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An Evaluation Tool for Physical Accessibility of Cultural Heritage Buildings

José Marín-Nicolás and Mª Paz Sáez-Pérez *

Department of Architectural Constructions, Advanced Technical School of Building Engineering, Fuentenueva Campus, Universidad de Granada, 18071 Granada, Spain
* Correspondence: mpsaez@ugr.es

Abstract: Persons with disabilities (PWD) account for 10–15% of the world's population. The lack of accessibility in the built environment imposes a constraint on its use by these individuals. In heritage buildings, this restriction includes access to other main qualities in addition to use. This problematic issue has been dealt with in different sectors, especially in the tourism sector. The objective of this study is to design and implement a physical accessibility assessment tool adapted to the particularities of heritage buildings. The methodology consists of two phases. In the first phase, the tool and the necessary instruments for its use are designed. Accessibility levels are also established. In the second phase, the tool is applied to a sample size of 45 buildings. The results show the tool and related instruments, as well as the data obtained from the analysis of the sample: identified barriers, the level of accessibility of the entire sample, and the level of accessibility by architectural typologies. The conclusions and discussion reflect on the utility of this tool, the feasibility of its extension to other domains, and the relevance of the information obtained from the sample to improve accessibility in architectural heritage.

Keywords: accessibility; person with disabilities; physical disability; cultural heritage; universal design; building information modeling; sustainable construction

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1. Introduction

The perception of disability has gone through various stages throughout history [1–4]. As of today, the most widely accepted model is the Biopsychosocial model of the World Health Organization's International Classification of Functioning, Disability and Health [4]. This model considers the term 'disability' as a combination of personal and contextual factors, including deficits, activity limitations, and participation restrictions.

According to the latest data published by the World Health Organization [5], it is estimated that 10–15% of the world's population lives with some form of disability. The WHO World Report on Disability states that the world population aged 15 and older living with some form of disability ranges from 15.6 to 19.4% (between 785 and 975 million people out of a total of 6.9 billion). If those under the age of 15 are included, the figure rises to 1 billion people. In addition, between 2.2 and 3.8% of the world's population would have severe limitations (between 110 and 190 million people). The magnitude of these figures shows the seriousness of the situation.

In Spain, the country where this study was carried out, according to data from 2017 [6], 9.1% of the population had been assessed, detecting a disability percentage of at least 33% (certain support measures are adopted above this percentage) in 6.8% of the population.

1.1. Classifications of Disabilities

There are various classifications regarding disability. The WHO International Classification of Functioning, Disability and Health [4] uses a medical approach. This classification provides a detailed categorization of body functions and structures, activities and participation, and environmental factors involved in disability. Another classification of the different types of disability, oriented towards the use of a space or object and practical for its simplicity, are the MGLC criteria contained in the UNE 170001-1 standard [7]. In some countries, the MGLC criteria determine four basic actions to be considered in accessibility assessment, and these are Motion, Grasp, Location, and Communication (abbreviated as DALCO criteria in Spanish). These criteria are the requirements to satisfy universal accessibility: ambulation, apprehension, localization, and communication. The groups of persons with disabilities are usually considered in terms of physical, sensory, cognitive, and organic disabilities. Each group includes several different types.

According to the MGLC criteria, ambulation involves moving from one place to another, including horizontal circulation (through corridors, rooms, etc.) and vertical circulation (up and down steps, stairs, lifts, ramps, etc.). Apprehension implies the ability to grasp and manipulate anything, including reaching. Based on these definitions, persons with physical disabilities are those who have an impairment that implies a total or partial limitation in ambulation and/or grasping. There are different degrees of physical disability, depending on aspects such as the type of impairment or the use of support instruments.

1.2. Literature Review

The built environment is where most human activity takes place. The existence of barriers or the absence of facilitators in this environment leads to a restriction in the participation and limitation of activity for persons with disabilities (PWD). The definition of the requirements for apprehension and ambulation [7] highlights the relevance of physical accessibility, without forgetting the rest, in the built environment. Its relevance justifies the number of studies related to it.

In the legal sphere, developed and developing countries have enacted their own legislation that recognizes the equal rights of persons with disabilities. In the international sphere, the International Convention on the Rights of Persons with Disabilities, approved in 2006 by the United Nations [8], establishes an agreement for the rights of persons with disabilities enforced by all ratifying countries. In general, the countries with the greatest evolution in the recognition of the rights of PWDs are in Europe, North America, and East Asia, areas where movements for the removal of architectural barriers or universal design originated [9,10]. In Spain, at the national level, the Royal Legislative Decree 1/2013 [11] guarantees the rights of persons with disabilities and their social inclusion, whereas the minimum requirements for a building or urban environment to be considered accessible are set out in the CTE-DB-SUA [12] and Order TMA/851/2021 [13], respectively. In addition, each Autonomous Community in the country has its own bylaws that complement the state regulations, increasing the complexity of joint analysis and thus justifying the conduct of comparative analyses, such as those of Alegre, Casado and Vergés [14] or Espínola [15].

The recurrence of accessibility in a multitude of studies confirms, on the one hand, the scientific interest of the subject and, on the other, its social relevance and the need for action in this regard. Thus, there are numerous publications on accessibility in urban environments, such as those by Wojtyszyn [16], Perry et al. [17], Setola, Marzi, and Torricelli [18], and Greco and Giacometti [19]. There is also abundant scientific literature focusing on public buildings, with studies carried out by Carlsson et al. [20], Duman and Uzunoğlu [21], Machado and de Oliveira [22], Setiawan et al. [23], Shapiro, Pate and Cottingham [24], Basha [25], Nischith, Bhargava and Akshaya [26], De Medeiros et al. [27] or Lau, Ho and Yau [28]. Similarly, the accessibility of residential architecture is widely studied [29–33] as it is the built environment closest to the user.

The interest in 'the design for all´ is not limited to the built environment but encompasses all spheres of activity, such as, transport or communication [10,34].

The specific case of architectural heritage also is not exempt from the study of its accessibility. Papers such as those by Mastrogiuseppe, Span, and Bortolotti [35], Zahari et al. [36], Tutal [37], Naniopoulos and Tsalis [38] or Marín and Sáez [39] focus on this, with different approaches. The study of accessibility in heritage poses additional conditioning factors, the difficulty of intervention in the building is the main one, without posing conflicts with property preservation.

Given the technological development, accessibility management has undergone a transformation in a similar fashion to other areas, emphasizing the use of virtual reality to allow access to non-accessible spaces, especially heritage sites [38,40], or the management of building maintenance and improvement of accessibility through building information modeling (BIM) technologies, and the like [41,42].

The implementation of this tool within a BIM building information modeling methodology is of interest to building administrators so the identification and introduction of architectural barriers in a BIM model facilitate the analysis and management of their removal within the integral maintenance process of the building.

Previous investigations [43] show that BIM modeling offers geometric and semantic data representations for building components as a single point of real conditions for all system users [44,45]. However, they are applied only in studies on new BIM designs [46], studying new living spaces by using the BIM model. With that, it is possible to define all incompatibilities properly and use them as design feedback to create effective living spaces, for example, for wheelchair users.

In the current design, Joy Choi [47] recognized that BIM is a tool that allows carrying out the accessibility assessment and verification of compatibility with accuracy, which without a doubt, will broaden the living area of disabled people and increase the quality of life. Creating a systematic standard will be the best solution for your application so that one item of information can be used in various ways, and everyone will share it and use it.

These standards, recognized by Badreddine [48], are proposed in new library elements in specific BIM software that simplify the process of implementing universal design (UD) criteria based on the list of recommendations or needs. Its application in the new designs has the potential ability to accelerate the process in a way that decisions and changes can be made early to reduce time and cost.

The design strategies for people with disabilities are still generic [46], and the needs of the disabled are not clearly identified. If the built environment is not envisioned considering the needs of persons with disabilities, the quality of their lives is negatively affected.

For that reason, it is very important to develop effective methods as standard elements that are more effective. Precisely, the use of BIM in the study of disability in the field of built cultural heritage sites does not currently exist in the investigations that centered on these possibilities of application.

With all its peculiarities, architectural heritage can be classified according to its characteristics. Garcés [49] proposed three types or groups: civil architecture, military architecture, and religious architecture. In relation to their accessibility, he pointed out that only military architecture can be considered, by design, inaccessible. In this regard, it is frequently stated that old buildings were not designed on the basis of accessibility and their adaptation is, therefore, difficult or impossible [37,50,51]. Other studies have raised the issue of the feasibility of adapting these buildings for PWD [37,38,51,52]. According to Monjó [53], the most widespread position is to maximize accessibility while guaranteeing the conservation of the monument. This approach includes the defense of the rights of persons with disabilities and the respect for the heritage building.

The tourism sector has been a sector that has implemented accessibility in monuments with greater emphasis, developing the concept of accessible tourism. This concept aims to remove any possible barriers that may prevent a potential visit, broadening the market base, reducing seasonality, and improving competitiveness [54]. Accessible tourism thus emerges from what several authors call the economic model of disability [1,2]. Recent studies highlight the interest in accessibility in tourism [36,54–58].

The special attractiveness of accessibility in the built environment in developing countries is also remarkable, as it can be found in the abundant scientific literature [23,26,36,57,59–63]. This is partly due to the issuing of local accessibility regulations, but in many of these cases, it is in response to the idea of accessible tourism mentioned above and the economic potential it entails for the country's development.

The methodologies of the studies analyzed consist of detecting barriers or checking compliance with regulatory parameters. Therefore, most of them are descriptive studies of the existence of barriers without relating these barriers to the use of the building. This is an approach that associates accessibility with the "absence of barriers". Although this is not incorrect, it is insufficient because it is disconnected from the context and the use made of the space under analysis and, therefore, from the World Health Organization's definition of the term "disability" [4], which underlines limitations in activity and restrictions in participation.

There is another type of research based on a single case study, such as that carried out by Tutal [37]. These studies do not propose a methodology applicable to several buildings but rather the detection of barriers in a building and the way in which they are resolved.

All of this highlights the absence of tools or methodologies focused on the analysis and evaluation of accessibility to the elements that attract the user and the needs of users in the building. The existence of difficulty on the path constitutes an architectural barrier if it is between the user and their destination. Therefore, an approach that first of all considers which aspects generate attraction in the building is necessary to assess the severity and usage limitation of the architectural barriers and, thus, the accessibility of the building. This highlights the need to establish a new methodology to determine the accessibility of the use of the building, which includes not only the visitor or user but also the worker in all the activities carried out in the building.

In any event, one of the motives is the activity that takes place inside the building and which can be carried out in other places, with slight nuances. Nevertheless, in the case of heritage buildings, there are other attractive features in addition to their use. According to the Venice Charter [64], a historic monument embraces not only a single architectural work but also the urban or rural setting in which the evidence of particular civilizations, significant developments, or historic events are found. A similar definition is found in Law 16/1985 on Spanish Historical Heritage [65], stating its 'artistic, historical, paleontological, archaeological, ethnographic, scientific or technical interest.' These attractive features, in addition to their use, constitute the main qualities that motivate the visit of users. Given the uniqueness that motivates their protection as an integral part of the cultural heritage, they are not developed in other spaces. Therefore, it is interesting to evaluate their accessibility, as these are the aspects that justify the need for access on the part of the user.

Based on the above information, the objectives of this work are the design of a physical accessibility assessment tool adapted to the circumstances and particularities of heritage buildings and the analysis of the accessibility of a study sample. This tool determines, firstly, what essential qualities the building has (aspects that generate use inside it) and, based on these, detects the barriers, identifies which activity inside the building it affects and its influence on each type of disability considered, finally establishing the level of accessibility in relation to the possible use without any type of limitation. Furthermore, the characteristics of this tool allow it to be applied to any type of building to determine its accessibility.

2. Materials and Methods

2.1. Cases of Study

The study sample has been selected from the lists provided by the autonomous administration and consists of 45 buildings out of the 117 that may be included. The buildings are located in the Region of Murcia (Spain). They have been cataloged as an Asset of Cultural Interest, falling within the category of a monument and classified as civil architecture, military architecture, and religious architecture by the above-mentioned administration. The selection of buildings was based on the representativeness criteria so that the sample reflects the variety of typologies, ages, geographical locations, or uses in the heritage buildings.

The distribution of buildings across these three categories and the type of buildings included in each are indicated below:

1. Religious building (18 buildings, 40% of the sample size). It includes temples and convents or monasteries (Figure 1).

(**a**) (**b**) (**c**)

Figure 1. Examples of religious buildings analyzed: (**a**) Saint Joseph's Church (Abanilla, Murcia, Spain); (**b**) Mary Magdalene's Church (Cehegín, Murcia, Spain); (**c**) Saint Francis Convent (Mula, Murcia, Spain).

2. Military buildings (9 buildings, 20% of the sample size). It includes castles, forts, walls, or towers (Figure 2).

(**a**) (**b**) (**c**)

Figure 2. Examples of military buildings analyzed: (**a**) Castle (Moratalla, Murcia, Spain); (**b**) Castle of Jumilla (Jumilla, Murcia, Spain); (**c**) Nativity Fortress (Cartagena, Murcia, Spain).

3. Civilian buildings (18 buildings, 40% of the sample size). It includes residential and administrative buildings, theatres, cultural and leisure spaces, and museums (Figure 3).

(**a**) (**b**) (**c**)

Figure 3. Examples of civilian buildings analyzed: (**a**) Palace of Llamas Family (Ricote, Murcia, Spain); (**b**) Cayitas Building (Alcantarilla, Murcia, Spain); (**c**) Marketplace (La Unión, Murcia, Spain).

2.2. Methodology

2.2.1. Collected Data

The collected data have been structured in three blocks to conduct this study:

Types of disability: the study analyses accessibility for users with physical disabilities, understanding as such those who present ambulation difficulties (ability to move by walking between two places) and/or apprehension difficulties (ability to grasp or manipulate objects with their hands). Two study groups are established based on the analysis of the state of the question and the different types of users:

a. Wheelchair user: a person with a physical disability who cannot move around and requires an electric or manual wheelchair to move around autonomously or with the help of third parties.
b. People with limited walking abilities: a person with a physical disability who is not a wheelchair user but requires canes, a walking frame, a prosthesis, or other aids to move around autonomously.

Building types: the buildings in the sample, classified as civil, religious, or military architecture, have common characteristics and spaces.

Area of analysis: any element of the built environment that allows or requires user interaction, enabling activities to be carried out. They comprise the accessibility chain [7]. The areas considered are listed in Table 1.

Table 1. Areas of analysis considered.

Area of Analysis				
Access	**Door**	**Moving Walkway**	**Furniture**	**Access**
Parking space	Staircase	Step with risk of falling	Musealization	Parking space
Information point	Ramp	Step lift	Signs	Information point
Horizontal circulation	Lift	Stair lift	Mechanisms	Horizontal circulation
Flooring	Escalator	Auditorium space	WC	Flooring

The methodology is divided into two phases: design of the accessibility analysis tool and implementation of the study sample. Each of the phases is structured in 4 stages, comprising a total of 8 stages.

2.2.2. Phase A: Design of the Tool

Stage 1: list of spaces. The conceptual division of the building into parts is common in accessibility studies since it facilitates the analysis [38,66,67]. Following the combined study of the areas of analysis and the existing spaces in the building typologies of the study sample (civil, religious, and military architecture), a list of typical spaces is developed.

Stage 2: list of main qualities. A building has different attractive features depending on its use, its architecture, its history, etc. They are given the name of 'main qualities´, and the accessibility of the monument depends on these qualities. The value of each main quality is defined according to the space analyzed in terms of:

a. Its use (C_U). It measures the need to use a space for the building's own use.
b. Its typology (C_T). It measures the relative importance of a space to perceive and understand a building typology.
c. Historical or artistic aspects (C_C). It measures the historical, artistic, or social importance of a room.

The sum of the three main qualities gives the total value of each space.

Stage 3: list of barriers. Different parameters are established for each area of analysis to establish the necessary characteristics to be considered accessible by the groups of PWD. To that end, the state regulation on building accessibility [12], the corresponding regulations of the different Autonomous Communities in Spain, and other non-legislative standards (UNE Standards) have been consulted. Structured surveys were carried out with persons with physical disabilities to determine which barriers affect each group and to what extent. Based on their responses, a limitation coefficient (L) is attributed to each barrier that assesses the severity of the barrier.

Stage 4: levels of accessibility. The sum of the limitation coefficients (L) of the barriers in each space determines the percentage of main accessible qualities of the space, whereby a higher summation of limitation coefficients implies a lower number of main accessible qualities, as shown in Table 2. The correlation established between the sum of the limitation coefficients and the main qualities that can be considered accessible in the space responds to the interest in showing the negative impact that the existence of limitations has on the disabled user's ability to make use of the space, and not limiting it to a simple accounting of regulatory deviations. The percentage of the main accessible qualities of the building is the summation of the main accessible qualities divided by the sum of the existing main qualities in each space. To ensure comprehension of the results of the study about building accessibility for any user, it is necessary to clarify them. For this purpose, different levels are established, the number and definition of which are based on the criteria of classification ease and identification speed.

Table 2. Elaboration of main accessible qualities of a space from the existing ones and the limitation coefficients corresponding to the existing barriers.

Sum of Limitation Coefficients	Main Accessible Qualities [1]
$\Sigma L \leq 0.2$	$C_X = C$
$0.2 < \Sigma L \leq 0.5$	$C_X = C \cdot (1 - \Sigma L)$
$\Sigma L > 0.5$	$C_X = 0$

[1] L = limitation coefficient; C = main qualities of the space; C_X = main accessible qualities of the space.

The first 4 stages comprise the elements of the accessibility analysis tool, which is applied in phase B to the study sample size of 45 buildings.

2.2.3. Phase B: Implementation of the Tool

Stage 5: documentation. This consists of obtaining the necessary information to have a better understanding of the building and to proceed to the following stages. The following information is collected: historical and architectural information, information on the operation of the property, type of users and activities, and the building planimetry.

Stage 6: definition of spaces. Using the list of typical spaces, the spaces that compose the building under analysis are identified, as well as the connections among them, obtaining an abstraction of the building that facilitates its analysis.

Stage 7: allocation of main qualities. Using the prepared lists, a main typological, historical–cultural, and of-use quality value is assigned to each defined space. The total value of the room is the sum of the three main qualities.

Stage 8: access audit. The barriers in the list existing in the building are detected in situ, assigning them to the space in which they are located. The sum of the limitation coefficients (L) determines the main accessible qualities of each space, and the sum of all the spaces allows us to obtain the percentage of the main accessible qualities of the building. This is used to obtain the level of accessibility.

Figure 4 summarizes the methodology graphically.

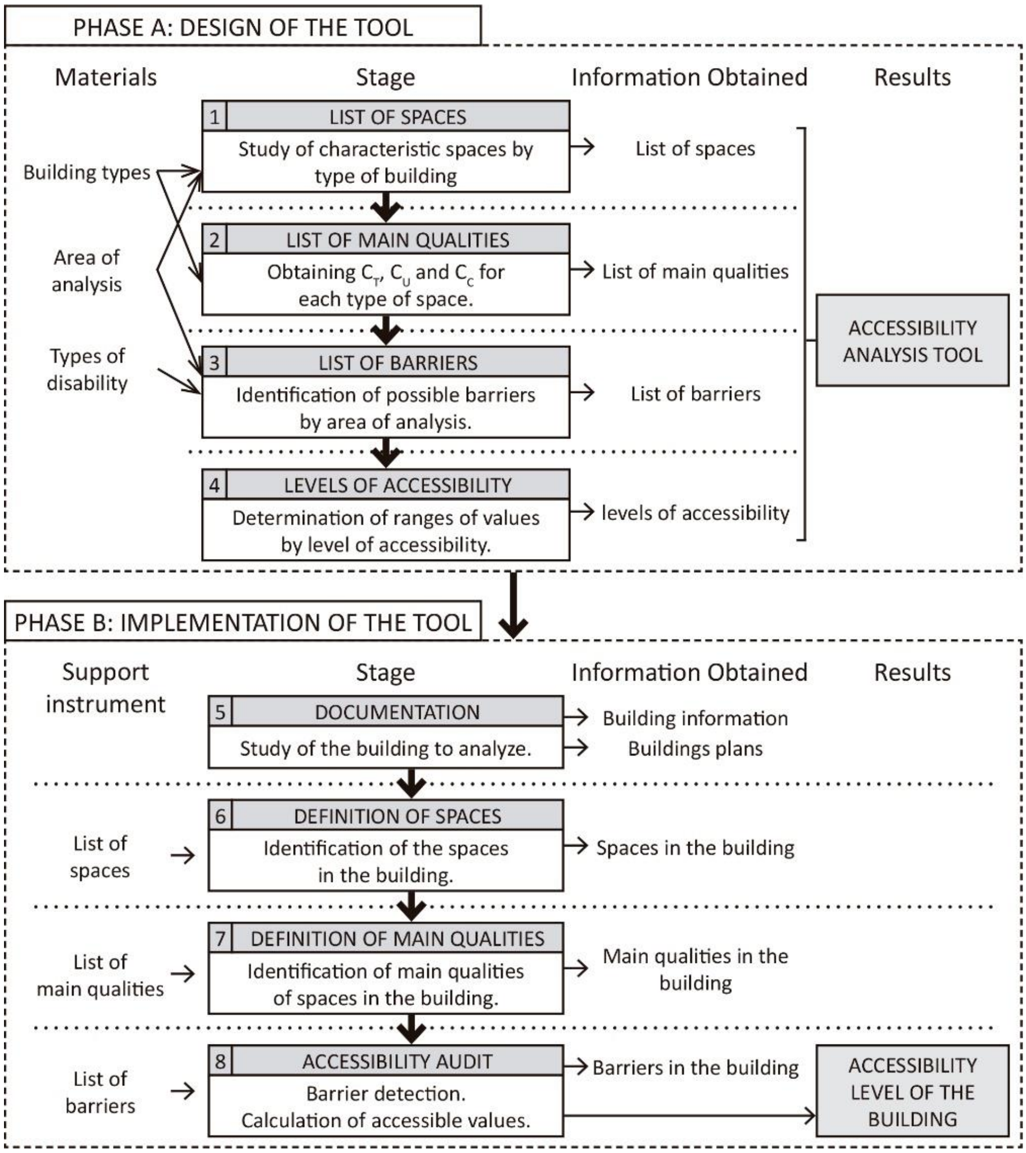


Figure 4. Methodology. The study is divided into two phases: A and B. Each includes four stages. Results are obtained at the end of each phase.

3. Results

3.1. Phase A

3.1.1. List of Spaces (Stage 1)

A series of typical spaces corresponding to the building of each typology has been established based on the study sample. Table 3 shows a selection of the most characteristic spaces for each typology.

Table 3. Selection of representative spaces by typology and corresponding main qualities of use (C_U) and main typological qualities (C_T).

Religious Architecture			Military Architecture			Civil Architecture		
Space	C_u	C_T	**Space**	C_u	C_T	**Space**	C_u	C_T
Presbytery	3	5	Parade ground	4	5	Living room	1–5	3
Nave	5	5	Tower. Access floor	4	4	Office	3	1–5
Aisle	4	4				Room	2	3
Chapel (with mass)	4	3	Keep. Access floor	4	5	Service area	1	4
Chapel (without mass)	2	3				Gardens	2	1
Ambulatory	4	4	Tower. Upper floor	3	3	Dining room	4	2
Crossing	4	4				Plenary hall	5	4
Transept	4	4	Keep. Upper floor	3	4	Meeting room	4	5
Sacristy	3	2				Hallway	1	4
Choirs	2	3	Private chapel	2	3	Stalls	5	2
Tower	1	3	Chemin de ronde	4	5	Hall	3	5

3.1.2. List of Main Qualities (Stage 2)

The main qualities considered in the architectural heritage for this study have been those of use, typological, and historical–cultural. Based on the study sample and other similar buildings, a main quality of use and a typological main quality value have been assigned to each typical space defined in stage 1. Table 3 shows the main qualities of use and the main typological qualities assigned to the most representative spaces of each typology.

The breadth of the definition of the cultural–historical quality prevents it from being generalized. For this reason, a value ranging from one to five is assigned to each space individually.

3.1.3. List of Barriers (Stage 3)

A total of 196 barriers affecting physical persons with disabilities have been identified. Out of these, 145 affect wheelchair users, and 151 affect cane users. The distribution of barriers by areas of analysis is shown in Table 4.

Table 4. Area of analysis considered, and number of barriers assigned to each one.

Area	Barriers
Access	4
Parking space	7
Lift	16
Horizontal circulation	9
Step with risk of falling	6
Auditorium space	8
Escalator	8
Staircase	26
Mechanisms	2
Furniture	8
Musealization	5
Information point	4
Stair lift platform	6
Step lift platform	12
Door	14
Flooring	5
Ramp	20
Signs	3
Moving walkway	7
Wc	26

As an example, Table 5 shows the barriers corresponding to the "parking" area, as well as the MGLC criteria affected for each of them.

Table 5. Barriers corresponding to the parking area, and MGLC criteria affected in each of them.

Barrier	Description	MGLC [1] Criteria
AP01	Insufficient number of reserved parking spaces.	Ambulation
AP02	Reserved parking spaces with no connection by accessible route or excessively far away from the access.	Ambulation
AP03	Reserved parking space not signposted vertically.	Location
AP04	Reserved parking space of insufficient size.	Ambulation
AP05	Reserved parking space not signposted horizontally.	Location
AP06	Location of reserved parking spaces not signposted at the access.	Location
AP07	Not identified pedestrian routes in car park by differentiated paving.	Ambulation Location

[1] MGLC means Motion, Grasp, Location, and Communication (abbreviated as DALCO in Spanish).

3.1.4. Level of Accessibility (Stage 4)

Three levels are established for each of the groups considered, with reference to the above-mentioned criteria of classification ease and identification speed. These levels refer to the percentage of the main accessible qualities of the building. The established levels are shown in Table 6.

Table 6. Accessibility levels established, and corresponding main accessible qualities.

Level	Main Accessible Qualities	Description
Accessible	90–100%	The building can be used by users in full or almost full autonomy, safely, and on equal terms.
Partially accessible	50–90%	The building presents relevant limitations for its use by users, but they can use it partially, still with some difficulties.
Not accessible	0–50%	The building has excessive limitations for its use by users.

The uneven distribution of the ranges of main accessible qualities among the three levels responds to the need to reflect on the negative impact of the existence of difficulties for persons with disabilities. For this reason, it does not follow a normal distribution, indicating the existence of 50% of the main qualities, which are not accessible, represents a remarkably high level of difficulty, preventing the minimum use of the building.

3.2. Phase B

3.2.1. Identified Barriers (Stage 8)

Accessibility is very diverse in the buildings studied, acknowledging some specific barriers that are present in 100% of the buildings, and others are not detected in any of them. Table 7 shows, as a representative example, the barriers found in more than 75% of the sample size.

In contrast to these barriers, which are repeated in a significant percentage of the sample size, there are 44 other barriers (22% of the total) that have not been found in any of the buildings. Most of the undetected barriers correspond to the following areas of analysis: car park, escalator, and moving walkway, areas that do not exist in the buildings evaluated. The average number of buildings where the barriers are present is 28%.

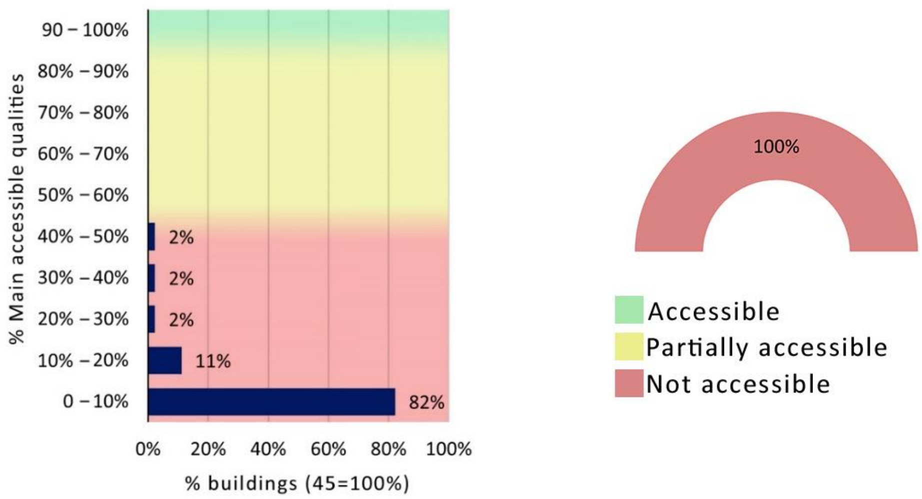
3.2.2. Level of Accessibility of the Whole Sample (Stage 8)

The analysis of the whole sample shows low percentages of the main accessible qualities and, consequently, negative accessibility levels for wheelchair users and cane users. However, there are differences between both groups.

Table 7. Identified barriers in more than 75% of the study population, grouped by area.

Area	Barrier	Description	Study Sample
Access	AC02	Access without accessibility signs	100%
	AC04	Access without accessible directory	91%
Horizontal circulation	CI01	Step width < 1.20 m	78%
	CI05	Undetectable obstacle	100%
	CI09	Insufficiently illuminated space	82%
	CI11	No accessible vertical communication	89%
	CI12	Single step with no accessible alternative	100%
Step	DE01	No signposted step	76%
Doors	PU01	Door with passage width < 0.80 m	96%
	PU02	Door with clear high < 2.00 m	76%
	PU03	Door with no room to maneuver	89%
	PU07	Insufficient distance between door and mechanism	87%
Staircases	ES03	Flight width < 1.20 m	87%
	ES05	Inadequately dimensioned riser	78%
	ES08	Step with nosing	80%
	ES10	Step with no edging signage	98%
	ES15	Staircase without complete handrails	98%
	ES17	Handrail ends not extended	96%
Ramps	RA05	Excessive longitudinal slope	78%
Furniture	MO01	Insufficient number of accessible seats	96%
	MO03	Seat without armrests	91%
Musealization	MU04	Exposed element at high height	78%
WC	WC01	Insufficient number of accessible toilets	80%

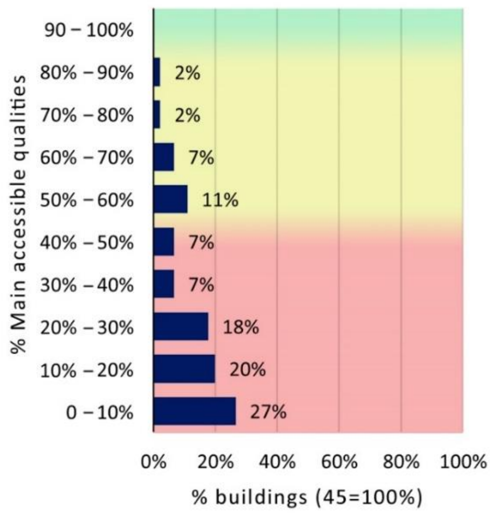
For wheelchair users, all buildings are considered not accessible, as shown in Figure 5b. Breaking down the results by the percentage of the main accessible qualities (Figure 5a), 82% of the sample size analyzed is within the band, with over 90% of the main qualities not accessible. The remainder of the study sample falls between the 10% and 50% bands of the main accessible qualities. Of these, 11% are in the band between 10% and 20% of the main accessible qualities, and in each of the remaining three bands, there is only 2% of the sample size.



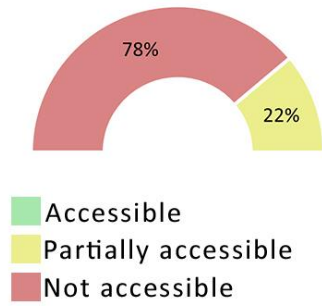
(**a**) (**b**)

Figure 5. Accessibility of the buildings in the study sample to wheelchair users: (**a**) Percentage of buildings by range of main accessible qualities; (**b**) classification of buildings by level of accessibility.

For cane users, the results are shown in Figure 6. In this case, 78% of the buildings are considered not accessible, and 22% are partially accessible (Figure 6b). No building is considered accessible for cane users according to the established classification. The presence of 27% of the buildings with less than 10% of main accessible qualities stands out, followed by the bands of main accessible qualities between 10% and 20%, and between 20% and 30%, with 20% and 18% of buildings, respectively. Of the partially accessible buildings, the majority are in the 50–60% band of the main accessible qualities (11% of buildings). Only 2% of buildings reach a level of 80 to 90% of main accessible qualities (Figure 6a).



(**a**)



(**b**)

Figure 6. Accessibility of the buildings in the study sample to cane users: (**a**) Percentage of buildings by range of main accessible qualities; (**b**) classification of buildings by level of accessibility.

3.2.3. Level of Accessibility by Typology (Stage 8)

Being the three building typologies analyzed (civil, military, and religious) separately, the level of accessibility shows small differences. These differences are slightly greater in the case of cane users. For the two groups analyzed, military buildings show lower percentages of main accessible qualities than civil and religious buildings. For wheelchair users (Figure 7), 100% of military buildings are in the lowest band (0% to 10% of main accessible qualities), as shown in Figure 7a. Conversely, civil and religious buildings show examples of main accessible qualities up to the band of 40% to 50%, although with very low percentages (Figure 7b,c). Most of the civil and religious buildings are also in the lower band. Therefore, 100% of the buildings of the three typologies are considered not accessible (Figure 7d–f).

For cane users (Figure 8), the analysis by typology offers similar results, although it extends over a wider range of bands. Overall, 100% of military buildings are considered non-accessible, distributed in all lower bands with less than 50% of main accessible qualities. The band with the highest concentration of military buildings is the lowest (0% to 10% of main accessible qualities), with 44% of examples (Figure 8b,e). Civil and religious buildings show examples reaching higher bands, from 80 to 90% of main accessible qualities (civil building) or 70 to 80% (religious building). However, most of their samples are found in non-accessible bands (below 50% of main accessible qualities), as shown in Figure 8a,c.

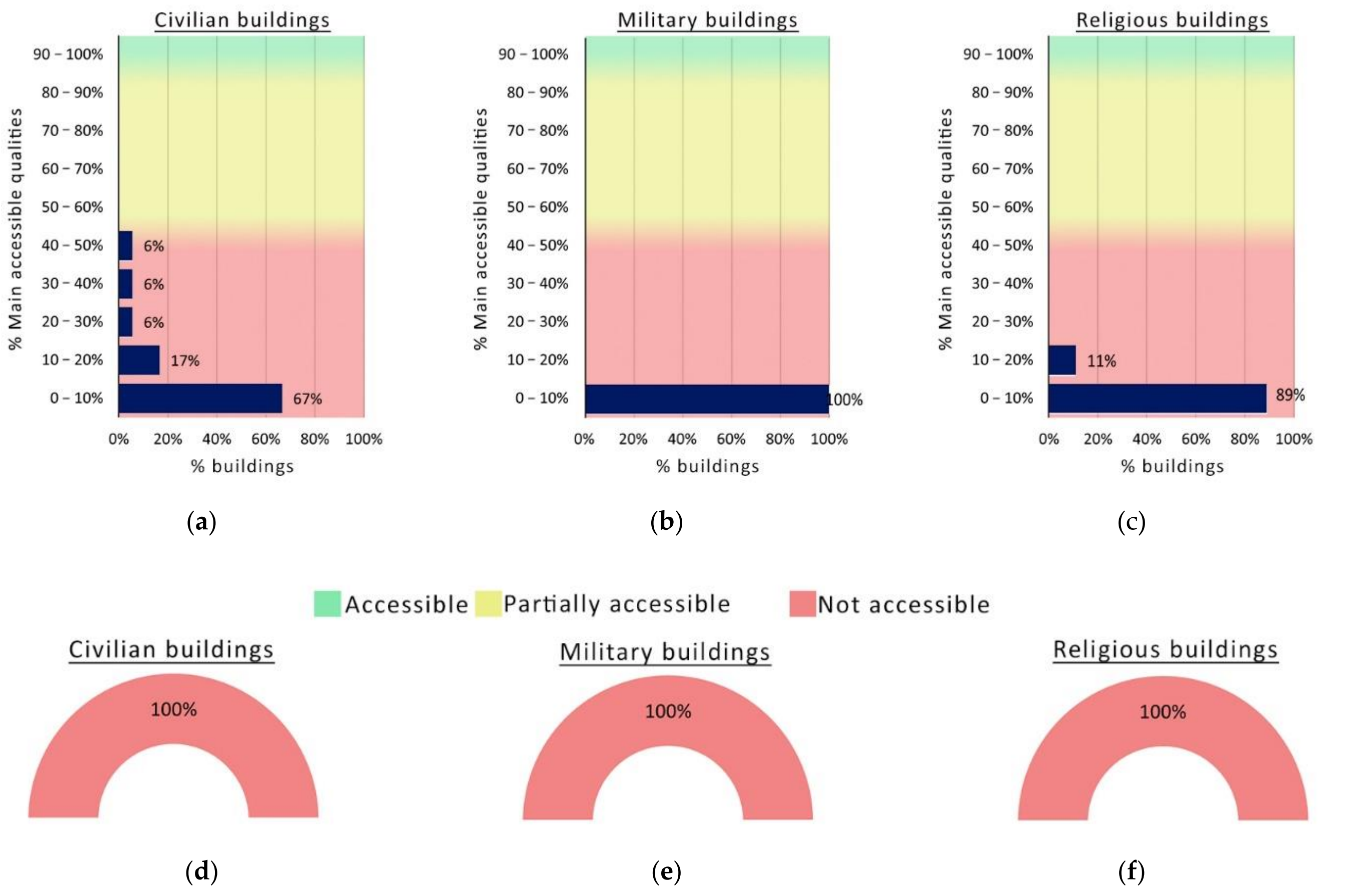


Figure 7. Accessibility of the buildings in the study sample to wheelchair users by typology: (**a**) Percentage of civilian buildings by range of main accessible qualities; (**b**) Percentage of military buildings by range of main accessible qualities; (**c**) Percentage of religious buildings by range of main accessible qualities; (**d**) classification of civilian buildings by level of accessibility; (**e**) classification of military buildings by level of accessibility; (**f**) classification of religious buildings by level of accessibility.

The civil building shows a distribution with a greater presence of examples in the upper bands compared to the rest, although no variation is noticeable. The biggest difference is found in the percentage of partially accessible buildings for cane users, with 39% of civilian buildings compared to 17% of religious buildings (Figure 8d,f).

Finally, the analyses show that 35 buildings (78%) are considered partially accessible for cane users. However, none buildings (100%) are accessible for wheelchair users. Furthermore, 10 buildings (22%) are considered not accessible for both cane and wheelchair users.

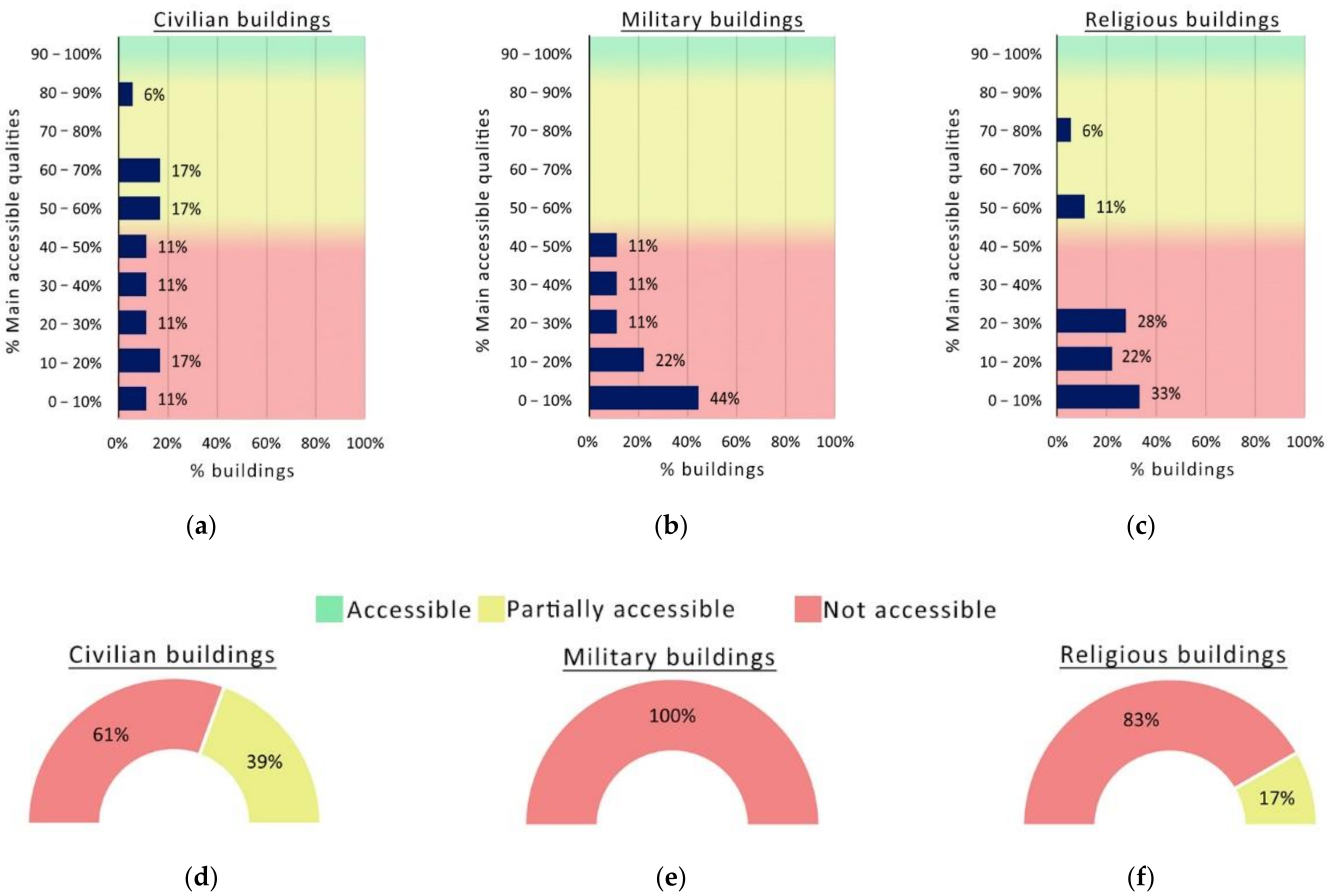


Figure 8. Accessibility of the buildings in the study sample to cane users by typology: (**a**) Percentage of civilian buildings by range of main accessible qualities; (**b**) Percentage of military buildings by range of main accessible qualities; (**c**) Percentage of religious buildings by range of main accessible qualities; (**d**) classification of civilian buildings by level of accessibility; (**e**) classification of military buildings by level of accessibility; (**f**) classification of religious buildings by level of accessibility.

4. Discussion

The methodology followed has enabled us to respond to the objectives set for the study in its different phases.

1. Phase A has developed an accessibility analysis tool based on the main qualities of the building, that is, those aspects that generate attractiveness and motivate the user to visit it. As mentioned in the introduction, numerous studies shown in the existing literature, such as those made by Mastrogiuseppe, Span, and Bortolotti [35], Zahari et al. [36], Tutal [37] or Naniopoulos and Tsalis [38], developed methodologies that identify architectural barriers and are useful for identifying the aspects that require action to solve problems, but it is of scant significance to determine whether a building is accessible or not and whether it is accessible to a greater or lesser extent in relation to others. The reason why a building is used is not considered. On the other hand, the proposed methodology makes it possible to quantify the level of accessibility for each type of disability considered, in addition to identifying existing barriers.
2. Meeting the planned objectives, stage 2 of this study defines the main qualities that signify the building and, providing that the user can access them as there are no activity restrictions or participation limitations, a level of accessibility linked to the user experience is obtained. Most of the studies reviewed identified the presence of architectural barriers [21,22,25,37]. The proposed tool also identifies the architectural barriers of the analyzed building, it does not only list them, but it also uses them

to calculate accessibility. A similar approach is proposed by Setola, Marzi, and Torricelli [18] for the trail network in a Nature Park, although the natural environment is simpler than the built environment.

3. A remarkable aspect is the modular character of the tool. The three lists generated in stages 1, 2, and 3 are independent elements that can be replaced or updated separately. This is interesting for exporting the tool to other built environments or other countries with different regulations, modifying the lists of spaces and main qualities in the first case and the list of barriers in the second. In the literature review, no tool with these characteristics has been found, so it is considered a novel contribution.
4. Phase B provided significant results in terms of the accessibility of the sample size studied. In addition, it has first allowed for the testing of the functioning and usefulness of the tool. The diversity of architectural environments has made it possible to observe many elements in different settings and analyze them in all their different forms.

In relation to the barriers detected, 22% of the barriers were non-existent in the entire sample size since certain areas of analysis, such as escalators or moving walkways, are not frequent in heritage buildings. On the contrary, the reiteration of certain barriers, with several being observed in 100% of the samples, enables a common pattern to be formed, facilitating the establishment of lines of action that include solutions to problems classified as common. Without forgetting the rest of the barriers, which, although infrequent, do not necessarily generate fewer limitations.

Most of the identified barriers are present in horizontal circulation areas (doors, corridors) and vertical circulation areas (stairs, ramps). Overall, 17 out of the 23 barriers found in more than 75% of the analyzed buildings correspond to these two concepts. This is a relevant aspect within the perspective of the 'accessibility chain´, according to which a non-accessible link prevents accessibility to subsequent links. Therefore, the correction of these barriers can lead to a much greater increase in accessibility than the elimination of others, allowing the continuity to the next links in the chain, and it can be identified as a priority factor.

5. Regarding accessibility levels, the analysis of the selected sample shows adverse results for both groups (cane users and wheelchair users), with 0% of buildings classified as accessible in both cases and only 22% considered partially accessible for cane users. Most of the main qualities of the heritage building are of a typological, historical–artistic, or cultural nature, (i.e.), they belong exclusively to that building and cannot be replaced by another, unlike the main qualities of use. Therefore, the study shows discrimination suffered by persons with physical disabilities due to the architectural heritage´s lack of accessibility.
6. The comparative analysis by typology shows a lower level of accessibility in military architecture. Overall, 100% of military buildings are classified as non-accessible. This could be framed within the idea put forward by Garcés [49] that if there is a type of architecture that is not accessible, it is military architecture. However, the difference is not sufficiently relevant to make such an assertion. The verification of this postulate must be carried out using only those architectural barriers that cannot be removed. Studies by the authors focus on this line of research.
7. The implementation of this methodology in a BIM environment needs, first of all, detailed modeling of the building. Existing investigations, such as those carried out by Greco y Giacometti [19] or Tutal [37], propose the study of the solution of each barrier within a conventional architectural project process in new buildings. However, no solutions for constructed buildings with the particularities of cultural heritage buildings exist. The advances in this research enable, in a BIM methodology, the removal of barriers as proposed through the introduction of adaptable library elements, which are modeled based on a list of standard solutions for each case that will be worked on in a future phase of the research. This is inside a continuous process of integral maintenance of the building instead of a succession of isolated interventions that enables dealing with solutions in packs.

5. Conclusions

The tool developed resolves the needs detected in the accessibility field and literature review. The analysis of the main qualities and the linking of these values with the barriers through the spaces of the buildings make it possible to obtain an analysis of accessibility focused on the user's interest in the building. This is the main novelty of the tool, as it is not limited to detecting barriers but identifies their influence on each activity to be carried out by the user in each space or building element.

The sum of the main qualities of the building constitutes the reference level with which to compare the current state of the building, thus making it possible to assess its accessibility in percentage terms. Likewise, the division of the building into spaces allows them to be studied separately, facilitating the identification of the areas with the greatest need for improvement.

One of the main attractions of the tool is its ability to determine the level of accessibility for each of the groups of people with disabilities considered, rather than a general level that aims to cover everyone at once. This allows for more accurate information for both the user and the manager. In this study, two different groups of people with physical disabilities have been considered. However, the modular nature of the tool makes it possible to incorporate modules with information on barriers affecting other groups and to obtain, for example, in a single audit, the specific level for wheelchair users, cane users, blind people, or people with hearing impairment. This implementation for other groups is being worked on by the authors.

During the previous discussions and fieldwork, the managers of the buildings analyzed were interested in the application of this tool to improve the accessibility of their buildings. One of the complex aspects pointed out by several of them is the economic feasibility of the interventions. In this regard, the tool makes possible priority actions according to the main qualities each barrier affects, allowing the creation of an action plan.

The potential of the approach of the designed tool is justified by the developed experience. In addition to academic research, the usefulness of the tool can be seen, firstly, for administrators to find out the current situation of their property. Secondly, to understand the conditions of accessibility to the main qualities of the buildings considering the groups of persons with disabilities, easily and intuitively.

The implementation of this tool within a BIM methodology is of interest to any building administrator, so the identification and introduction of architectural barriers in a BIM model facilitate the analysis and management of their removal within the integral maintenance of the building.

BIM provides the capability to attach an infinite range of data to components of the model and creates a potential data repository that is useful beyond construction documentation [48]. Research advances, such as the one carried out in this study, offer new possibilities to the UD concept, making interventions in public access buildings, such as heritage buildings, barrier-free and attached to the latest trends in construction technology, being integrated into the main BIM tools as BIM standards.

Currently, BIM is implemented in intervention projects in heritage buildings. The implementation of this tool to find the solution in these projects will include building information modeling standards when the building has been analyzed. It will resolve the main problems in designing new solutions implemented with constructive ancient and existing systems without accessibility problems.

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