	CI	SS	C	1	1	-	-	-
MR		1966	S	2	FTBC	2	S	SS	C	1	1	-	-	-
Transition and reserve														
	TR_1	1949	S	2	FT	4	S	RB	R	2	1	Y	1	-
	TR_2	1950	S	2	FT	6	S	RB	R	2	2	Y	1	-
TR	TR_3	1950	S	2	FT	5	S	RB	R	2	2	Y	1	-
	TR_4	1955	S	4	FT	6	S	RB	R	2	2	Y	1	Y
	TR_5	1956	S	F	FT	5	S	RB	R	2	2	Y	1	Y
	TR_6	1961	S	2	FT	7	S	RB	R	3	2	Y	1	Y
TC		1975	S	F	FT	4	CI	RC	R	4	3	Y	1	Y
TE		1975	S	F	FT	7	H	RC	R	4	3	Y	1	Y
TH		1975	S	F, 2	FT	5	H	RC	R	4	3	Y	1	Y
TV		1980	S	F, 2	FT	4	S&T	RC	C-R-C	4	3	Y	1	Y
TF		1990	S	F	CET	7	H	RC	C-R-C	4	4	Y	1	Y
Port														
P		1952	S	F, 2	FT, CET	5	S	RB	R	7	4	Y	1	Y
Seed selection														
SV	1971	T	F	FT	3	S	RB	R	3	1	Y	2	-	
SA	1960	S	F	FTBC	3	S	RB	R	2	1	Y	2	-	

[1] See text for abbreviations. [2]: S: square; T: T-shape; +: cruciform; L: L-shape. [3]: F: flat roof; 2: gable roof; 4: hip roof; F-2: flat and gable roof; F, 2: flat in tower and gable roof in the rest. [4]: IT: interior tower; CT: corner tower; FT: front tower; ST: side tower; FTBC: front tower between two cells; CET: central tower. [5]: S: Square; CI: circular; T: trapezoidal; H: hexagonal. [6]: RB: reinforced brick; CB: concrete block; RC: reinforced concrete; SS: sheet steel. [7]l: R: cells raised off ground storey floor; C: cells resting directly on ground storey floor; C-R-C: alternating rows of rows resting on and raised off ground storey floor. [8,9]: Y: exists.

In these double- or four-pitch roof silos the cells stand off the floor over an open plan ground storey. Some are enlarged on one, two or three sides with three rows of three to four approximately 1000 t cells each, giving rise to four subtypes: A_{1000} (original silo); A_{2000} (silo A_{1000} with an addition at the rear); A_{3000} (silo A_{1000} with additions on the two sides) and A_{3500} (silo A_{1000} with additions on the rear and both sides) (Fernández-Fernández, 2016) (Fig. 2.2-2.4). In two cases (La Roda, Albacete and Trujillo, Cáceres) the additions are not attached to the original building except at the top for loading (Fig. 2.5). These early silos are richly adorned, in keeping with the vernacular architecture. They feature a dado to the height of the ground story ceiling; brick facing in columns, doors and windows; and a main body in which the columns, rendered or otherwise depending on the region, are clearly outlined. A top the main body stands a cornice, clearly distinct from the eaves and crowned with ornaments such as pinnacles (at Salvatierra, Ávila and El Carpio), mouldings, dados and finishes in local colours (as in the intensive use of brick facing on the structure for the A_{3000} silo at Valladolid), as described by García (2016).

— The first B or second type of receipt silo was built in 1952 at Marchena, Sevilla and the last in 1981 at Plasencia del Monte, Huesca, although construction was most intense in the nineteen fifties, when 22 of the total 38 were erected. In these silos the tower is positioned in one corner and is larger than in the A silos. The three rows of cells are raised off the ground storey, below which there is a basement. With one exception they all have flat roofs. Two subtypes can be distinguished by the shape of their floor plans. The original 2200 t to 5000 t type B has three rows with four cells each, with the tower in one corner protruding off the building and a flat roof (Fig. 2.6), whereas 7500 t type B_{7500} has an L-shaped floor plan with the tower in one corner and a flat roof over the centre row of cells and a pitched roof over the side rows (Fig. 2.7). Architecturally speaking type B is much simpler than type A, in particular in terms of the abutment between the cell façades and the upper distribution storey. The ground storey is still integrated in the overall structure. The most outstanding feature is a reinforced concrete or steel canopy. The few exceptions to the rule include the one at Zamarramala (Segovia), which to blend with the town's nearby historic centre was faced with brick throughout, covered with a four-pitch roof and richly adorned (Azcárate, 2009).

— Unlike the preceding two, type C has two rows of (three to six) on-the-floor cylindrical cells comprising cement block walls that at the same time form part of the structural walls of the silo itself. The tower is positioned between the two rows of cells and features a double-pitch roof. The capacity of the 22 silos of this type, built over only a 4 year period (1952 to 1956), ranges from 1650 t to 3150 t. According to Azcárate (2009), their simple, inexpensive construction was more or less inspired by the cylindrical, unadorned façade silos built in the U.S. Their rudimentary construction posed substantial maintenance problems, however (Fig. 2.8). Precast blocks were also used to build silos in Mussolini's Italy after 1939 to economise on cement and steel (Vaquero, 2011a).

— Over the 34 years (1953-1987) they were built, the 389 type D silos (58.5 % of the total studied) underwent many variations. In an attempt to compete with the low cost of the type C units, the designers maintained the three-row arrangement. The outer rows cells rest on while the centre row is raised off the floor. Subtype D_1 has bare façades from the ground to the double-pitch roof. The upper gallery is positioned over the central raw and fitted with mansards for readier access to the outer cells. The tower, built flush against the front façade, features conventional windows. The inventory identified 120 units of this type (Fig. 2.9). D_2 silos are D_1 units with an addition on one of the side façades, an arrangement that affords them certain peculiarities (Fig. 2.10). Only six such silos were identified, all built between 1954 and 1957, for this fairly unusual layout may have been mandated by lot shape or some other impediment to adding to the silo at the rear along the longitudinal axis (Fernández-Fernández, 2016).

The sole subtype D_3 silo was built at Barbadillo, Salamanca in 1957. For want of space, as it is located between a granary on one side and a stream on the other, it has a single row of six on-the floor cells (Fig. 2.11). It is aesthetically the same as a D_1 silo without the two outer rows of cells except that its reception hopper and steel canopy are positioned at the rear, opposite the tower.

The 124 subtype D_4 units inventoried were built from 1957 to 1971. Although arranged interiorly to the same on- and off-the-floor row as D_1, it differs from that subtype in that it has a parapeted flat roof and its tower has continuous rather than conventional windows. Two small structures attached to either side of the tower house offices and a bulk loading area. The result, an elegantly proportioned building, might well epitomise the NNSG silo (Fig. 2.12).

Subtype D_5 is a D_4 in which the side structures, built up to accommodate cells, flank the tower to the top, providing for a more compact but perhaps less aesthetically pleasing volume than in D_4. The 138 units of this, the most numerous type, were built across a period of 30 years (1957-1987). In 20 cases, primarily in northern Spain where rainfall is heavy, they were fitted with a pitched roof to better evacuate rainwater, detracting from the overall elegance of the design (Fig. 2.13). Some authors have classified the D_5 silos with pitched roofs under a separate subtype, D_6 (Azcárate, 2009; Moreno, 2014).

— Over time the need for greater storage space gave way to type E silos, with capacities of 4500 t to 8000 t. Their layout is reminiscent of two type D silos in which

Figure 2. Silo types and subtypes: 1) A_{1000} at Salvatierra, Vitoria; 2) A_{2000} at Madrigal de las Altas Torres, Ávila; 3) A_{3000} at Valladolid; 4) A_{3500} at Ávila; 5) A_{3500} with detached addition at Trujillo, Cáceres; 6) B at Villafranca de los Barros, Badajoz; 7) B_{7500} at Badajoz; 8) C at Cantalapiedra, Salamanca; 9) D_1 at Villardefrades, Valladolid; 10) D_2 at La Tabla, Zamora; 11) D_3 at Barbadillo, Salamanca; 12) D_4 at Herrera de Pisuerga, Valladolid; 13) D_5 at Cuellar, Segovia; 14) E at Arévalo, Ávila; 15) F at Salamanca; 16) GV at Monesterio, Badajoz; 17) H at Madrigal de las Altas Torres, Ávila; 18) J at San Cristóbal de la Vega, Segovia; 19) MC at El Pedroso de la Armuña, Salamanca; 20) MR at Palanquatos, León; 21) TR_1 at Alcalá de Henares, Madrid; 22) TR_2 at Córdoba; 23) TR_3 at Mérida, Badajoz; 24) TR_4 at Jerez de la Frontera, Cádiz; 25) TR_5 at Toro, Zamora; 26) TR_6 at Palencia; 27) TC at Trujillo, Cáceres; 28) TE at Pancorbo, Burgos; 29) TH at Medina del Campo, Valladolid; 30) TV at Barcial del Barco, Zamora; 31) TF at Valchillón, Córdoba; 32) P at Málaga (photo: Archivo Histórico Málaga); 33) P at Santa Cruz de Tenerife, Tenerife; 34) SA at Briviesca, Burgos; 35) SV at Badajoz; 36) National Grain Service nameplate on a type C silo at Villarubio, Cuenca.

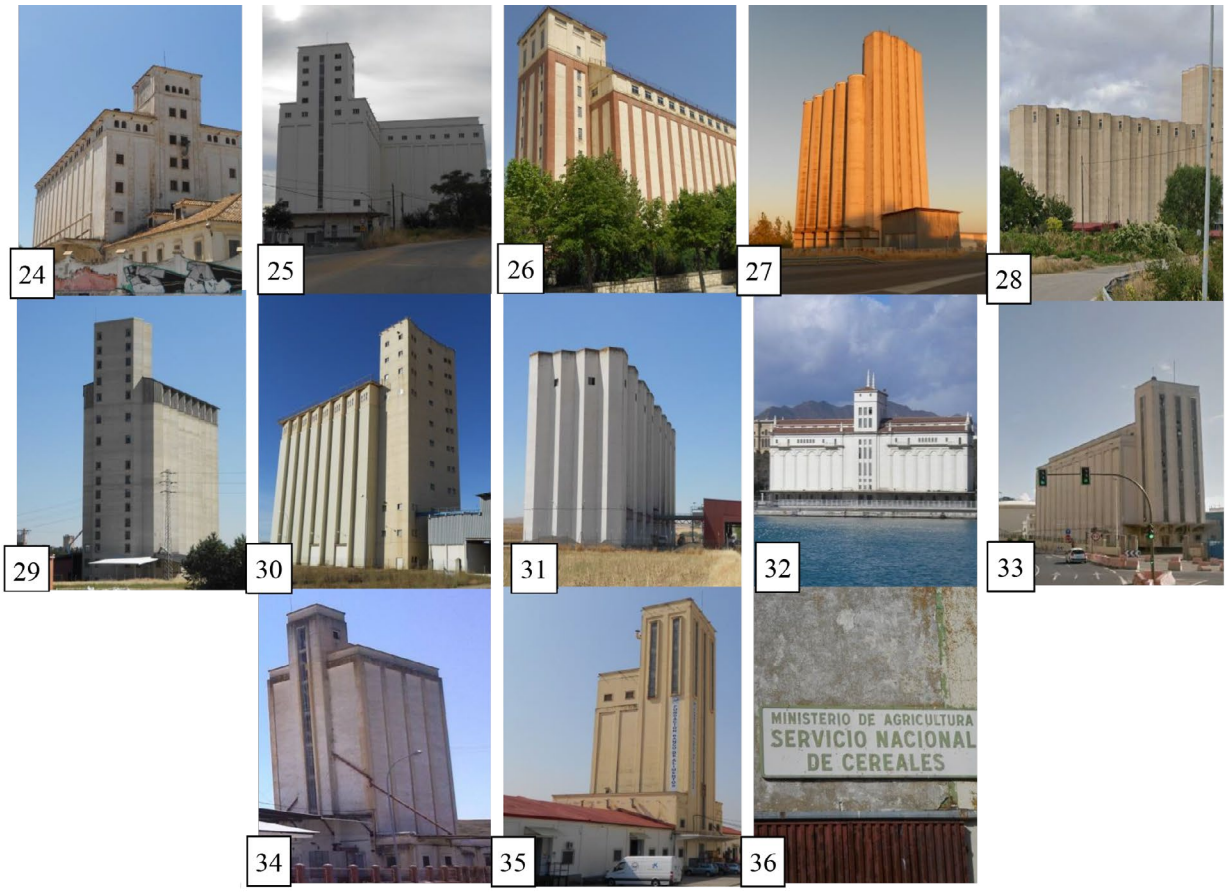

Figure 2 (Continued)

one longitudinal row of cells has been removed: *i.e.*, on- and off-the-floor cells alternate, separated by two corridors. With one exception they all have flat roofs. Like the D_4 units, these compact, unadorned silos have a rectangular floor plan off which a tower protrudes at the front (Fig. 2.14). The 41 VSUs of this type were built between 1958 and 1981.

— Type F, which is similar to the much older subtype A_{3000}, was built from 1959 to 1965. Its cruciform floor plan has symmetrical axes, off-the-floor cells throughout and an internally positioned tower. It can be said that, despite the higher capacity of these six units (3500 t to 4000 t), that similarity to the earlier model constitutes a step backward in silo construction. Their architecture features a ground-storey height dado and over it the corpus housing the cells. The internal tower and an upper gallery protrude through the four-pitch roof. In some units (Zamora and Salamanca-Tejares) the structure is brick-faced (Fig. 2.15).

— To continue in chronological order, the first of the 14 GV (initials for 'granero vertical', vertical granary) units was built in 1962 and the last in 1968 (Fig. 2.16). They are characterised by their low (1000 t) storage capacity, provided by a row of three on-the-floor cells and a second row of two off-the-floor cells that flank the tower. The structure is surrounded by a horizontal storage unit. These silos normally stored grain in areas of the Spain with low output where the quantities involved did not warrant a silo.

— The 13 type H silos built between 1965 and 1969 all have a capacity of 2800 t. Conceptually they consist in two type D silos attached along their respective front façades, generating a wholly symmetrical structure with the tower in the middle. The result is a very compact and efficient silo that minimises horizontal transport. Although endowed with a distinctive profile, it is less attractive than type D because the tower is positioned internally. As in D, the cell boundaries are marked externally from the ground to the pitched roof and the upper distribution gallery, also fitted with a pitched roof (Fig. 2.17).

— The five type J silos were built rather late, in 1981 and 1982, at the same time as when macrosilo construction was booming. With a mean capacity of 3200 t to 7500 t, they have three rows of cells. Although as in type D their on- and off-the-floor cells alternate, the rows cross the silo transversally. The frontally positioned tower houses both machinery and a lift. Given the date of construction, they were all built with reinforced concrete instead of the reinforced brickwork used in the earlier units. Architecturally speaking the result is a well-defined volume which while made of reinforced concrete retains the vertical lines of the cells that afford the building its stately appearance.

In keeping with contemporary practice, the double-pitch roof is nearly flat (Fig. 2.18).

— While the earliest type MC silo appeared at Jimena de la Frontera (Cádiz) in 1960, construction was at its most intense in 1966-1969, when 35 of the 37 such small- to medium-capacity (600 t to 5000 t) units were built. Unlike all the preceding silos, this model was awarded to and built by a private company to lower costs (Azcárate, 2009; Fernández-Fernández, 2016). The initials 'MC' refer to the Spanish expression 'metálico circular' (circular metallic), for they are steel-plated, as a result of which they aged so poorly that 43.2 % have had to be demolished. They have a very simple structure with three, four or six steel on-the-floor cells, with the hoisting machinery and a staircase in-between. The upper distribution gallery is likewise steel whilst the infills and the double-pitch roof are made of fibre-cement. Outwardly they are simple and unadorned like silos in the U.S. and are presently substantially deteriorated due to lack of maintenance (Fig. 2.19).

— Type MR ('metálico rectangular', rectangular metallic) appeared in 1966 and met with much the same fate as type MC. The 30 units built through 1973 have or had capacities ranging from 600 t to 5000 t. Eleven have since been demolished and only the silos at Cañaveras, Cuenca and Albalate de Cinca, Huesca, are still in use (Fig. 2.20).

A comparison of the receipt silos described here to the ones built in Italy for similar purposes showed that the capacities were similar in most cases and the Italian structures were also made of stone or brick to minimise the use of concrete and steel. Their construction depended on each province's farm consortium, however, in contrast to the centralised governance existing in Spain (Vaquero, 2011a,b).

Transition and reserve silos

The transition and reserve category is divided into six types of silos: TR, TC, TE, TH, TV and TF (see Table 1). The group name describes the purposes of these units: they stored grain from the receipt silos until it was dispatched, keeping a reserve for use in bad years. As those were the primary functions for the SNT, the transition and reserve silos, along with the A, B, C and D receipt silos, were the earliest built (Table 2). The transit and reserve (TR) silos built in the nineteen fifties and sixties were followed after 1975 by the construction of the so-called macrosilos (>10,000 t). Five types can be defined (TC, TE, TH, TV and TF), one each for the private companies to which construction was awarded. They nonetheless share a number of features, including slip form reinforced concrete construction, flat roofs (nearly throughout) and compliance with explosive atmosphere legislation (EC, 1994; Azcárate, 2009; Fernández-Fernández, 2016). The type of construction involved favoured vast heights and capacities, which ranged from 10,000 t at Paredes de Nava, Palencia, to 40,000 t in two silos in Andalucía. These silos brought the network into line with agro-industrial building trends in other countries (García, 2016).

— The non-uniformity of the first type in this group, TR, determines its division into six subcategories. From the standpoint of construction, the TR units are similar to most of the receipt silos, *i.e*., with reinforced concrete columns and beams, reinforced brickwork walls and initially pitched and subsequently flat roofs. The sole subtype TR_1 silo was built at Alcalá de Henares, Madrid, in 1949, essentially as a 'practice' facility for all those involved in VSU construction (Fernández-Fernández, 2016). At 2300 t it is the smallest of the TR silos, with four rows of off-the-floor cells. Architecturally it is a blend of styles with pediments, triglyphs, decorative façades and any number of adornments (Azcárate, 2009), including balconies that interrupt the verticality of the tower (Fig. 2.21).

Subtype TR_2, built at Córdoba in 1950, with 19,000 t capacity. All six of its rows of cells stand off the floor. Its Neomudejar yet rationalist architectural design (BOJA, 2015) is characterised by a wide frontal tower with two taller bodies flanking a middle lower unit (Jordano, 2012). The ornamental brickwork on its façades and cornices and a pediment adorned with a rose window on its rear façade make it, even today, a distinctive building which in 2015 was listed as one of Córdoba's cultural heritage assets (BOJA, 2015) (Fig. 2.22).

While built in the same year as the Córdoba unit, the one at Mérida, Badajoz, is only half as large (10,500 t) and constitutes another subtype, TR_3. It features off-the-floor cells arranged in five rows, as in subtypes TR_1 and TR_2 and rendered and painted façades adorned at the corners. The vertical lines marking the cell edges afford it a plainer, more 'industrial' appearance than the preceding two (DOE, 2017). In all three cases the low-rise body attached to the tower to facilitate grain handling detracts from the prominence and elegance of the tower (Fig. 2.23).

The first subtype TR_4 was built at Jerez de la Frontera, Cádiz in 1955 and two years later the second went up at Huesca, in keeping with the practice, instituted with the receipt silos, of capitalising on an existing model. The six rows of off-the-floor cells afforded these two TR_4 units a capacity of 5,200 t. Although still adorned (semi-circular arches, cornices…), this subtype features light-toned rendering and fewer frills than the preceding three (Fig. 2.24).

In 1956 another TR subtype, TR_5, was built at Medina de Rioseco, Valladolid, with none of the adornments or unnecessary cladding present in subtypes TR_1 to TR_4. This 12,000 t unit was subsequently repeated at Bellpuig in the province of Lleida and at Toro in Zamora, although the latter was designed to an 'L'-shape to accommodate up to 19,000 t. The five rows of cells in TR_5 all stand off the floor. The balanced architecture of this type of silo is

highly rational and austere, while its flat roof is similar to the type B roof (Fig. 2.25).

The six-row, off-the-floor-cell silos built at Burgos in 1961 (22,000 t) and Palencia in 1964 (21,000 t) constitute high capacity subtype TR_6. The regressive use of double-pitch roofs may have been a concession to their location in historic cities where the austerity of the TR_5 model may have been deemed less fitting (Azcárate, 2009). It may have also been due to more practical considerations, however, such as rainwater evacuation. At Palencia the columns were cladded with red brick whereas at Burgos the rendered and painted façades were embellished with cornices and other ornaments (Fig. 2.26).

— Three TC silos (transit units with cylindrical off-the-floor cells resting on ramped walls that provided for vehicle access to load the grain) were built in 1975-1977. Architecturally, these silos are characterised by their semi-cylindrical façades comprising the cell walls, counterpointed by a straight, asymmetrically positioned tower that rises four storeys above the silo, creating a building in which the outline differs with the viewer's perspective (Fig. 2.27).

— At the same time as the TCs, four TE silos (with off-the-floor hexagonal cells) were built. Two parallel sides of the hexagons run parallel to the main axis of the silo to maximise space. The façades are consequently very jagged, with three sides of one cell alternating with one of the next. The result is a play on light and shadow, although the most prominent structure is the hexagonal tower with its windowless front façade (Fig. 2.28).

— The four TH silos also built in the same period (1975-1976) have off-the-floor hexagonal cells, with the parallel sides perpendicular to the main axis of the silo to optimise the use of floor space. As a result the façades have regular, 30º sawtooth exteriors with double-pitch roofs over the cells and a flat roof over the tower. The upper galleries of these structures have outward-protruding fibre cement enclosure walls. As in the other macrosilos the massive volume, alternating light and shadows on the façades and front-positioned tower are the most prominent features (Fig. 2.29).

— Later, in 1980-1985, 12 TV silos (trapezoidal and rectangular cells) were built. With a capacity of 40,000 t each, the ones at El Cuervo, Cádiz, and Marchena, Sevilla, are the two largest both of this type and in the NNSG. On- and off-the-floor cells alternate transversally in these units for loading vehicle access. The trapezoidal cells on the outer rear rows, in conjunction with the rectangular inner cells, afford these units their peculiar sawtooth shape. The slanted planes forming the tower further highlight those façades. The outcome is a strikingly simple profile enhanced by the play on light and shadows (Fig. 2.30).

— The last NNSG silo built, in 1990, was also a macrosilo, a 20,000 t type TF unit sited at Valchillón, Córdoba. It differs from type TE in that in its irregular hexagons the sides parallel to the main axis of the silo are longer than the rest. As its on- and off-the-floor cells alternate in the transverse direction, lorries can access its interior to load grain, as in type TV (Moreno, 2014). Its distinguishing feature is the wholly symmetrical, central position of the tower, that barely rises above the rest of the structure (Fig. 2.31).

All the foregoing supports the Salamanca-Cascos *et al.* (2010) observation that the adornments on receipt and transition/reserve silos, in particular those built in the NNSG's early years, were based on traditional architecture that sought to distinguish the public buildings erected by the Francoist regime from the rationalist tendencies in vogue in the rest of Europe. The latter trend ultimately prevailed in the NNSG silos built in and after the nineteen sixties, however.

Port silos

Although on the grounds of their role in import/export operations port (P) silos (Table 1) could be classified in the transit and reserve group, they are deemed to constitute a separate category because of a series of structural peculiarities. Only two were ever built, at Málaga in 1952 (demolished in 2006, Fig. 2.32) and at Santa Cruz de Tenerife in 1965. The one in the Canary Islands has a capacity of 12,000 t and like most network silos is made of reinforced concrete with five rows of square reinforced brickwork cells resting on the ground and a frontal tower. It is characterised architecturally by its straight, austere lines reminiscent of subtype D_4, although it differs from that archetypal network silo in that its wide tower is frontal and has continuous windows (Fig. 2.33). In Italy, in turn, after 1936 when all wheat had to be handed over to the State, many of the large silos were sited in ports such as Venice, Cagliari or Rome, while other major cities housed the very largest, with capacities of 5,000 t to 20,000 t and even up to 40,000 t (Foggia). These structures were designed jointly by architects and engineers who conformed to the rationalist trend predominant in Europe. The outcome was buildings with clean, orderly lines devoid of any useless ornamentation, similar to the Spanish macrosilos built after 1971. They differ in that the windows around the entire perimeter and on all four or five storeys in the Italian structures are lacking in the Spanish buildings. The former were operational until the nineteen sixties and, unlike their Spanish counterparts, later given a new use (Vaquero, 2011a,b).

Seed selection silos

The seed selection group of silos is divided into types SV and SA. These units were built to select and improve seeds returned to farmers for new crops.

— Type SV ('selección vertical', vertical selection) has reinforced concrete structures with three rows of reinforced brickwork off-the-floor cells and an open plan ground storey for grain handling. Its wide frontal tower that spans the three front cells and beyond houses all the selection machinery. Architecturally this silo has a somewhat vague profile, for attached to it is a low-rise T-shaped structure. Nonetheless the tower with its continuous windows both on the upper part of the front and side façades where the selection machinery is kept forms a well-proportioned whole (Fig. 2.34). The 10 units built in 1971 and 1972 have capacities ranging from 1650 t to 3000 t, although some (at Lerma, Sevilla and Villar de Chinchilla) were subsequently enlarged to 6500 t. Type SA ('selección y almacenaje') covers selection and storage silos. Their construction is similar to their SV counterparts, with an open plan ground storey with a basement underneath. They house a larger number of smaller cells than in proximity silos, given the need to accommodate lesser amounts of a wider variety of grains. The tower for housing the selection machinery is simpler than in the preceding type.

Technological development

Receipt silos

As discussed in item ´Architectural and typological development´ this, the most numerous group of silos, is divided into types A, B, C, D, E, F, GV, H, J, MC and MR. The study showed that 92.9 % of the silos built lie under this category, designed to receive grain from farmers and store it until it was shipped to transit and reserve silos or sold to millers or other farmers. The machinery consequently had to be suited to those purposes. The capacity was consistently small, nearly always under 100 t/h (SENPA, 1990). The most prominent technological features are summarised in Table 2 by NNSG silo typology.

— The equipment present in the type A silos consists in two elevators in the internally positioned tower. Both receive grain loaded off of carts, trailers or lorries through a reception hopper or chute (Fig. 3.1). All the elevators used in the silos have two square section frames inside which a strap carrying small scoops rises on one side and descends on the other (Fig. 3.2 to 3.4). One of the elevators (hereafter the grain elevator) raises the grain to the top of the tower where it is emptied onto a circular distributor (Fig. 3.5) and dropped into free-fall tubes connected to the storage cells. The other (hereafter the cleaning elevator) is only used where necessary to remove impurities, raising and then dropping the grain into the cleaning machinery. The cells empty through a manual damper onto a rectangular section, chain-driven belt that conveys the grain to the unloading gate or gates. Portable telescopic tubes are also installed to redirect the grain back to the elevators if necessary. Since the distance from the tower to the cells is longer in the enlarged A silos (A_{2000}, A_{3000}, A_{3500}), they also have one or several upper belt conveyors sited in a gallery positioned over the central row that loads all the cells. The facility likewise includes by-pass valves, automatic weighing systems, endless screws for the reception hopper or for bulk unloading and portable telescopic tubes to connect the cell unloading gates to the lower belt conveyor. All the machinery is electrically powered. In some A_{3000} and A_{3500} silos dust collectors consisting in ducted vacuum systems with one or several venting units carry the suspended particles to fabric filters and cyclone separators for removal. Although the type F units appeared 10 years later, they are fitted with essentially the same machinery as the A_{3000} VSUs.

— The technology in the type B silos is similar to the A and F units, except that it has three elevators (grain and cleaning as in type A and a third for unloading) as well as separate automatic incoming and outgoing weighing systems so the two both operations can be performed simultaneously. Instead of circular distributors the L-shaped B_{7500} silos have horizontal belt conveyors with dust collector systems and portable telescopic tubes underneath the belts to pour the grain into the cell to be loaded (Fig. 3.6),

— Although the first type C silos were built slightly after the others mentioned, they are fitted with much simpler machinery, including an elevator that empties onto two upper horizontal belt conveyors that distribute the grain to the cells through dampers and ducts. As the cells rest on the floor, each has an endless screw for unloading and in some cases a second in the reception hopper. These silos have no dust venting system.

— Although the type D silos improved on A and B silo construction, they differ very little from the standpoint of machinery. Here the elevator receives the grain directly from the reception hopper or from a belt conveyor if the hopper lies underneath a railway track, raising and emptying it onto an upper horizontal belt conveyor, where either through portable telescopic tubes in the earlier (D_1 and D_2) or dampers and manual or motorised valves in the later (D_4 and D_5) models, it is distributed across other tubes to one of the three cells in each bay (Figs. 3.7 to 3.11). The grain is unloaded onto lower horizontal belt conveyors lying at different heights depending on whether the cells stand off (central) or on (side) the floor. From there it is carried to a raised cell for bulk offloading onto a lorry or railcar (Figs. 3.12 to 3.14). Subtypes D_4 and D_5 have vacuum dust collection systems similar to the facilities in types A and B (Moreno, 2014) (Fig. 4).

— As the E silos have five rows of cells, unlike the preceding types they require redundant machinery, with

Figure 3. 1) Reception hopper in type J silo at Corrales del Vino, Zamora; 2) grain elevator in type MC silo at El Pedroso de la Armuña, Salamanca; 3) grain elevators in type TV silo at Zuera, Zaragoza; 4) detail of elevator scoop in type TH silo at Medina del Campo, Valladolid; 5) circular distributor in type B silo at Villafranca de los Barros, Badajoz; 6) portable loading tube in subtype D_1 silo at Piedrahita de Castro, Zamora; 7) upper horizontal belt conveyor and loading tubes in subtype D_5 silo at Manganeses de la Lampreana, Zamora; 8) load tubes in type TV silo at Coscurita, Soria; 9) detail of damper and bypass valves in type TV silo at Coscurita, Soria; 10) detail of drive chain and crossbars inside upper horizontal belt conveyor in type TV silo at Coscurita, Soria; 11) loading tube and cell in type J silo at Cella, Teruel; 12) offloading tubes and lower horizontal belt conveyor in type J silo at Santa Eulalia del Campo, Teruel; 13) telescopic offloading tubes in type TV silo at Barcial del Barco, Zamora; 14) external bulk offloading tube in subtype D_4 silo at Herrera de Pisuerga, Palencia; 15) cleaning machinery in Type E silo at Lora del Río, Seville; 16) detail of cleaning screens in type TV silo at Coscurita, Soria; 17) interior of steel cells in type MR silo at Palanquinos, León; 18) control panel in subtype TR_5 silo at Medina de Rioseco, Valladolid; 19) automatic scales in type TH silo at Medina del Campo, Valladolid; 20) dust collector in type TE silo at Cariñena, Zaragoza; 21) dust filter in type TE silo at Cariñena, Zaragoza; 22) dust extraction chimneys in type SV silo at Badajoz; 23) thermometric sensors in type TH silo at Medina del Campo, Valladolid; 24) refrigeration facility in type TH silo at Medina del Campo, Valladolid; 25) lift in type TE silo at Pancorbo, Burgos; 26) intercom in type TV silo at Osma La Rasa, Soria); 27) lift to access cells for cleaning in type TE silo at El Carpio (Córdoba).

Figure 3 (Continued)

two elevators for grain, cleaning or unloading as appropriate. They are also fitted with two cleaning machines and two upper horizontal belt conveyors for cell loading and two lower belts for unloading, along with the necessary automatic valves to control the grain flow and vacuum collection systems where dust is generated (Figs. 3.15-3.16).

— The 6 type F silos have the same technological equipment as the A_{3000} subtype except that they incorporate one more elevator (grain elevator).

— The vertical granary (GV) silos have even simpler machinery than found in the type C units. A single elevator carries the grain from the reception hopper to the top of a circular distributor where it is emptied into the three off- and two on-the-floor cells. The cells are unloaded at the bottom where the free-fallen grain can be carried to the elevator and from there to one of the two off-the-floor cells adjacent to the tower where it is bulk offloaded onto vehicles.

— The machinery in the type H silos resembles the equipment in the type D units except that as the tower is positioned centre-internally in the silo, one horizontal belt conveyor runs along each side of the elevator to load the cells through distributor valves and fixed tubes. Offloading is similar to the procedure described for type D units.

— In the type J silos built in 1981 with alternating on- and off-the-floor cells, the front position of the tower simplifies the machinery required: grain and cleaning elevators, a single upper horizontal belt conveyor to load the cells as in types D and H and a single lower belt, all as described above.

— The MC silos have one grain and one unloading elevator. The former empties the grain onto a circular distributor or an upper horizontal belt conveyor which carries it to the respective cell across valves and tubes. The silos' off-the-floor cells are fitted with an endless screw for unloading onto a lower horizontal belt conveyor. The grain is carried from there to an elevator for offloading as bulk or into a bagging machine.

— As in the MC silos, the type MR units have a single elevator and an upper horizontal belt conveyor that empties into the cells through dampers and tubes (Fig. 3.17). The cells are unloaded on a lower horizontal belt conveyor that empties into the elevator, for the grain must be poured into an off-the-floor cell for bagging. Neither the MC nor the MR silos have vacuum dust collection systems.

Transition and reserve silos

Inasmuch as the purpose of the 'transition and reserve' silos (types TR, TC, TE, TH, TV and TF) is to store the grain received from the receipt silos until it is commercialised (Moreno, 2014; Fernández-Fernández, 2016), they are all well connected by road and have a railway spur track. Although there are only 34 such units (5.1 % of the total), they account for 26.2 % of the NNSG's storage capacity, for the category includes the so-called macrosilos (>10,000 t) (SENPA, 1990). Those VSUs, particularly the macro-units built after 1975, are more mechanised and designed for simultaneous loading, un- and offloading, cleaning and even seed selection. They can move vast amounts of grain daily (300 t/h) from an automated control panel (Fig. 3.18). They are consequently fitted with four (three grain and one cleaning and unloading) elevators from which

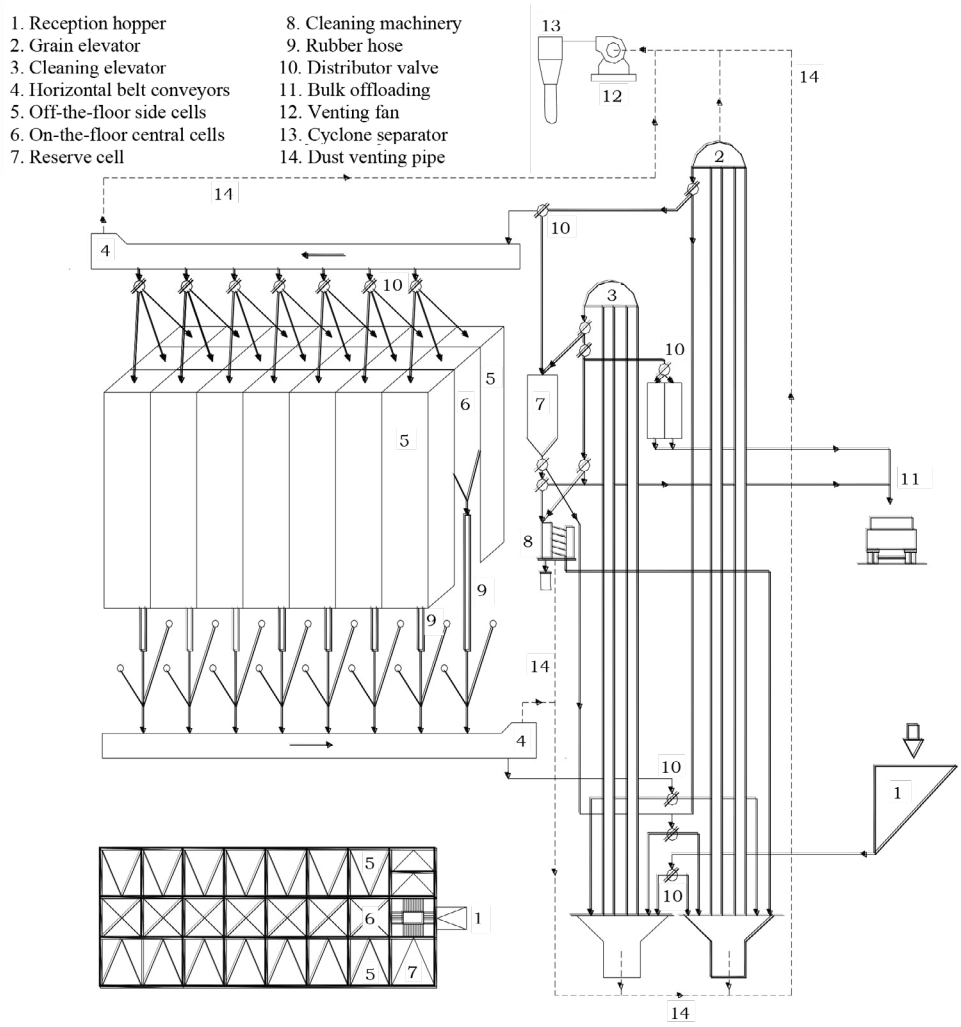

Figure 4. Machinery operation in subtype D_5 silo

grain received from lorries or railway cars is emptied onto horizontal belt conveyors leading into the various reception hoppers. The three grain elevators empty onto an upper horizontal belt conveyor that in turn pours the grain across dampers and motorised distributor valves into three tubes that feed three rows of cells, arranged so that any given cell can receive grain from more than one tube. The fourth elevator raises the grain for subsequent cleaning or to fill raised cells for bulk offloading onto lorries or railway cars. Other equipment includes automatic weighing systems, swivel distributors, vacuum dust collection systems with fabric filters and cyclone separators (Figs. 3.19 to 3.22). These structures are also fitted with gas dosage systems for phytosanitary treatments to combat pests that could damage the grain, while some have thermometric sensors in the cells to measure the inner temperature in the grain and refrigeration systems that pump air into the cells to cool it as needed (Figs. 3.23 and 3.24). Although not exclusive to these units, facilities such as intercoms, lifts to the upper storey and electric transformer stations in or near the silo to power it directly from high voltage lines are particularly necessary given their large size (Figs. 3.23 and 3.26). The silos built from the nineteen seventies on have sometimes been called machine-buildings (Azcárate, 2009; García, 2016).

Port silos

Port (P) units are the most intensely mechanised silos in the NNSG. The machinery in place at the Santa Cruz de Tenerife facility, the sole P silo still standing, is similar to the equipment in the transit and reserve VSUs, differing in the need to quickly offload the grain from ocean vessels. This unit consequently has reversible belt conveyors with an air-driven system designed to both offload the grain from and bulk load it back onto vessels. P type silos have four grain and three cleaning and offloading elevators for more agile and efficient loading, offloading onto vehicles and shipping (SENPA, 1990). The machinery installed in Italian silos was similar to the facilities found in the three groups of Spanish silos (receipt, transition/reserve and port), except that in Italy grain was carried horizontally

on conveyor belts and in Spain on horizontal chain conveyors (Vaquero 2011a; Salamanca-Cascos *et al.*, 2013).

Seed selection silos

The seed selection machinery in the SV (vertical selection) and SA (selection and storage) type silos in this group is vertically positioned in a wide tower spanning the three front cells, which are wider than in any other kind of NNSG silo. These units are fitted with three elevators that feed the vertical seed selection train over vibrating screens, recessed cylinders and free-fall separators (SENPA, 1990; FEGA, 2003). They are likewise equipped with vacuum collection wherever dust is generated, along with the respective filters and cyclone separators. The purpose of the only SA type silo still in place, at Briviesca, Burgos, is to store seeds for subsequent sowing. It has one grain and one selection elevator and simple selection machinery consisting in horizontal screens and two air separators.

Most of the silos in all the groups are fitted with a more or less modern portable hoisting and lowering device powered by a geared motor with two winches and a car for operators to access the inside of the cells from the top for cleaning purposes (Fig. 3.27).

Conclusions

Spain's national network of silos and granaries (NNSG) is a unique event in the world due to the large number and variety of silos built. As its construction comprised a great period of years (1949-1990) there has been a considerable formal and architectural change in these buildings. The 41 year period (1949-1990) over which Spain's national network of silos and granaries (NNSG) was built witnessed considerable formal and architectural change in these buildings. The earliest, small capacity units used local materials such as brick to lower costs and were richly adorned in keeping with vernacular style in an attempt to blend into the surrounds. They gradually gave way to the arresting, highly functional, unadorned, reinforced concrete macrosilos built in the nineteen seventies. The machinery installed in the oldest units is simpler, essentially consisting in equipment to load the cells at the top and unload the grain at the bottom and to clean it of impurities before or after storage. As time passed silos were fitted with new types of machinery with other purposes such as selecting and conditioning seeds (types SV and SA), spraying the cells with phytosanitary treatments or even refrigerating the grain. In other words, the machinery evolved over time in both quantity and processing capacity, with the most sophisticated equipment installed in the silos built from the nineteen seventies on. Ancillary facilities included automatic weighing scales and vacuum dust collection systems fitted with venting filters and cyclone separators.

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