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Multicriteria Decision Tool for Sustainable Reuse of Industrial Heritage into Its Urban and Social Environment. Case Studies

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Abstract: Most of industrial heritage assets need new activities to ensure their survival. In addition, the collection of assets is very broad, many of their locations have now become central and are targets for speculation, and the nature of these sites displays great specialization. Consequently, processes for reusing these assets are necessary to conserve them, but they risk destroying features whose value has been inadequately identified. This work faces this multicriteria problem by adapting the Analytic Hierarchy Process (AHP) to create two independent criteria structures, one for heritage valuation and another for analyzing the spatial compatibility with new uses, and then connecting them considering the relations between criteria of both structures and the relevance of the heritage aspects involved. All this to select those activities that cause minimal harm to the heritage value to be conserved. This work analyses three case studies to evaluate the performance of a tool based on an adaptation of AHP. The results are exposed and some application guidelines are provided, since doubts in the way to applying and interpreting the criteria are in practice a common problem of this type of approaches and that is rarely addressed. Thus, this work shows the potential of the proposed tool as a resource for sustainable urban development strategies.

Keywords: sustainable urban development; decision-making; industrial heritage; AHP; building reuse

1. Introduction

In recent years, the need to argue for accepting industrial heritage as a type of cultural heritage has disappeared. Society now recognizes this type of asset as a type of cultural heritage. The growth of national and international associations [1], projects, conferences and seminars, publications and even specialist training and strategic plans [2] reflect this change in its status. As a result, the challenge facing this type of heritage and the assets it includes now no longer revolves around arguing its case and defending its characteristics, values and the need to conserve the most representative examples. As this initial stage of recognition has now largely been achieved, the current challenge has more to do with how these assets are managed.

Conserving this type of industrial asset involves reusing them for new purposes and represents an appropriate strategy for the sustainable urban development [3] and for the sustainable management of heritage buildings [4]. In that sense, the approaches that incorporate public participation in decision-making on how to recover this type of assets are of great interest [5,6]. From the Industrial Revolution to the latter decades of the last century, a great number of industries developed, notably increasing the number of assets of this type, something that various cataloguing initiatives have underlined [7–9]. Some involved massive growth of existing cities, while others resulted in the appearance of new centers of population. However, all industries sooner or later must face the end of

production [10], often resulting in the disappearance of their installations, which in some cases are of great value. In other cases, the installations survive to the present day, albeit unused. The number of unused industrial buildings in our cities is significant in many cases, making it necessary to find new uses [11] for them to give them a new purpose and make their conservation sustainable [12]. Introducing new uses in these spaces is not a problem, as they are generally large and airy with flexibility for adaptation. Along with a certain popularization of the industrial aesthetic, which is in fashion, this makes these buildings [13] and even old industrial districts [14–16] attractive assets for new activities. In this context, finding examples of the reuse of industrial assets for new activities is simple [17].

However, the real challenge is to ensure that this reuse does not harm the heritage value of these assets. Something becomes an element of cultural heritage because it has cultural value, that is to say, its physical form embodies knowledge that justifies protecting and conserving it [18]. Cultural heritage must transmit this knowledge. It is not enough to preserve it; it must be capable of promoting and transmitting it. To do so, the parts or elements of these assets in which the value and knowledge reside must first be conserved without being damaged in the process of adapting them. Secondly, they must be accessible so that they can be observed and interpreted and so become a vehicle for transmitting the knowledge they contain. This does not mean new uses must be rejected but rather coexistence between the new activity and the preservation–display of these elements must be sought. Accordingly, it is vital to identify the uses or activities that are most compatible with the characteristics of the asset to be conserved [10,19].

Selecting new uses for industrial assets where cultural value has been identified is therefore a difficult task, which involves considering a significant number of criteria of very different types simultaneously and in an integrated way [20,21]. On the one hand, there are criteria relating to evaluating the cultural value [18] the asset contains, which comes from particular parts or elements of it. On the other hand, there are criteria that relate to the asset's capacity to house possible new activities in each case. Figure 1 shows this idea graphically. There are two potential routes when faced with the disappearance of an asset and the complete loss of its values. Turning these assets into a museum to display their original productive activity is the ideal scenario as it enables the element to be fully protected, but not all assets of this type are of sufficient interest and value to justify such an action, nor will it be viable or sustainable as a general strategy for the particular type of assets. So, an alternative method must aim to find room for other activities, accepting that part of the value of the asset can be affected while ensuring the protection of its most relevant features and attempting to minimize the impact of adapting the asset to its new use.

In this context, using multicriteria tools to assist decision making has great potential. One of the techniques used most widely and in very varied contexts is the Analytic Hierarchy Process [22], commonly referred to as AHP, developed by Thomas Saaty in the late 1970s [23,24]. Many studies have been published based on the application of this type of technique in very varied fields that differ greatly from each other. Its use for studying industrial buildings is especially noteworthy [25,26] in the framework of this study, as well as its more recent use in the field of cultural heritage in general [11,21,27–30] and industrial heritage in particular [3,19,31,32], and in guiding the process of reuse of heritage buildings [3,31,33]. All of these adaptations of multicriteria techniques show the interest and potential of these techniques for developing tools to manage industrial heritage assets.
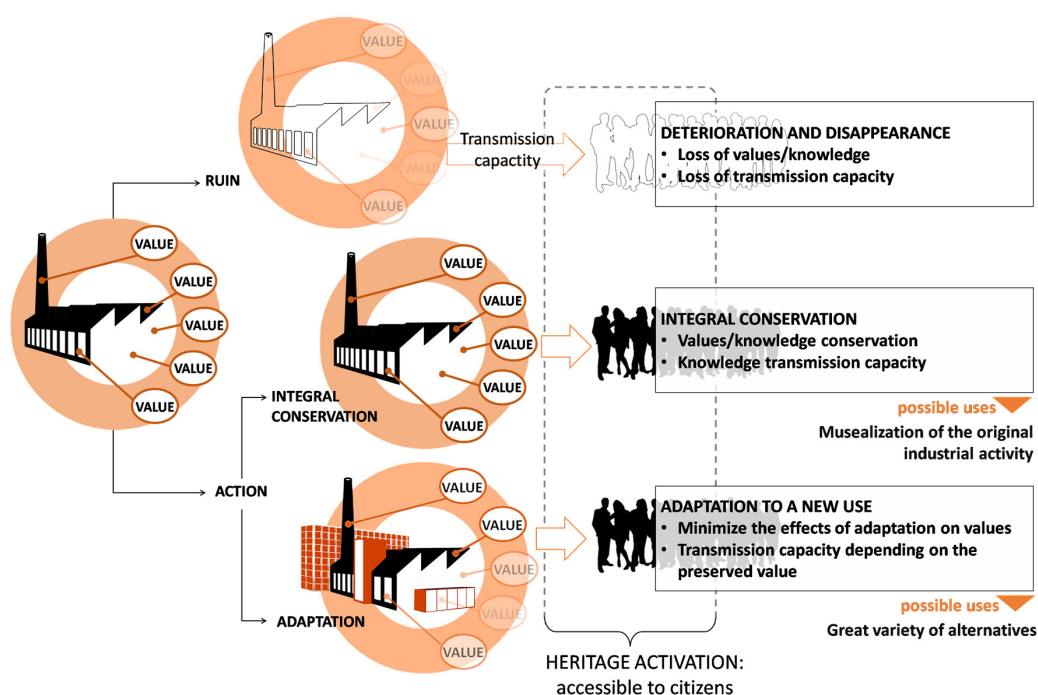
Figure 1. Conservation and activation of industrial heritage. Impact of actions for adapting to new uses.

The present work shows the application of an AHP-based methodology developed by the authors [19] to three representative practical cases. Using the tool to study real examples makes observing and validating its functioning possible. In this way, the work explores the proposed methodology's potential and usefulness as a tool for guidance when making decisions relating to selecting new uses that are compatible with conserving the cultural value of assets that form part of the industrial heritage. The principal objective of the methodology developed is to avoid conservation actions that in practice are too aggressive towards this type of asset and result in them losing cultural value. A phenomenon of which many examples could unfortunately be given in the case of industrial heritage.

2. Materials and Methods

This section briefly sets out the basic aspects that make it possible to understand the methodology whose application forms the basis of this work [10,19]. It also introduces the three case studies proposed for applying the methodology. The process of applying the methodology to these case studies and the analysis of the results obtained are the main contribution of this work as they make it possible to observe the methodology's performance and evaluate its potential and opportunities. As all three case studies are in Madrid, a very brief introduction to the city's industrial development is provided as partial support for the rationale for selecting these examples.

2.1. Multicriteria Methodology

The methodology applied to the case studies is expressed through three processes that can function and be understood independently or jointly and integrated into the overall methodology. The first is an extensive catalogue of industrial sites of heritage interest developed by the authors [7,34], which makes it possible to determine their classification in the territory being studied, in this case Spain. This catalogue currently contains over 1600 assets throughout all of Spain, and it includes 61 classification criteria for each of them, enabling multiple analyses. The other two processes are criteria structures based on applying AHP supported by the information from this catalogue [10,19]. Figure 2 gives a schematic outline of the main aspects of the methodology.

The first of the criteria structures, shown at the top left of Figure 2, considers the estimation of the cultural value of each particular element studied. The structure, in the top right of Figure 2, studies the compatibility of the sites with the potential new uses being considered based on the sites' characteristics and the needs of the new activity. In both cases, a series of criteria are identified that are deemed to be relevant for the respective analyses as they relate to defining characteristics of the asset's cultural value on the one hand and of the architectural characteristics of the site on the other. Using AHP prioritizes some characteristics over others in the two structures, and this hierarchy can be applied to any asset that is analyzed.
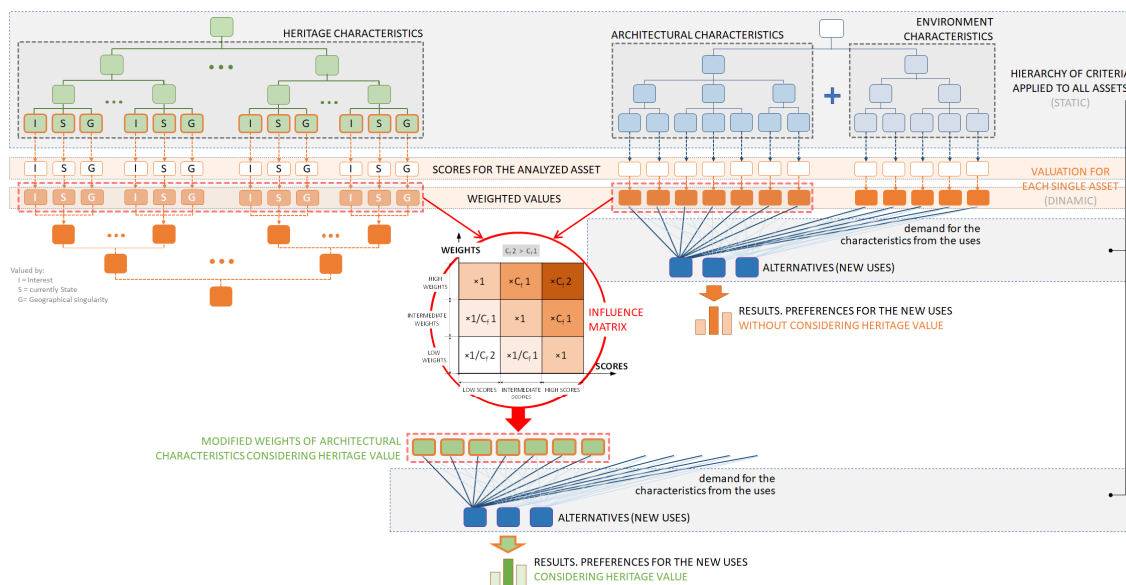

Figure 2. Multicriteria structures integrated within the global methodology developed [10,19].

Next, and again in both structures, there is a level of criteria that evaluates the presence of each characteristic from the previous level in the asset under analysis. Consequently, only characteristics actually found in the analyzed asset will have an effect, and characteristics that are not observed in the asset are rejected from the evaluation. In the case of the second structure, alternatives are considered, which are the potential new uses, making up the corresponding preference matrices for each use depending on the extent of the demand of each of the site's characteristics. This analysis is completed by considering the demand for the provision of public services and the existing activities that can be identified in the asset's surroundings so that the real demand for each use can be estimated and incorporated into the decision.

The results from both structures can be interpreted independently, in terms of cultural interest and heritage value for the first structure and direct compatibility of the architectural characteristics of the site with the requirements of the different uses in the case of the second structure. However, the two criteria structures are connected: the cultural values that the first one identifies in parts of the site can affect its scope for adaptation to the uses considered, making adaptation of the associated architectural aspects desirable or undesirable [10,19]. Unlike other works in which multicriteria decision making techniques are applied to guide the reuse of heritage assets [3,30], the proposed methodology separates the criteria considered into two different structures. Initial works developed by the authors in this field also proposed a single criteria structure [35]. However, when applying the designed criteria structure to the study of several case studies, the approach was modified and the structure was divided into two independent parts [19] one for the heritage valuation and another for the study of the architectural characteristics. Identifying the characteristics that have heritage value is necessary for their protection, but these characteristics do not determine by themselves the capacity of these assets to host different activities, which has more to do with the architectural characteristics.

Thus, this methodology incorporates the influence of the heritage value through the links, when they exist, between the characteristics of different natures that both structures collect.

2.2. Case Studies: Industrial Evolution of the City of Madrid and Selected Examples

Industrialization in Spain and in the city of Madrid had an important forerunner in the form of the *reales fábricas* (royal factories) established under the Bourbon dynasty. It then received an initial boost with the construction of the railways and was greatly expanded after the start of the twentieth century. Madrid's distance from the coast hindered its industrial development, but the importance of this was reduced by the coming of the railway.

There were no major changes until the middle of the nineteenth century. In 1851 the first stretch of railway between Madrid and Aranjuez opened. In 1858 the first of the reservoirs of the Canal de Isabel II supplying water to the city was opened. Then, in 1874 the regular service of the gasworks on calle Embajadores was established, which supplied Madrid's lighting network. At the end of the century, the first electricity companies were established. The railway was the main element of change and new industries developed around the lines. The Atocha, Delicias and Estación del Norte stations are especially noteworthy. The presence of the railway stations explains the concentration of industries in the Arganzuela district. There was considerable industrial activity in other districts, but generally on a more modest scale. The Fábrica o Fundición de Tipografías de Richard Gans (Richard Gans type factory or foundry) from 1903, in the Argüelles district, is an important example.

After the Spanish Civil War, a policy of autarchy was pursued, which the state implemented through the now-abolished Instituto Nacional de Industria (National Institute for Industry, INI) [36], founded in 1941. Its aim was to consolidate the industrial sector and restrict imports as much as possible. Madrid, Barcelona and Asturias were the main areas affected. Large industries were established under the influence of the government and were concentrated in areas specializing in certain manufacturing sectors. Three industrial areas stand out. The Arganzuela district which is part of Madrid's consolidated urban fabric, and two peripheral areas in the spheres of influence of the A-1 and A-2 radial motorways [37]. From the 1940s, other peripheral centers developed such as Villaverde, which was also stimulated by the railway, Vallecas and Carabanchel. This movement towards the periphery continued over the following decades but the number of industries inside the city was still much higher than on its periphery. From the 1950s, this situation gradually started to reverse. Several phases can be observed in this process. Figure 3 illustrates the evolution of Madrid's industrial network between 1940 and 1990, in other words, towards the end of the last century.
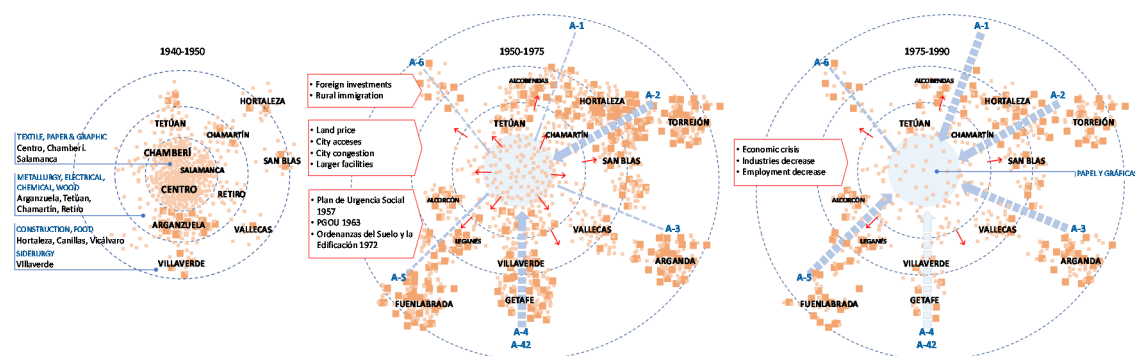

Figure 3. Development of Madrid's industrial network between 1940 and 1990.

By the end of the 1950s, three successive zones can be seen, which could, in a simplified way, be likened to concentric rings. The textile and paper industries and graphic arts were predominant in the inner zone, because their installations were best suited to the urban network of this area and because of the need for direct interaction with agents in the city. The second ring housed industries from the metallurgical, chemical, woodworking and electrical sectors. Arganzuela clearly stands out, with some

large-scale industry. A third zone comprised centers of population that were not integrated into the city at that time, although they are now, and which had larger scale industries principally dedicated to construction and food. However, for the moment only Villaverde was a consolidated industrial center. In any case, the arrangement of peripheral industries, starting to form axes, becomes apparent.

From the 1950s, different factors strengthened the peripheral locations. The Stabilization Plan of 1959 put an end to the policy of autarchy and allowed access for foreign capital. The INI's policy of strengthening the main industrial centers instead of non-industrialized areas created a large migratory movement towards cities such as Madrid. The growing number of industries, their increasing size and the growing population resulted in a lack of land that greatly increased prices in the central area, which was also congested. The periphery offered undeveloped land at low prices and the roads into the city had improved. At a legislative level, the Plan de Urgencia Social (Social Emergency Plan) of 1957 [38], the Plan General de Ordenación Urbana (General Urban Management Plan, PGOU) of 1963 [39] and the Ordenanzas del Suelo y la Edificación (Land and Building Ordinances) of 1972 [40], pushed industry towards the periphery. Only Arganzuela maintained a clear industrial character, although its decline had also already started. Small companies remained in the center, primaril in the graphic arts sector. Industry was consolidated in satellite towns such as Torrejón, Arganda and Fuenlabrada, with their facilities located along Madrid's main access roads. Various axes can be clearly identified, with the Getafe-Villaverde-Atocha axis standing out to the south and the San Blas–Hortaleza–Torrejón axis to the east.

This exodus from the city was joined in 1975 by the economic crisis that led to the closure of many industries. A major process of replacing the industrial fabric with fundamentally residential uses occurred, a phenomenon that would also very strongly affect Arganzuela. The movement of industry towards the municipalities surrounding the capital became consolidated and from the 1980s the tertiary sector, providing services to production, grew significantly in contrasting with manufacturing activity itself. In the central zone, some companies from the graphic arts sector remained, as a result of the advantages of this location.

Figure 4 shows the distribution in the city of Madrid and its immediate surroundings of the 169 assets listed in the catalogue prepared by the authors [7,10]. It also shows the three case studies proposed for this work and superimposes the concentric zones identified in Figure 3 and the access routes into the city mentioned above. We can see that when the successive zones are shown on a map, the simplified and more or less circular geometry used in the schematic representation in Figure 3 is altered. Furthermore, it is apparent that this type of asset is isolated in many areas that were previously strongly industrialized but are now primarily residential.

As Figure 4 shows, the case studies selected are the Fábrica de Tipografías de Richard Gans, the Serrerías Belgas and the Nave de Boetticher y Navarro. The choice of these three examples is attractive for various reasons. On the one hand, these assets are in different locations within the concentric distribution mentioned above. The Fábrica de Tipografías de Richard Gans in the Chamberí district is representative of one of the traditional industries of the central ring, graphic arts. The Serrerías Belgas are on the boundary between the Arganzuela and Centro districts, in a strategic location next to the Atocha railway station. The Nave de Boetticher y Navarro is representative of the industry of one of the main later peripheral cores, in this case Villaverde. Furthermore, these three cases represent very different situations that make it possible to apply and test the methodology in very different contexts. The Fábrica de Tipografías de Richard Gans is in a state of neglect and is on a street with considerable commercial activity. The Serrerías Belgas have been reused for cultural purposes and are located on the city's main museum route, the Paseo del Prado. Additionally, the Nave de Boetticher y Navarro has also been reused as a center for technology and conventions and is intended to help revitalize its area. A brief description of the three industrial assets is provided below.
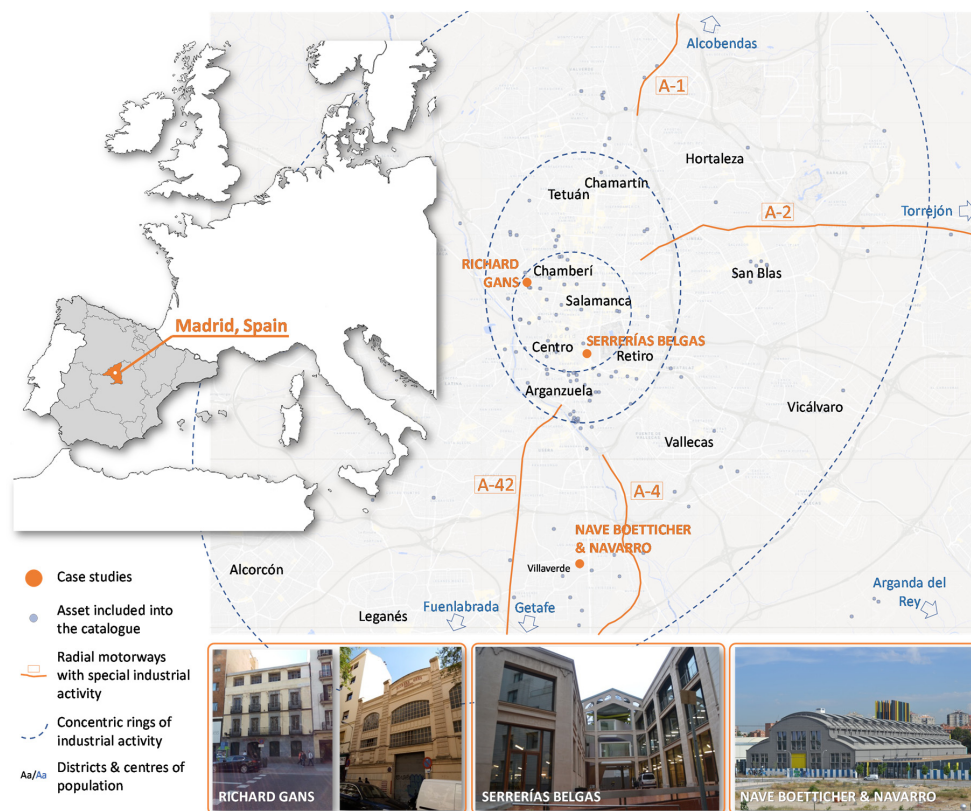
Figure 4. Locations of the proposed case studies referring to the areas identified in Figure 3.

The Nave de Boetticher y Navarro was built in 1949 in the Villaverde district in an area of intense industrial development principally driven by the railway. Its construction enabled the transfer of the facilities the company had used since 1915 from Madrid's calle Zurbano, in the context of the exodus of industries towards the exterior. In the setting, a neighborhood for the workers was built which is also conserved. The factory was renovated in 2006. It is currently called La Nave [41] and houses events and initiatives primarily intended for professionals from the technology sector.

The current building is the main section of a much larger complex that has not been conserved. It stands out for its imposing scale at 139 m in length and 43 m wide and for its design, which is reminiscent of the iconic AEG turbine factory in Berlin built between 1909 and 1910 by the architect Peter Behrens. The factory is built in three wings that recall those of a church. The central wing, with a vaulted roof, is 19 m wide and 16 m high, which along with its 139 m of length, create a continuous space on a monumental scale. The side wings are 7 m wide and 8 m high. Until 1984, the site was used as a foundry. Later, after being absorbed by Thyssen and until its closure in 1991, it was used for manufacturing equipment for use in buildings, primarily boilers and lifts.

For its part, the Serrerías Belgas building is located a few meters from the CaixaForum Madrid events center and next to the Paseo del Prado, a strategic position given the proximity of the old Atocha Station, which opened in 1851. The first installations in calle Alameda date back to 1840 and underwent various transformations over the years. The sawmill building that survives today is the work of the architect Álvarez Naya and dates from 1924–1925. The building is positioned on a 1861 m^2 plot, forming a U-shape with a gross floor area of 3513 m^2 and a reinforced concrete structure, a notable feature for the period, which permits large openings in the façade. It comprises two main structures parallel to each other, one facing onto calle Alameda which was used for workshops and wood cutting, and another facing onto calle Cenicero which was a store and was used for drying the wood. Between the two is a space forming a patio which was later covered with a lightweight roof

with a metal structure and ceramic tiles. The two parallel wings were initially connected by a porch to which two stories were later added, matching the height of the structure on calle Cenicero.

From the perspective of the production process, the most interesting element is the workshop building, where the machinery was located and which was the focus of production. In it, there was a small basement level where the airtight chambers for shavings and sawdust that can no longer be seen were located. Before it was redeveloped, the ground floor of the workshop contained all of the original machinery from its last period of use, machinery which was already in use in 1927 [42]. The workshop's upper floor was an almost completely open space that also included a modelling room, a storeroom and washrooms, and was connected to the ground floor by two large openings in the floor. The terrace above the porch under which carts passed connects this building to the stores and drying building, with an open floor plan and without walls separating it from the central patio. Activity ceased here in the 1970s and work to redevelop it as the Medialab–Prado headquarters [43] was completed in 2012, a role it still serves.

The Fábrica de Tipografías de Richard Gans [44] occupies two plots facing onto calle Princesa and Altamirano respectively, on the border between the Chamberí, Centro and Moncloa–Aravaca districts. The original building of the complex, which is located at calle Princesa number 63, dated to 1886 and was intended to house the company's growing activity and for exhibiting machinery. The section facing onto calle Princesa initially comprised a ground floor with two stories above it. Another storey was added at a later date. As well as production spaces, this structure contained the home of the Gans family, which, owing to the need for space for the installations, later moved to a new building opposite the factory on the other side of calle Princesa, on the site of the current number 66. Behind this section, there are bays parallel to the street.

In 1911, a new building was constructed on calle Altamirano on the site of the current number 3, designed by the architect Luis López López based on a plan by the German architect Karl Schweickart. The new building contained mechanical workshops and displays of machinery. The two buildings were linked by a patio at the back of the plot of the building on calle Princesa, which allowed access to the side of the new building on calle Altamirano. The new structure comprised a single, continuous, double-height space, with a continuous ground floor occupying all of the area and a second level which featured a perimeter balcony around a large central opening. The façade displays the supporting structure's configuration in the interior space. It comprises three sections with large glazed openings that are cut through showing the inner floor of the first story: the main one in the center, which corresponds to the double-height inner space and where the main entrance is, and two smaller side ones, which match the width of the perimeter balcony on the first story and the position of the structure of metal pillars that supports it. The lighting of the inner space is complemented from above by seven skylights over the central space. Both production buildings are currently in a state of neglect, and the building on calle Princesa has been partially demolished, while the family's home is used for commercial purposes.

The information in the catalogue developed [7] for each of the three assets selected as case studies is of great value for putting them in context within the sample using basic characteristics that serve to classify them. However, it is not sufficient for applying the criteria structures designed for assessing the heritage value of assets and for selecting the potential new uses for them that are most compatible with the values identified. Using these structures as tools to help with decision making requires a better knowledge of the sites analyzed so that well-founded evaluations can be made for the characteristics whose importance in the decision is articulated through the hierarchized structures.

To do this, data sheets are prepared for each case to help document the assets analyzed. Figure 5 illustrates this situation. So, for each element there is prior information provided by the catalogue, however, searching for and gathering other types of information is also required. Firstly, images showing the original functioning of the installations and also their condition prior to any reuse adaptations that might have occurred. Secondly, images of the current exterior and interior condition, taken during visits to the industrial asset in order to prepare this documentation and with the aim of applying the

criteria structures to the study of the element. Thirdly, plans of the asset analyzed are drawn up to evaluate the spaces that comprise it and their possibilities for new uses and to localize the elements identified as being of the greatest cultural interest. Finally, a map of the analyzed asset's surroundings is prepared, covering a circular area with a diameter of one kilometre around the asset being studied and showing the current situation regarding the presence or absence of the uses considered as options. This information will be fundamental for identifying whether or not there are needs for provision of services that necessitate a particular use, as well as for evaluating the presence of activities that can build synergies with some of them. The information created will support the application of the criteria structures in the study of the assets analyzed.
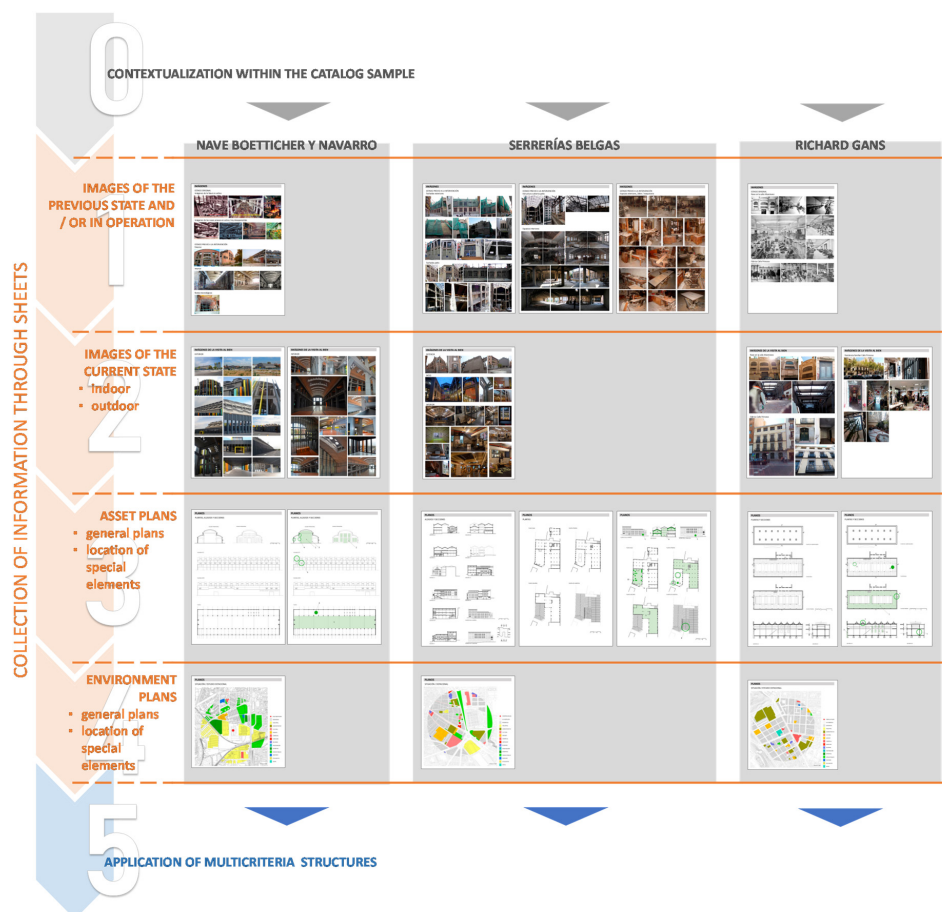

Figure 5. Preparation of graphic datasheets for documenting each element prior to applying the criteria structures.

3. Application to Case Studies

The functioning of the criteria structures that comprise the proposed methodology is not the object of this work and is set out sufficiently in other previously published works by these authors [19]. Therefore, this work does not aim to explain or set out the choice of the criteria in the structures of the methodology nor the hierarchy established among them. However, this work does set out to validate the application of the methodology by using it in practical cases. In this context and in view of its use as a working tool, it is of great interest to set out some complementary considerations and criteria to consider when using it. Accordingly, some of the guidelines developed for the methodology for the appropriate implementation and use of the criteria structures designed when applied to the study of specific industrial assets are discussed as examples.

Subsequently, for each asset selected as a case study, the values entered in the criteria structures are explained. It is important to note that the analysis of each asset takes into consideration the situation

before reuse of two of the selected assets. This is because the aim of the analysis is to evaluate the tool's ability to provide support for this type of initiative. So, in the cases that have been adapted for reuse for new activities, the selection proposed by the methodology can be compared to what actually happened in practice. This focus is valuable because it presents the methodology as a diagnostic tool both for future adaptations of abandoned assets such as the Fábrica de Tipografías de Richard Gans, and also looking to the past to evaluate the appropriateness of the use made of assets that have already been adapted, such as the Serrerías Belgas or La Nave.

3.1. Complementary Guidelines for the Application of the Methodology in the Study of Specific Assets

As Figure 2 shows, the criteria structures designed include the introduction of evaluations for the characteristics located in their final level. This evaluation may require complementary guidance. Various situations of this type can be identified when analyzing the importance for each use of the criteria or characteristics from the last level of the second criteria structure, in other words, how much each one contributes to the land or building's capacity to house a given activity.

Sporting uses, in the case of games played on courts and other areas that have requirements for surface area and unrestricted headroom that must be fulfilled, are a good example. In these cases, the dimensions and the absence of obstacles are characteristics that must be clearly prioritized, as they are not just desirable but vital. However, sports courts come in very different sizes and the spaces in the assets analyzed might be appropriate for some but not others. It is therefore necessary to develop complementary criteria and guidance to evaluate the extent to which the spaces in an analyzed asset offer opportunities for sporting use.

With this in mind, the reference that must be used in Spain, where the case studies are located, is the Normativa sobre Instalaciones Deportivas y para el Esparcimiento (Sports and Recreation Facilities Regulations) [45], frequently referred to as the NIDE regulations. The regulated playing areas for different sports means it is necessary to identify clearly the minimum requirements a space must fulfil if it is to be able to house these activities. Various analyses are performed on the basis of the information contained in these regulations. Figure 6 shows the categories or groups of sport courts and their variants. In the case of athletics tracks, only the largest of them is shown, which generally contains other sporting activities in the free central space. Of the groups covered by the regulations, large pitches and athletics tracks are rejected given their size which make it impossible to fit them in the spaces of the assets being studied. In the category of ice sports, long-track speed skating tracks (PVH-PL) are rejected for the same reason. Other sport courts are considered, taking their space and unimpeded headroom requirements into account.

Figure 6. Categories and sport courts considered in the Normativa sobre Instalaciones Deportivas y para el Esparcimiento (NIDE) regulations.

Figure 6 shows the different free area requirements of each playing area according to the dimensions specified in the NIDE regulations. In some cases, these dimensions are flexible, allowing different dimensions depending on whether they are intended for use by amateurs or professionals, for example. In the study performed here, the maximum dimensions or where applicable those advised by the regulations for official competitions were taken as the reference, in all cases including the exterior perimeter indicated in the regulations. The larger end of the areas needed is considered, not to prioritise professional use but because no space is anticipated for stands or spectators in the regulations, and so having some degree of leeway is preferable. Figure 7 shows the sport courts grouped within three ranges of dimensions.

Figure 7. Study of the special height needs of sport courts according to the NIDE regulations.

The free headroom different playing areas require for performing adequately the activity they provide for is also considered. Figure 8 studies the free headroom necessary in each case. Three height ranges are considered: up to 5 m, up to 10 m and up to 15 m. The range each sports field falls into according to the requirements set out in the NIDE regulations can then be seen.
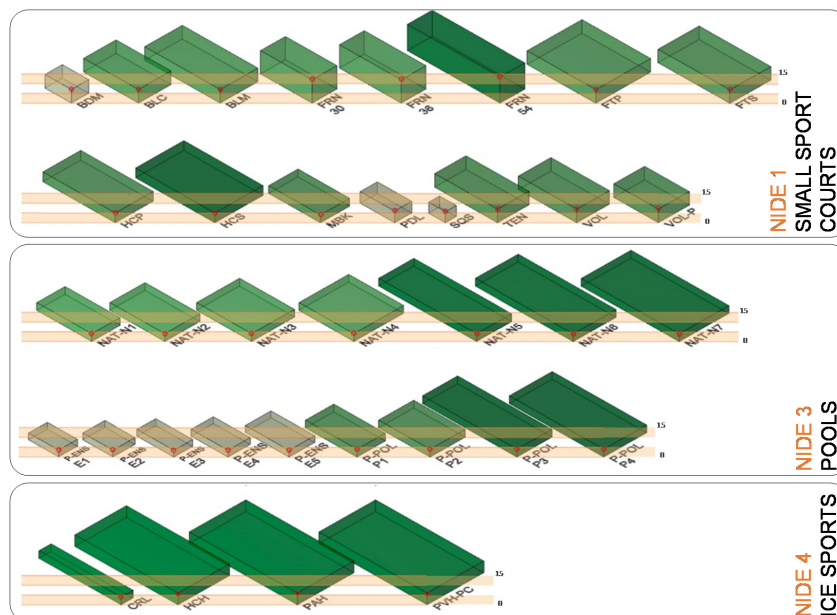

Figure 8. Study of the special height needs of sports fields according to the NIDE regulations.

The two analyses of area and height requirements performed show that there is no direct relationship between area and height requirements. For example, with an area of 300 m^2 a short pelota court (FRN 30), which is in the intermediate group, requires a smaller area than a basketball court but requires a minimum height of 13 m, which places it in the group with the greatest requirement. Meanwhile, a 50 m by 25 m swimming pool (NAT-N7), which, including the walkways around its perimeter, requires 1653 m^2 and is in the group with the greatest area requirements, only requires a height of 4 m, less than the limit of 5 established for the group with the lowest height requirements. Therefore, there is no relationship between the demands for the two requirements. Nonetheless, when evaluating whether a structure can be repurposed for sporting uses, it is necessary to have general references about its ability to house particular dimensional groups. Therefore, how each category fits into one of the ranges defined for height and area is identified. Figure 9 shows the surface area, height and volume requirements for each sports field considered, and determines which range or demand group it belongs to in each case.

NIDE Group	Code	Sport			PLAYING FIELD maximum or recommended dimensions			TOTAL (playing field + free space)			Area Group			CLEARANCE HEIGHT (m)		Height Group			VOLUME	
				LENGTH (m)	WIDTH (m)	AREA (m²)	LENGTH (m)	WIDTH (m)	AREA (m²)	L	M	H	MIN (m)	RECOMM (m)	L	M	H	MIN (m³)	MAX (m³)
NIDE1. FIELDS	BDM	BADMINTON		13,4	6,1	81,74	15,4	10,1	155,54				7	12				1088,8	1866,5
	BLC	BASKETBALL		28	15	420	32	19	608				7	-				4256	-
	BLM	HANDBALL		40	20	800	44	22	968				7	10				6776	9680
	FRN	SHORT FRONTON 30		30	10	300	30	14,5	435				12	13				5220	5655
		SHORT FRONTON 36		36	10	360	36	14,5	522				12	13				6264	6786
		LONG FRONTON 54		54	10	540	54	14,5	783				13,5	13,5				10571	10571
	FTP	BEACH FOOTBALL		36	28	1008	40	32	1280				7	-				8960	-
	FTS	INDOOR FOOTBALL		40	20	800	42	24	1008				7	10				7056	10080
	HCP	INLINE HOCKEY		40	20	800	42	22	924				5	7				4620	6468
	HCS	INDOOR HOCKEY		44	22	968	46	28	1288				5	7				6440	9016
	MBK	MINIBASKET		28	15	420	30	17	510				4	7				2040	3570
	PDL	PADDLE		20	10	200	-	-	-				6	-				1200	-
	SQS	SQUASH		9,75	6,4	62,4	-	-	-				5,64	-				351,94	-
	TEN	TENNIS		23,77	10,97	260,7569	36,57	18,29	668,8653				7	9				4682,1	6019,8
	VOL	VOLLEYBALL		18	9	162	34	19	646				7	12,5				4522	8075
	VOL-P	BEACH VOLLEYBALL		16	8	128	26	18	468				7	12,5				3276	5850
NIDE 2. BIG FIELDS	FUT	FOOTBALL		105	68	7140	120	80	9600				15	-				144000	-
	FUT-7	FOOBALL 7		65	45	2925	68	50	3400				15	-				51000	-
	HCH	FIELD HOCKEY		91,4	55	5027	99,4	65	6461				5	7				32305	45227
	RUG	RUGBY		144	70	10080	154	80	12320				15	-				184800	-
NIDE 2. ATHLETICS		Different disciplines. Running track used as reference		176,91	92,52	16367,7132	179,91	95,52	17185,003				4	12				68740	206220
POOLS	NAT	SWIMMING	N1	25	12,5	312,5	32	16,5	528				4	-				2112	-
			N2	25	16,5	412,5	32	20,5	656				4	-				2624	-
			N3	25	21	525	32	25	800				4	-				3200	-
			N4	25	25	625	32	29	928				4	-				3712	-
			N5	50	16,5	825	57	20,5	1168,5				4	-				4674	-
			N6	50	21	1050	57	25	1425				4	-				5700	-
			N7	50	25	1250	57	29	1653				4	-				6612	-
	NAT-SIN	SYNCHRONIZED SWIMMING		In pools that meet competition requirements in each case															
	P-CHAP	SPLASH POOL		Entre 50 m² y 250 m² con formas libres															
	P-ENS	LEARNING POOL	E1	12,5	6	75	17,5	11	192,5				3,5	-				673,75	-
			E2	12,5	8	100	17,5	13	227,5				3,5	-				796,25	-
			E3	16,5	6	99	21,5	11	236,5				3,5	-				827,75	-
			E4	16,5	8	132	21,5	13	279,5				3,5	-				978,25	-
			E5	20	10	200	25,5	15	382,5				3,5	-				1338,8	-
	P-POL	MULTI-PURPOSE POOL	P1	25	12,5	312,5	30	16,5	495				4	-				1980	-
			P2	25	16,5	412,5	30	20,5	615				4	-				2460	-
			P3	50	16,5	825	55	20,5	1127,5				4	-				4510	-
			P4	50	21	1050	55	25	1375				4	-				5500	-
	P-REC	RECREATIONAL POOL		More than 200 m²															
	SAL	TRAMPOLINE DIVING		Sizing of platforms, not of vessels															
	WAP	WATERPOLO		In pools that meet competition requirements in each case															
ICE	CRL	CURLING		45,72	5	228,6	47,72	7	334,04				4	-				1336,2	-
	HCH	ICE HOCKEY		60	30	1800	-	-	-				6	-				10800	-
	PAH	FIGURE SKATING ON ICE		60	30	1800	63	33	2079				6	-				12474	-
	PVH-pc	SPEED SKATING ON ICE IN STOL		60	30	1800	63	33	2079				6	-				12474	-
	PVH-pl	SPEED SKATING ON ICE IN LONG TRACK		179,57	66	11851,62	182,57	69	12597,33				6	-				75584	-

Figure 9. Area and height requirements for each category and identification of the range for each case.

Based on this information, sports fields can be classified according to their area and height needs at the same time. Figure 10 shows the resulting classification. This study is very interesting as it provides an initial reference point against which to evaluate a site's suitability as a sports venue. Consequently, it is possible to establish an initial reference point for the dimensions required for this use when introducing evaluations in the methodology's criteria structure. Figure 10 includes a potential association of these groups to values on the scale of 1 to 9 proposed by Saaty [23]. The proposed matrix classification, based on the area and height requirements of each one of the analyzed sports courts, allows one to establish nine categories or groups whose spatial characteristics would allow the practice of different sports. Some of these sport activities have fewer special demands, but others require spaces with unusual characteristics. As a general criterion, it can be said that positions within the matrix towards the upper right corner represent spaces capable of hosting a greater range of sport activities because they have spaces of special amplitude and are free of obstacles. Thus, these situations should receive high scores when the spaces of a certain asset are valued.
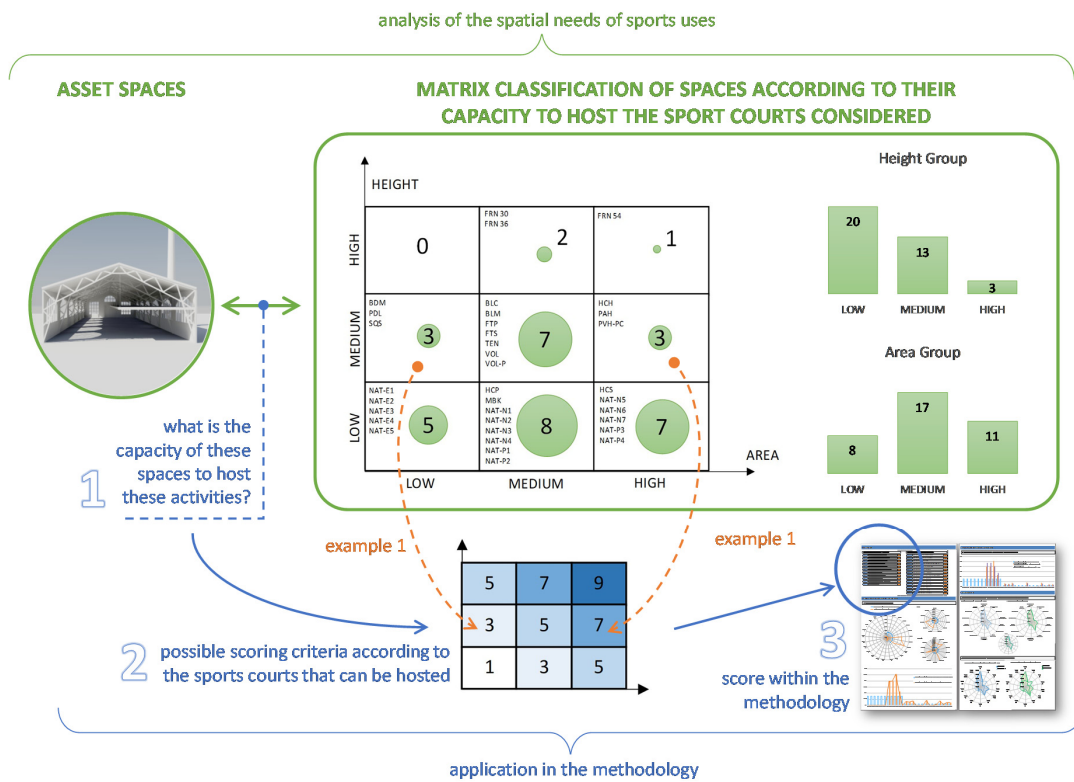
Figure 10. Classification of sports fields by their area and free headroom requirements and guidelines for evaluating them.

3.2. Application of the Methodology to the Boetticher Factory

Special importance of the group of values associated with the functional singularity of the building is noted. These are the characteristics of its design that make it possible to appreciate its special connection to the productive process it housed and for which it was designed. This situation is shown in the first two graphs, which relate to the analysis of weights and which are at the top of the data sheet shown in Figure 11. The next prominent group is the one relating to the historical values of the building. Next, are the values associated with the singularity of the building's construction and with the singularity of its manufacturing process. In the case of the analysis of its technological singularity, no value is identified in the asset, as it has been virtually stripped of content of this type.
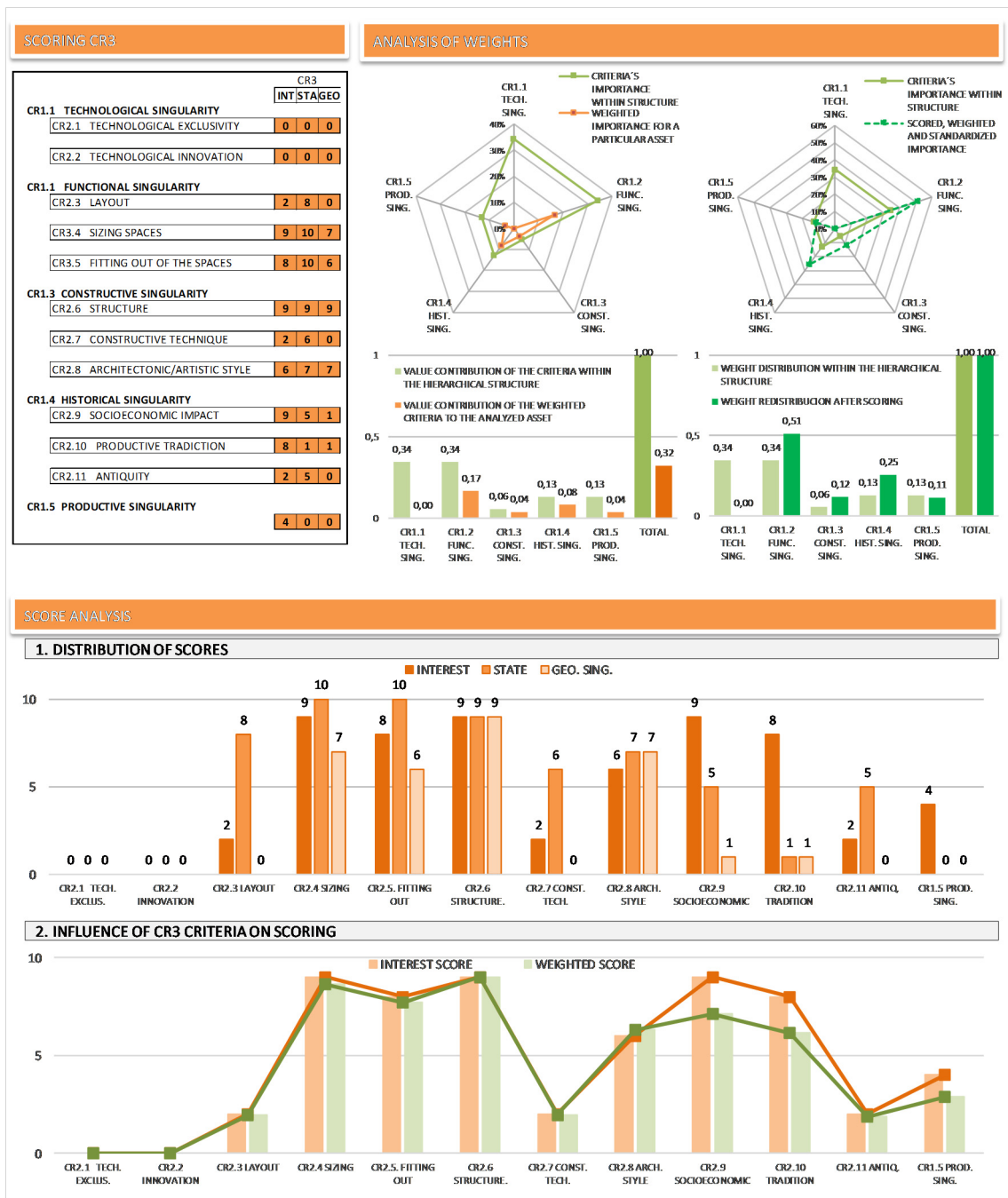
Figure 11. Heritage evaluation data sheet for the Nave Boetticher y Navarro.

The graphs in the lower part of the sheet show the scores given for each CR2 criterion, which is the denomination used for the criteria located at the scoring level of the structure, and their influence on the evaluation of the asset. The first graph, featuring the distribution of scores, shows the evaluation of each criterion from the three focuses considered: interest, current conditions and geographical singularity. As noted above, the machinery has been removed, with just one furnace being conserved, and while this is of interest, it is not enough to reflect the original activity and its complexity.

As noted above, the functional aspects are of most interest, with the exception of the layout, as the factory has a single, continuous main space which does not contribute value to this criterion. If the attached wings had been conserved and the asset could be understood as a whole, this aspect might have scored more highly. The size of the space, its lighting and its structure are characteristics that

are considered to be of value and which are also conserved in good condition. The existence of assets that are similar in these aspects in the nearby area, such as the TAFESA railway workshops, reduce its current geographical singularity with regards to these characteristics, which are of value with regards to the structural system used.

The criteria relating to historical singularity are assessed as being of interest. Firstly, owing to the influence on its surroundings of this asset's original activity, with other production facilities associated with it, the construction of a workers' colony for its employees and examples of social development based around its activity, such as the sports facilities of the workers' football team. Of these elements, the colony of Nuestra Señora de la Paz, the sports facilities and the installations of the same company's lift factory have been conserved. This is not the case with the buildings attached to the asset analyzed, which have been removed, preventing it from being interpreted as a whole. The asset's age does not score highly as it results from the industrial development of Villaverde in the 1940s, making it a recent element.

The graph referring to the different criteria in the heritage evaluation shows that its historical interest, represented by the two CR2 criteria relating to this, is reduced as a consequence of the loss of some of the elements that allow a contextual reading of the asset and also because of the existence of similar situations in its setting, with other industries being equally important in Villaverde's industrial and urban development. For its part, the evaluation of the functional singularity of this asset shows that its interest is scarcely reduced, primarily owing to the good state of conservation of the characteristics of the asset related to this singularity.

The multicriteria methodology has generated the two sheets of results shown in Figure 12 based on the scores for the scoring criteria of the second criteria structure, known as CR5, relating to the morphological characteristics that can be appreciated in the site and the density of services in its setting. The redistribution of the weightings of the CR5 criteria after scoring them identifies the existence of very large and tall open spaces, links to other elements in the setting, the existence of outdoors spaces and good natural lighting as the asset's principal characteristics. As for public services in the asset's setting, the low presence of social, cultural and health services is noteworthy. In addition, there is a high density of industrial activity in the area. This reflects the current situation of a traditionally industrial area where manufacturing installations have gradually been replaced by residential areas. So, the coexistence of industrial spaces, primarily from the second half of the twentieth century, and residential spaces that have mainly been constructed recently is now apparent. As a result, the new urban fabric still lacks some service infrastructure, while the industrial activity, albeit in clear decline, is still of considerable importance.
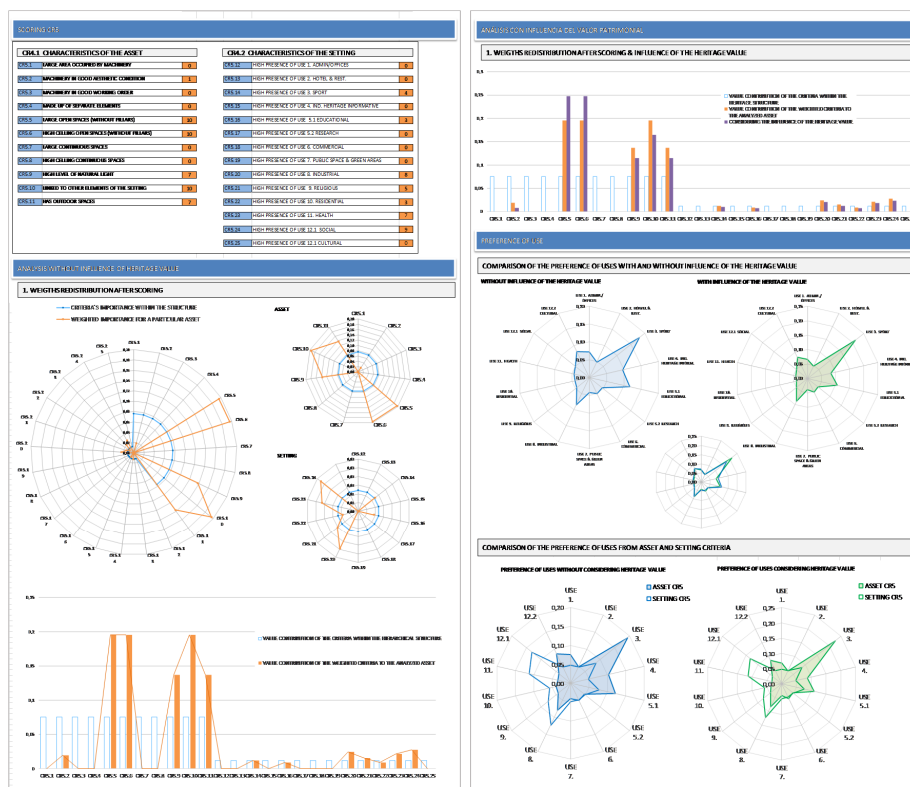
Figure 12. Data sheets identifying the most suitable uses for the Boetticher y Navarro factory.

The link between the morphological characteristics identified and aspects of value redistributes the weightings of the CR5 criteria in the structure [10,19]. The first graph from the second use evaluation sheet, shown in Figure 12, shows how the influence of the identified heritage value increases the importance of the continuity of the factory's main space in both height and area as the principal characteristic to be protected. Although they maintain a clear importance, the weightings for environmental condition, exterior spaces and connection to elements in the setting are reduced somewhat when the associated heritage values are incorporated into the analysis.

3.3. Application of the Methodology to the Serrerías Belgas

Figure 13 shows the scores given to this asset for the heritage criteria. It also shows graphs with the results provided by the methodology. The characteristics that stand out as the aspects with the greatest heritage value are those belonging to the functional singularity group, followed by the technological singularity and productive singularity. In the first case, this is because of the capacity for interpretation of the stages of the production process that the installations allowed before the intervention, thanks to the strong link then existing between the activities these spaces housed and their organization, size and environmental condition. The parts of the complex, the function of each of them and their relationships within the production process can be identified clearly. The conservation of the workshop space stands out with all of the machinery in its original locations. The size and condition of each space are clearly differentiated according to its particular requirements. The double height connections between the workshop, the open storerooms for drying the timber and the covered patio are singular examples. The ability to read the layout at the level of the site as a whole and within the workshop as a main production space mean the maximum score is given for geographical singularity.
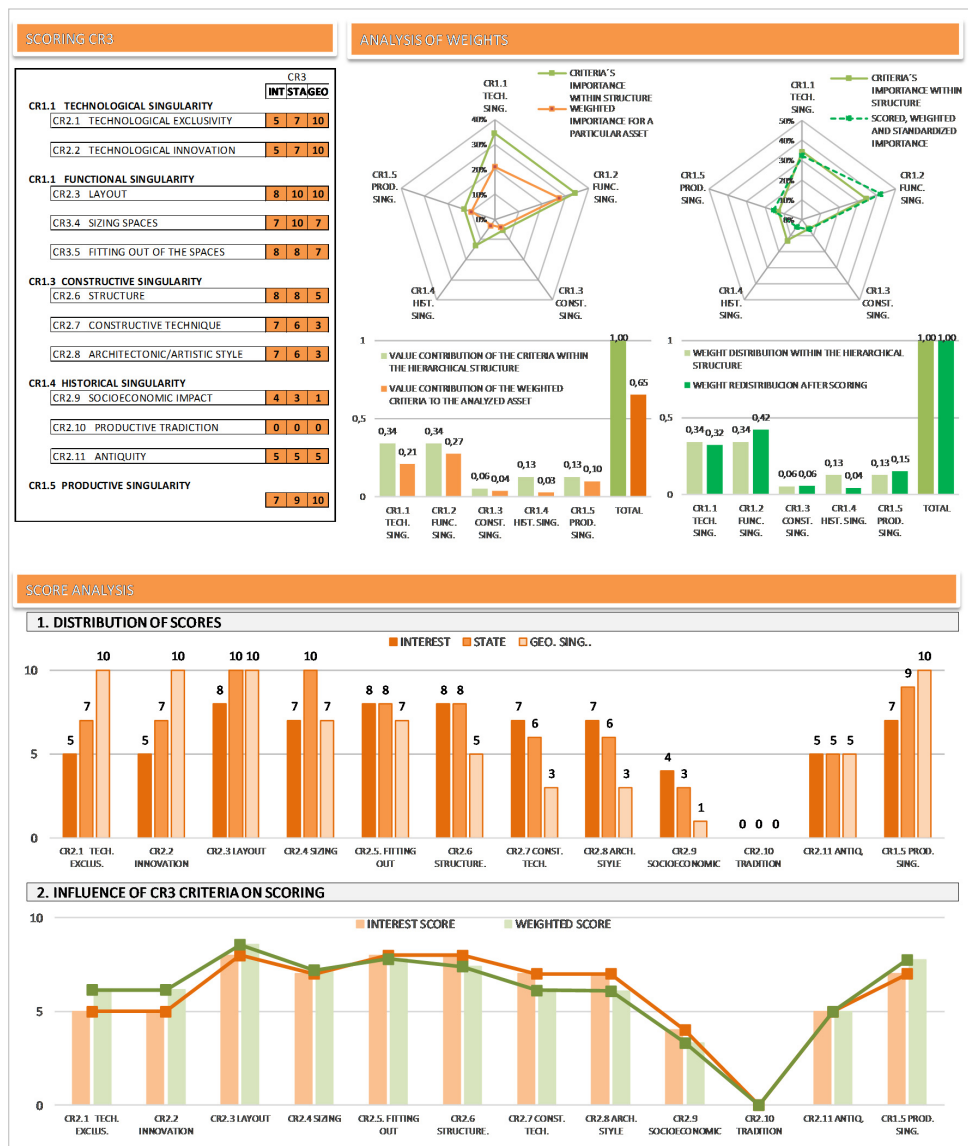
Figure 13. Heritage valuation data sheet for the Serrerías Belgas.

Its technological singularity is also noteworthy. The conserved machinery is not an example of exclusive or innovative technology, but rather commonplace equipment. Therefore, it does not score particularly highly in this regard, with five points. However, as stated in the preliminary studies performed before the site's adaptation for reuse [42], as a whole they represent a complete workshop with all of its equipment and drive system, as well as abundant tools and equipment. Consequently, it is an example of a workshop from the start of the twentieth century that has survived in its entirety to the present day, something almost miraculous and which gives it great value and interest. Therefore, it gets the maximum scores for geographical exclusivity.

It also scores highly for structural singularity. The open reinforced concrete structure—innovative in its period and of an attractive design—and the metal roof over the patio are regarded as valuable and well-conserved elements. The construction technique and architectural style also score highly. Although this group's weighting is not prioritized in the methodology, this interest is reflected in the proposed data sheets.

The production singularity, as this is an industry with few urban examples, particularly ones of this magnitude, also scores well. The relationship with other elements in its setting, although it did once exist, did not score any points as it has not been conserved.

The first of the data sheets in Figure 14 shows the scores given to the morphological characteristics of the structure and to the services in its setting, all considered in the CR5 criteria. The scores reflect the presence of an area occupied by machinery. This presence is significant in both occupation and in interest in the workshop, but is non-existent in other elements of the complex, such as those used for storage, and so the score is moderate as there are spaces representing both situations. The state of conservation of the equipment is good with regards to its capacity for reuse as items that can be reused for display. Returning it to operation is possible but more difficult, and so it scores noticeably lower and would require a study that is now impossible, as the machinery was removed during the adaptations for reuse.
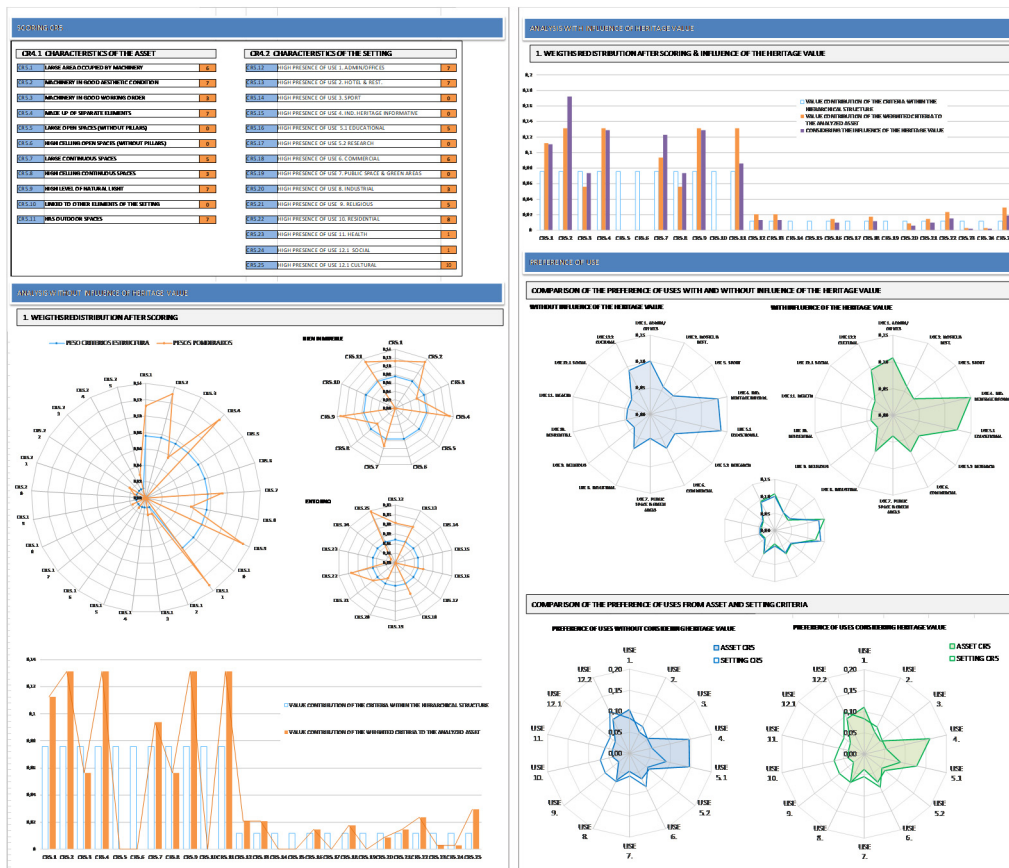
Figure 14. Data sheets identifying the most appropriate uses for the Serrerías Belgas.

On the other hand, the scores reflect the fact that the asset comprises several independent elements and the existence of external spaces that link them. The good natural lighting of all of the spaces is also noteworthy.

The scores relating to the setting identify the area's large cultural offer, which was also identified in the study relating to existing activities that were performed. Similarly, a high density of commercial and hospitality services is identified, principally associated with the streets noted in the study mentioned above relating to the asset's surroundings. Administrative and residential use also have a major presence. These aspects might suggest synergies faced with the selection of new activities.

3.4. Application of the Methodology to the Fábrica de Tipografías de Richard Gans

Figure 15 shows the data sheet created by the methodology relating to the heritage evaluation. As in the case of the Nave Boetticher, it can be seen that the asset has been stripped of technological singularity. This is because the original machinery used here has been removed. If it were still present, it would be of considerable value. The asset's functional singularity is of some value. Neither the

layout, the size of the space, nor its condition is especially distinctive, and so although they have some weight in the hierarchized structure, they do not contribute much value. Nonetheless, the size of the double height space and its configuration are of interest as examples of this type of production facility at the start of the twentieth century.
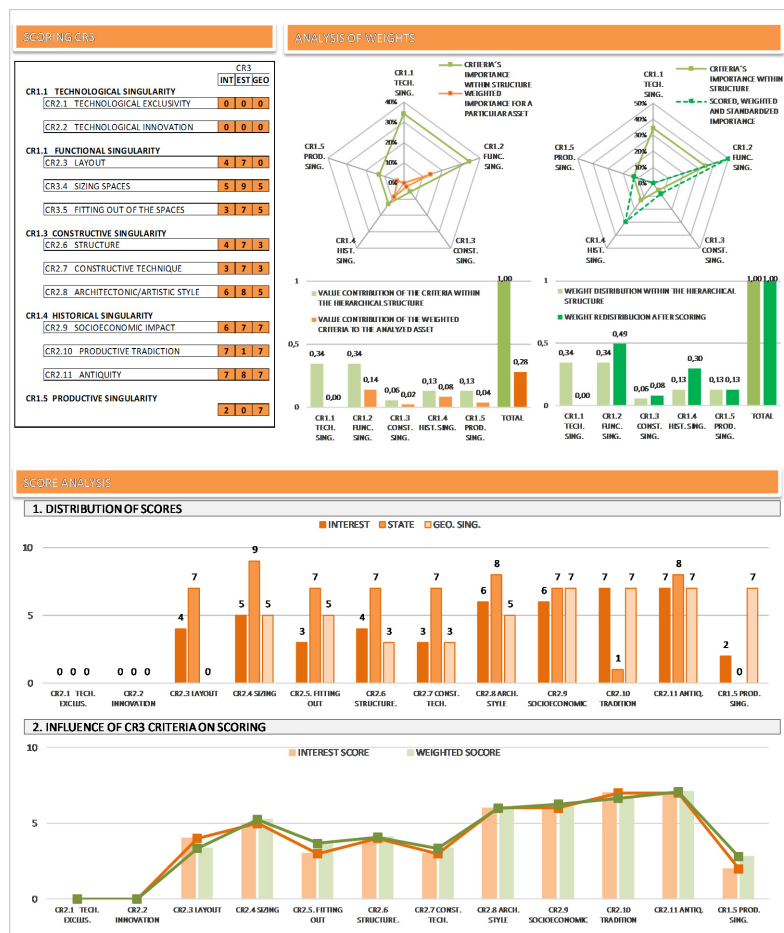

Figure 15. Heritage evaluation sheet for the Fábrica de Tipografías de Richard Gans.

In terms of its construction, it is also not a particularly singular asset, although this is still of interest, especially thanks to the good state of conservation of all of its parts; the metal structure, façade, skylights, etc. The interior metal structure and its connection to the aerial drive system are noteworthy, although the rest of the supporting system is conventional, comprising outer load-bearing walls. The composition of the façade is of interest, and it is very well conserved.

Historical singularity is an aspect of this asset that scores highly. Its relationship with other elements, such as the still existent adjoining installations and the home of the Gans family contribute to this. Furthermore, graphic arts are an activity with a long tradition and presence in the centre of the city, and this asset is a valuable example of them from the early years of the twentieth century, although the elements that illustrate the process, mainly the machinery, have not been conserved. Furthermore, it is located in an area of the city which has been strongly affected by loss of industry. The scores make it possible to see the interest of these aspects compared with the other ones, aside from the hierarchization associated with the focus of the work.

The scores given to the characteristics of the building that are studied, which are shown on the first data sheet in Figure 16, reflect the loss of its technological aspects, as the large amount of machinery that used to occupy the space has not been conserved. Although some isolated remains were identified in the previous studies, for example from the aerial system, these are not sufficient to justify being given

a score. Clearly, they must be identified, as has been done, and conserved, but they are not sufficient to be marked as characteristics that would restrict uses, as their isolated nature means conserving them would not be problematic in any case.
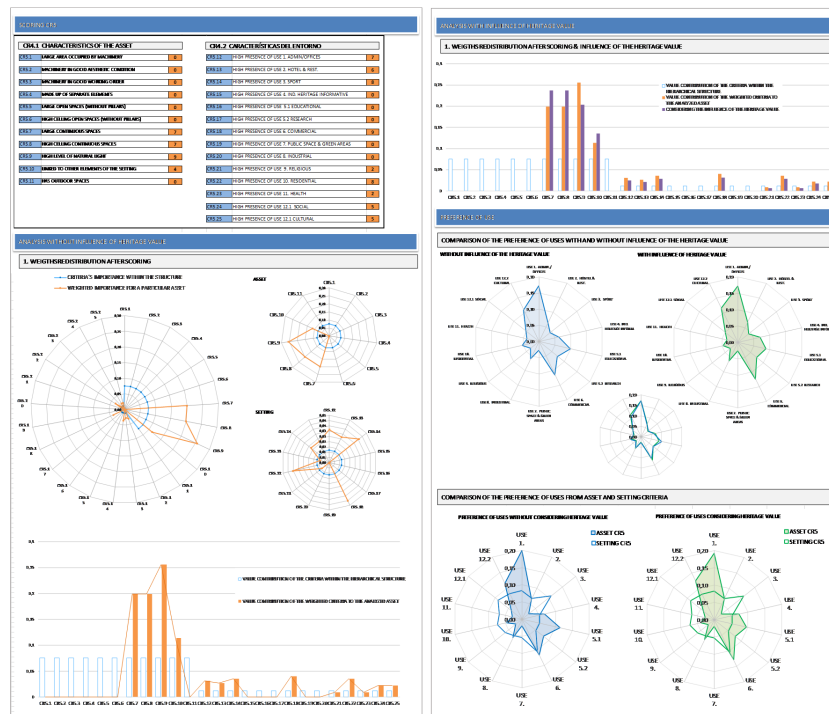

Figure 16. Data sheet of the most suitable uses for the Richard Gans type factory.

For its part, the continuous nature of the space and how it expands over double height are reflected, as is the level of natural lighting provided by the openings in the façade and the skylights providing light from above. Commercial activity, administrative and residential uses and a lack of sports facilities stand out in its setting.

When considering heritage value, the continuity of the space and its height are given weight in the hierarchical structure, helping to prioritize the uses that these characteristics enable. This is also done by the relationship with the elements from the setting with which the asset is associated, while lighting loses weight as it is linked to elements with little heritage value, such as the skylights, which do not score highly in the structural singularity. Accordingly, some modification would be permitted if required, although they maintain weight in the criteria structure and so this would have to be performed in a controlled way.

4. Results and Discussion

The data sheets generated by the methodology for each case study provide considerable information, which is presented graphically for ease of interpretation. As stated above, the proposed methodology is made up of partial methodologies which can act independently and provide their own results [19]. However, when using the overall methodology, the fundamental result obtained is the prioritization of uses, specifically identifying those that are most compatible with the heritage characteristics identified. Therefore, this section sets out the uses identified by the methodology in each case study, which are included in the "preference of uses" section of the data sheets shown in Figures 12, 14 and 16.

As a summary, Figure 17 shows these graphs of special interest for each of the case studies. In the upper part of the figure, the graphs which represent the preference of uses, both considering and without considering the heritage values, are shown superimposed. In this way, it can be seen how

considering the heritage values in the final decision effectively modifies the preference of uses obtained when only the compatibility of the new activity with the morphological characteristics of each asset is considered. Thus, some alternatives increase their preference, since they do not affect to these heritage values, while others decrease their preference due to the effects that these activities could have on the conservation of those characteristics. This represents the main result of the methodology developed and the information that should most affect the final decision, contributing to the protection of these values.
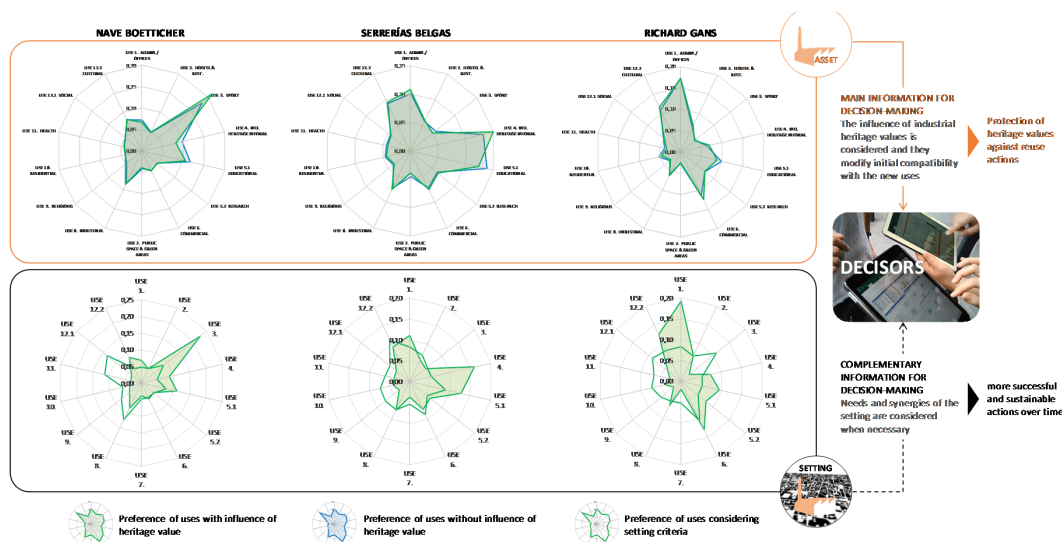
Figure 17. Main results shown in the data sheets generated and contribution to decision-making.

On the other hand, in the lower part of the figure, the preference of uses obtained from the analyses of the characteristics of the assets, and considering the heritage values, is shown superimposed with the preference of uses obtained when considering the criteria related to the setting of each asset. Since the main objective of the methodology is to protect the heritage values of industrial nature when reuse actions are promoted, the decision must take into account mainly the first analysis. However, when two or more uses have similar preferences in the previous analyses, considering the needs and synergies of the setting can contribute to selecting the most demanded and sustainable uses over time.

4.1. Evaluation of Possible New Uses for the Nave Boetticher

The first group of graphs showing preference of uses compares the prioritization of new activities when the influence of the heritage value is included and is not included. The graph that superimposes both results shows that sporting uses' strong requirements for the characteristics of the asset that are of the greatest heritage value, namely its spatial continuity in area and height, further increase the previously identified compatibility with this use, which in the direct analysis of compatibility was already high.

The last two graphs separately compare the preferences for use based on the building and its settings, in each case considering both the direct reading and the reading including the influence of the heritage value. The setting's demand is not applicable in this case, as it will be used in cases where the preferences indicated for the building are unclear, to make the final decision. Protecting the principal aspects of value clearly identifies sporting use as the most suitable use, and so this influence does not have any consequences for selecting the new use, but it is of interest when observing the real need for this function in the setting. In this sense, there is some degree of demand for sporting use, albeit below others such as health and social uses, and so it is not regarded as a bad option. Although there are sporting facilities in the area, only one, located outside of the zone of the study relating to its surroundings although close to it, is covered, and it has a low capacity.

4.2. Evaluation of Potential New Uses for Serrerías Belgas

The influence of the heritage value when included in the study is shown in the first graph on the second page of results. The scores redistribute the weightings of the CR5 criteria, both for the asset and for its setting. The increased weight of the aspects relating to the conserved machinery can be seen, which means they require more protection by selecting uses that are compatible with them. Similarly, the continuity of the spaces and the vertical connection between some of them, specifically in the workshop area, also increase their weightings, favoring uses that make it possible to conserve these characteristics. As heritage value has been identified in the asset's characteristics, the setting's influence on the selection of uses is reduced.

In view of all of this, the prioritization of uses identifies providing information about industrial heritage as the most interesting use, a direct result of the presence of the conserved machinery and of the clear functionality displayed by the design of the complex as housing a production process. Teaching, administrative and cultural uses are the next activities identified as appropriate. Activities which are indeed present in the reuse action actually performed in the asset. Consequently, as has been noted, this action is generally rated as being respectful and successful. Nonetheless, the removal of the patio's metal roof and, in particular, the loss of the machinery from the workshop, are regarded as poor decisions.

The conservation of the workshop space, specifically its ground floor where most of the machinery was located and its layout was visible, is regarded as being perfectly compatible with the asset's current use and would involve the coexistence of another use–providing information about the original productive activity—which in this case is regarded as fundamental. The token conservation of the two saws is insufficient. Dedicating the workshop space to this informative use would have been perfectly possible given its area in comparison with the area of the asset as a whole and its independence from the rest. Especially in view of its current function, as a multipurpose and exhibition space.

For their part, the criteria relating to the setting support the cultural function, owing to the density of provision of this type in the area. An informative complement relating to the industrial use as part of the asset's cultural offer is again classed as being of interest for the new activity. Similarly, the area's large footfall of people interested in cultural leisure is evaluated as an opportunity to introduce an element of information about industrial heritage values in the city's principal museum circuit. This opportunity was largely lost when the machinery was removed, ruling out an informative use.

4.3. Evaluation of Potential New Uses for the Fábrica de Tipografías de Richard Gans

The prioritization of new uses identifies administrative and commercial use as the principal options along with cultural use. All three respond to typologies that evaluate the characteristics of this asset. So, professional offices and medium-sized business places would easily fit in with this building's open spaces and its good lighting. Cultural exhibition spaces would also be a very appropriate use. Use as commercial premises for clothing and fashion, in accordance with the clearly dominant activity in the area, is another activity that is perfectly compatible with the characteristics identified in the asset.

In this way, observing the preference of uses from the criteria of the setting could be of interest as a complement to the decision. Accordingly, when observing independently the prioritization of activities from the criteria associated with the building and its setting, the greater preference for two uses from the focus of the activities and services present in the asset's surroundings can be observed. The first one is sporting uses and is associated with a lack of this type of services. This asset could only house categories such as gymnasiums as it has a continuous but not unobstructed space and it does not have sufficient area or free headroom for sports played on courts. The second use identified by the criteria of the setting is commercial, in line with the significant activity of this type in the area. Accordingly, adaptation as commercial premises relating to clothing and fashion could be an interesting use, as the adaptation work would be minimal and reversible, and would mainly centre on decorative aspects that cause little harm.

5. Final Comments and Conclusions

Applying the multicriteria tool developed to the three proposed case studies provides results that authors regard as solid, interesting and useful, both for studying built industrial heritage and for supporting decision making in future projects to reuse this type of asset as part of sustainable urban development strategies. The functioning of the two criteria structures and the mechanism connecting them are shown to be sound. The hierarchization of criteria in each of the structures seems to be equally appropriate in view of the results obtained for the proposed cases, although, in any case, the authors understand that establishing preferences between criteria from the different levels should be under constant vigilance in each new case study developed, in order to refine and improve the tool. The results presented in this work show the potential of the tool developed, both with its current criteria structure and for future studies that require the incorporation of new analysis criteria.

Beyond the two criteria structures, the need to set guidelines for interpretation and application for some of the criteria or characteristics considered is an interesting contribution by this work. The complexity of applying multicriteria techniques to decision making means that works considering this type of approach increasingly set out the criteria considered, their hierarchies and the general functioning of the criteria structure. However, at the same time they often omit the complementary guidelines that are necessary if they are to be applied successfully. Accordingly, doubts about how to put what has been proposed into practice arise. This work exemplifies this type of situation and throws light on the matter for other future developments in the field of multicriteria decisions.

Finally, the validation of the proposed methodology as a tool makes it possible to open up two lines of work in which the authors are already making progress. On the one hand, there is its implementation as a teaching resource in specialized education in industrial heritage provided by the Universidad Nacional de Educación a Distancia (UNED). Whilst on the other, there is the focus on its mass application for the integrated management of groups of assets within a single territory.

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