Universal Design-Based Framework to Assess Usability and Inclusion of Buildings

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Abstract. Universal Design (UD) offers different sets of principles that can be used as reference in design practice to meet the needs of the vast majority of a population. However, there is a lack of an accountable approach to measure and analyze the built environment through UD performance.

This study aims to develop an evaluation framework to assess UD in public buildings to determine, in addition to accessibility requirements, the usability and inclusion of projects for different users.

Multicriteria Decision Analysis (MCDA) was adopted as research methodology to systematically and scientifically develop the framework, which was structured based on knowledge derived from: an in-depth literature review on UD evaluation and workshops with stakeholders and experts. The selection and comparison of a pool of criteria is described including the cognitive mapping technique for translating information gathered by workshops.

A hierarchical framework was created, consisting of three main categories of UD (i.e. physical-spatial quality, sensorial-cognitive quality, and social quality), eight criteria (i.e. usability, functionality, safety/security, wayfinding, understanding, environmental factors, well-being, and social inclusion), and 21 indicators. The proposed framework can be considered as an innovative approach in the field of accessible design evaluation since it explores the relation among a multiplicity of aspects, including human performance and social factors, to evaluate the quality of UD buildings.

Keywords: Design for All · Inclusive design · MCDA · Universal design · Workshop · Cognitive mapping technique

1 Introduction

Universal Design (UD) strategy aims to meet the needs of the greatest number of people, regardless of age, gender, physical and cultural features, abilities or disabilities. Architect R. Mace introduced UD in 1985 [1] as a strategy that encourages designing environments or products that are usable by the vast majority of a population, without adaptation or stigma. It refers to a universal human experience since all individuals can be impaired by "temporary impairments" (e.g. age, broken limb, pregnancy) or "situational impairments" generated by the built environment (e.g. inaccessible transportation or public buildings, negative attitudes, and limited social support) [2].

O. Gervasi et al. (Eds.): ICCSA 2020, LNCS 12253, pp. 1–16, 2020.
https://doi.org/10.1007/978-3-030-58814-4_22

In architecture, UD overcomes architectural barriers where accessibility is the minimum design requirement [3]. Accordingly, UD offers people with different needs the possibility to use and enjoy a space in a dignified way, providing all users the same experience despite different design solutions.

In this study, UD and Design for All (DfA), which is design that aims for diversity, social inclusion, and equality [4], are considered equal since both are driven by the same objectives even though they come from the American and European contexts, respectively [5]. These design strategies aim to promote diversity and develop projects that overcome all kinds of impairments: physical (e.g. dexterity, movement, static and dynamic stamina), sensorial (e.g. sight, hearing, touch), cognitive (e.g. memory, understanding), and social (e.g. social participation, culture, religion, etc.) [6, 7].

1.1 Problem Definition

Although physical, cognitive, or social inclusion can affect users' well-being, architectural environments are still not often designed to consider users' needs and experiences within space [8]. Ways to link UD knowledge and practice are also still inadequate [9, 10]. In many cases, the lack of consideration for users' needs can negatively influence users and compromise the performance of the entire service [11]. The inclusion of social aspects only at the end of the design process has tangible effects on individuals' well-being, furthermore this can generate extra cost and time for adjustments to disable situations [12]. For these reasons, it is fundamental to evaluate the usability and inclusion of projects before and after construction. There is an urgent need to study and develop specific evaluation tools based on performance, which allow designers to assess and compare project features in terms of usability and inclusion [13].

In this context, UD evaluation explores how well a building works for a wide range of users [14]. It overcomes the focus on architectural barriers and specific categories of users concerned with accessibility and underlines UD variables that positively influence people's well-being. As such, clear criteria and indicators are needed to better understand the impacts of the environment on users' behavior and well-being [15]. As Preiser states, "a rigorous and accountable approach must be taken in measuring and analyzing" based on UD performance [16], clear features are therefore needed to assess the usability and inclusion of built environment.

1.2 Objective of the Study

The evaluation systems currently used for the assessment of building performance, such as Leadership in Energy and Environmental Design (LEED) [17] and the Building Research Establishment's Environmental Assessment Method (BREEAM) [18], check the presence of certain technical, design, and system aspects through a series of indicators and a specific scoring method. These tools provide a reliable evaluation of overall aspects of a building (e.g. indoor air quality, thermal comfort). This approach has been followed aiming at developing a framework to measure how universally designed buildings are in terms of usability and social inclusion. The purpose is to fix the basis for an evaluation method that can be applied to new buildings and renovations (i.e. project audit) or in Post-Occupancy Evaluation (POE) [14] to objectively define the priority

of interventions in existing buildings. Accordingly, the study addresses the following research questions:

i) What are the most prevalent criteria used to measure UD building performance?
ii) How can these aspects be adopted to generate an evaluation framework for UD?

Section 2, in particular, describes the general methodology on which the framework is built (i.e. Multicriteria Decision Analysis (MCDA)) and the specific methods used for its development (i.e. literature review and workshops with users and experts). Section 3 explores the results generated from each of the methods that enable the development of the framework. Section 4 presents the final discussion, while Sect. 5 contains the conclusion with future perspectives.

2 Methodology

2.1 Multicriteria Decision Analysis Approach

As previously stated, the main objective of this study is to provide a UD evaluation of building design based on outcomes that can improve the well-being of as many users as possible, instead of merely focusing on specific categories of users. The application of this concept to the evaluation of public buildings involves a plurality of users with various physiological, sensorial, cognitive, and emotional needs and circumstances [19], which in turn adds complexity to the evaluation process. This process must thus consider several quantitative and qualitative aspects related to social factors and human performance.

For this reason, the study focuses on multicriteria methodologies since they can be used to structure and solve complex decision and planning problems involving multiple qualitative and quantitative criteria and the analysis and comparison of the full range of aspects related to a project [20]. The MCDA approach [21] delivers specific models that can solve issues of real situations through eight main steps [20]. This study adopted the second step "identifying objectives and criteria" to systematically develop the framework. After establishing a decision context (i.e. first step) [20], which in this case is UD evaluation with related stakeholders, the second step involved breaking down the issue into different objectives or criteria to define the structure of an evaluation framework [20]. The described criteria are parameters for evaluating a system through quantitative, qualitative, or descriptive measures that represent its main features. After selection, criteria were organized in a hierarchical framework (i.e. decision tree), which consisted of criteria and indicators clustered in high-level and lower-level objectives. This evaluation is therefore characterized by a performance-based approach, such as UD, that focuses on the achievement of objectives rather than on the prescription of rules [22].

The research is developed through different phases, shown in Fig. 1, that allow to elaborate the contents of the framework (i.e. categories, criteria, indicators) through knowledge assembled from two methods: a literature review and a workshop with stakeholders.

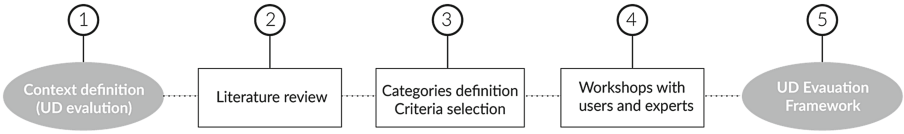

Fig. 1. Methodology flow chart

2.2 Literature Review

A literature review was conducted to investigate current and existing studies on UD and DfA evaluation methods and tools. This analysis aims to explore existing knowledge on UD and DfA assessments and collect data to systematically and scientifically select items for the development of a decisional and assessment UD framework.

The Scopus database was used to search for articles, using a specific three-level set of keywords: *Universal Design* OR *Design for All* OR *Inclusive Design* OR *Accessibility* AND *Evaluation* OR *Assessment* OR *Performance* AND *Architecture* OR *Built environment.* Eligibility criteria were used to select and include or exclude them from the analysis. Articles were excluded if they related to case studies because they contain results that are too specific or pertain to an "education" issue, especially because there are fields under UD and DfA related more to education and learning than design.

Twenty-three articles were included in the final analysis, subdivided into four main categories: evaluation theories, criteria, methods, and tools. The analysis revealed that there are different sets of criteria to assess UD and DfA adopted by different evaluation methods found in the literature. The specific methodology and results of the literature study have been described in a previous work [22]. This study compares criteria to identify the most prevalent topics.

2.3 Workshops: Stakeholders' Analysis and Cognitive Mapping Approaches

When defining criteria in MCDA, the involvement of different perspectives is a typical approach suggested for the development of assessment frameworks [21]. Since UD is a discipline based on users' needs, it is fundamental to include a plurality of viewpoints in the framework definition as such accommodates different possible approaches to a problem. In this study, stakeholders (i.e. users and experts) were involved through workshops that aim to determine if some of the main objectives were excluded or if they overlap with the criteria in the literature review. In particular, the paper proposed the stakeholder analysis [23] to identify which actors should be involved in the workshop and the cognitive mapping technique [24] to organize content. Recent studies have combined these methods to ensure a more inclusive approach in the identification of relevant objectives and criteria [25]. Stakeholders represent actors interested in the decision-making process as they either directly affect or are affected by its resolution. Meanwhile, the cognitive mapping method is well suited for complex problems; it provides a well-arranged systematization of available concepts for the structuring of decision trees [26].

3 Results

3.1 Data Analysis of the Literature Review: Categories Definition and Criteria Selection

Many evaluation tools for accessibility and usability highlight the spectrum of disabling situations for users in any given building setting [28]. This approach can work in private space evaluation, such as a home [3]. Conversely, public buildings bring extensive complexity to the evaluation because of the plurality of space settings and users involved [22]. For this reason, the criteria analysis in this study did not focus on users' disabilities, but rather worked with performance criteria that represent the main objectives to develop environments universally usable and enjoyable for a wider number of users.

Different evaluation tools for UD building features are often based on the *Seven Principles of Universal Design* [29]. These principles refer to human performances, particularly usability issues and aspects related to people's perception of the space (e.g. sensory and cognitive issues) [28]. However, the in-depth literature review provided an overview of different criteria sets in UD (see Table 1) and highlighted social issues over human factors as important aspects that differentiate UD from other user-centered approaches. Social factors ensure evaluation or design for people's needs, thus contributing to their overall well-being and overcoming basic accessibility.

These aspects were introduced in Preiser's *Habitability Framework* [16], specifically in the third order of needs related to social and experiential factors, and in Lawton's *Need Satisfaction Behavior Framework* [30]. Moreover, Sanford proposed adding two principles to the original ones: social and contextual integration [31]. Similarly, Froyen's *Aspects of Universal Design Patterns* [3] extended the *Seven UD Principles* with elements of comfort quality (e.g. light, acoustic properties, and thermal comfort) and features related to wellness (e.g. privacy and esthetic appeal). More recently, the new definition of UD proposed by Steinfeld and Maisel clearly introduced social and health factors, defining it as "a process that enables and empowers a diverse population by improving human performance, health and wellness, and social participation" [7]. Accordingly, the *Eight Universal Design Goals* [7] have been formulated to update the UD principles and identify measurable outcomes where "health" and "wellness" represent the intersection of human performance and social factors. Finally, the *Accessibility Goals* available in the ISO GUIDE 71:2014 [32] were included in this analysis since they aim to provide an approach for the identification and development of standards for project design and evaluation.

Categories Definition

The previous analysis based on the literature review described how UD projects strive to design for diversity and consider all kinds of impairments (e.g. physical, sensorial, cognitive, and social). This is reflected in the analysis of the evaluation criteria sets in the literature, which concerns three main categories (see Fig. 2): two related to human performances (i.e. physical aspects and sensorial-cognitive aspects) and one focused on social aspects. Accordingly, it is possible to define three UD categories in relation to the theories and criteria sets previously analyzed:

Table 1. Criteria sets resulted from the literature review analysis

Universal design principles [29]	Habitability framework [16]		Need satisfaction behaviour [30]	Universal d esign patterns – aspects [30]	Universal design goals [7]		Accessibility goals [32]
Equitable use	Regulations	Health	Security/Safety	Security measure	Human performance	Body fit	Suitability for the widest range of users
Flexibility in use		Safety	Function	Ergonomic measure		Comfort	Conformity with user expectations
Simple and intuitive use		Security	Cognition	Size and Space for approach and use		Awareness	Support for individualization
Perceptible information	Technological knowledge	Functional	Comfort	Light		Understanding	Approachability
Tolerance for error			Order	Acoustic properties			Perceivability Understandability
Low physical effort		Efficiency	Autonomy	Thermal comfort		Wellness	Controllability
Size and Space for approach and use		Workflow	Privacy	Perceptible Information			Usability
			Stimulation	Visual Information	Social participation		Error tolerance
	Social factors	Psychological/Social	Affiliation	Wayfinding		Social integration	Equitable use
		Cultural	Individuality	Identification		Personalization	Compatibility with other systems
		Aesthetic	Spirituality	Privacy		Cultural appropriateness	

- Physical-Spatial Quality: the capability of the environment to foster easy, comfortable, functional, and safe use of space and objects. This means being able to physically interact with a system;
- Sensory-Cognitive Quality: the capability of the environment to foster orientation, comprehension of the service, and comfort of users. This refers to the features that impact peoples' senses and cognition;
- Social Quality: the ability of the environment to enhance well-being and inclusion. It considers emotional stimuli and social integration among users.

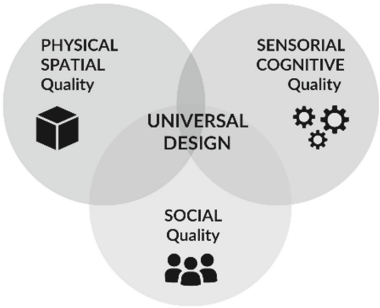

Fig. 2. Framework's categories: physical-spatial quality, sensorial-cognitive quality, social quality.

Criteria Selection

MCDA suggests grouping criteria into a series of sets to separate distinguishable components of the overall objective for the decision [20]. This procedure is helpful when there is a large number of criteria to compare to the current study; it enables shifting from a list of criteria to a hierarchical framework through a comparison aimed at understanding the redundancy of criteria.

Figure 3 shows the complete list of analyzed criteria clustered according to the three categories, as well as their frequency, to develop a preliminary selection and comparison. The different criteria had an average presence of 50%. This value was defined as the exclusion thresh-old value. Nine of the 20 criteria had a frequency lower that the limit value. The criteria selected, considering only their frequency are safety and security, size and space for approach and use, usability, functionality/flexibility, understanding, perceptible information, comfort (environmental factors), health/wellness, and social integration.

	CRITERIA	UD Principles [31]	Habitability Framework[19]	Need Satisfaction Behaviour [32]	Universal Design Patterns [34]	Universal Design Goals [10]	Accessibility Goals [35]	N°	%
PHYSICAL/SPATIAL QUALITY	Safety and Security	Error Tollerance	x	x	x		Error Tollerance	5	83%
	Equitable Use	x					x	2	33%
	Size and Space for Approach and Use	x			x	Body fit	Approachability	4	67%
	Usability	Low physical effort	x				x	3	50%
	Ergonomics				x			1	17%
	Functionality/Flexibility	x	x	x			Support for individualization	4	67%
	Autonomy		Efficiency	x				2	33%
	Personalization					x		1	17%
	Workflow		x	Order				2	33%
SENSORY/COGNITIVE QUALITY	Understanding	Simple and intuitive in use x		Understanding /Awareness	Identification	x	x	5	83%
	Perceptible Information				Perceptible and Visual Information/ Wayfinding		Perceivability	3	50%
	Comfort (Environmental Factors)			x	Light/Acoustic/ Thermal comfort	x		3	50%
	Stimulation			x				1	17%
SOCIAL QUALITY	Health/Wellness		x	Spirituality		x		3	50%
	Aesthetic		x			x		2	33%
	Cultural		x			x		2	33%
	Appropriateness								
	Social Integration		Psycological Social factors	Affiliation		x	Suitability for the widest range of use	4	67%
	Privacy			x	x			2	33%
	Individuality			x				1	17%
	Controllability						x	1	17%

Fig. 3. Criteria selection and comparison

3.2 Data Analysis from Workshops with Stakeholders: Cognitive Mapping

This section shows how stakeholder analysis and cognitive mapping were used for the definition of objectives that characterize the multicriteria model. Workshops were conducted to understand stakeholders' needs, objectives, and expectations [23] regarding the UD project and compare these with criteria found in the literature review.

The study involved experts, such as designers whose work relates to disability, accessibility, and UD, since they have more technical knowledge about accessible design and can provide specific data about UD building features that impact people's well-being. Moreover, users with impairments (e.g. motor, sight, hearing, and mental) were involved to identify needs that designers often ignore and utilize user experiences to improve the environment for all. For instance, people with sensory problems can provide interesting feedback regarding sensorial quality, such as "wayfinding" criteria. Considering the scope of the research, which is improving the environment performance under three

different UD categories found in the literature (i.e. physical-spatial, sensorial-cognitive, and social quality), the stakeholders were divided according to the area they belong to, as shown in Fig. 4.

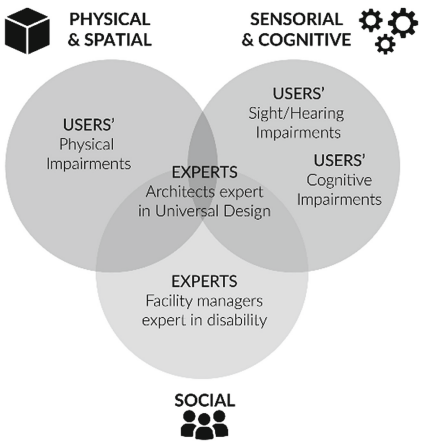

Fig. 4. Stakeholders' analysis in relation to categories.

With the aim of fostering creativity, the workshop's interactive setting (i.e. five participants at most) was used to build the cognitive map. Five workshops were conducted, one with experts (i.e. architects and designers specialized on accessibility and UD) and four with users with motor, sight, hearing, or cognitive impairments. The workshops lasted approximately two hours and consisted of the following phases:

- Introduction: The research topic was described to the participants.
- Feedback: The participants were asked the question, "What are the most important aspects that should be present in a Universal Design space?"
- Post-it session: A common discussion was conducted so that participants can share ideas about major needs and expectations. Meanwhile, post-it are hang on a panel by the facilitator of the workshop to fix the main concepts (e.g. problems, goals, etc.)
- Analysis: The main concepts discussed were reviewed together to find relations and define criteria and indicators.

The cognitive mapping technique was used to compare the results of the workshops. In this study, the final maps summarized the outputs of the post-it phase (i.e. repetitive concepts were eliminated, and similar concepts were merged). Figure 5 presents an example of a cognitive map of the results of the workshop with people with physical impairments. In Fig. 5, the gray boxes represent the main objectives (i.e. criteria) mentioned in the workshop, while the white boxes refer to characteristics that enable the achievement of the main objectives (i.e. indicators).

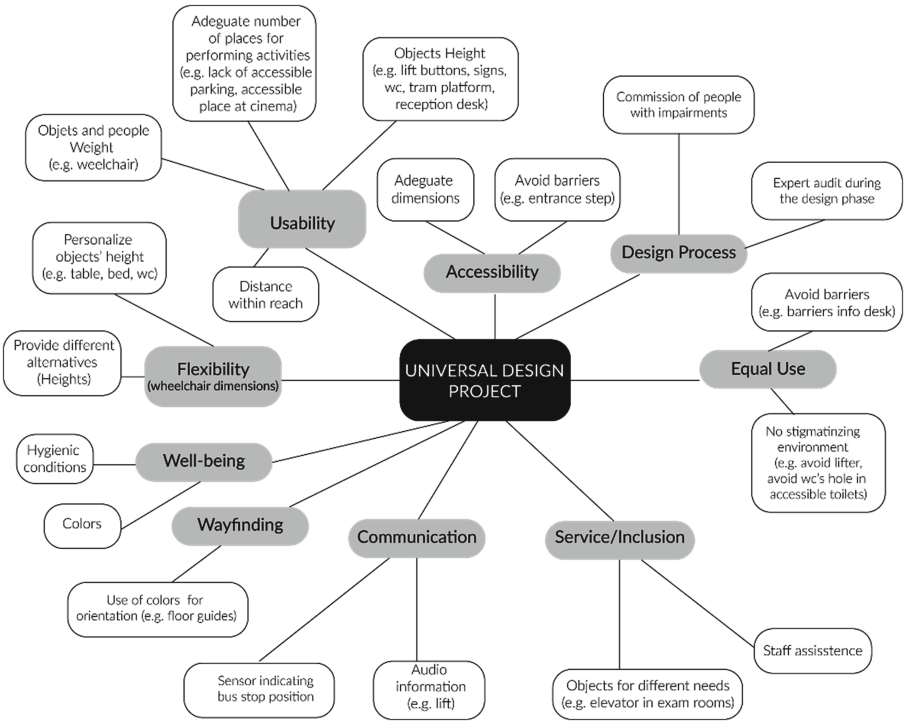

Fig. 5. Cognitive map of the workshop with people with physical impairments.

3.3 Universal Design Objectives in Relation to the Needs of Different Users

The five workshops supported the identification of users' and experts' objectives regarding a UD environment. Figure 6 clearly highlights that the objectives of people with visual impairments referred mostly to aspects related to sight, such as orientation, communication and light. Meanwhile, the objectives of people with motor impairments were more related to the use of the space and furniture.

The cognitive maps derived from information gathered during the workshops were converted into a unique hierarchical structure to identify information that overlap or differ from any group. The decision tree generated (see Fig. 6) shows the overall goal, the stakeholders involved, the set of criteria obtained from the literature and the stakeholder's objectives identified in the workshops. Moreover, this analysis reveals that 'usability' is related to the use of both space and object and it includes the criteria 'size and space for approach and use'.

3.4 Universal Design Assessment Framework: Categories, Criteria and Indicators

The previous analysis enabled the development of a hierarchical model of criteria that represents a preliminary attempt to define a framework, also called decision tree, of UD measurable objectives.

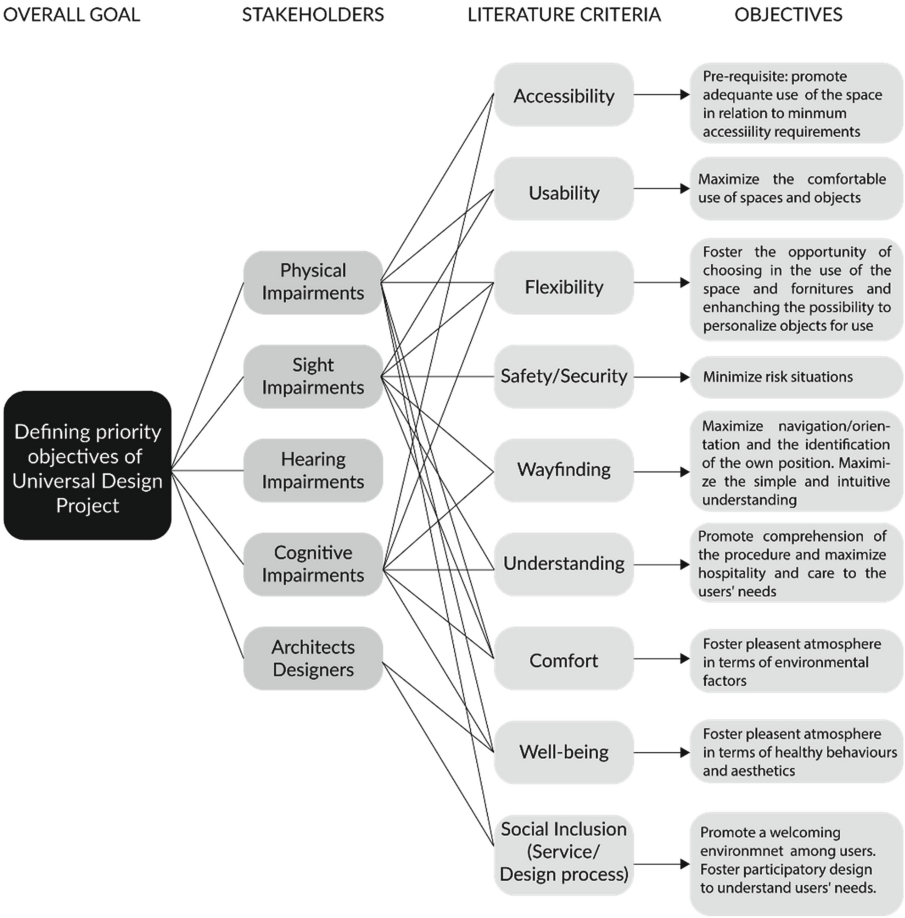

Fig. 6. Hierarchical structure of the objectives expressed by the stakeholders resulted by the comparison of the cognitive maps.

Table 2 shows the proposed framework developed from the previous analysis. The framework is composed of three main categories, a set of eight criteria, and 21 indicators. The *physical-spatial quality* category refers to the way people interact with the space in a physical way. The *sensorial-cognitive quality* category focuses on activities that involve the senses and the intellect as orientation in a space. The *social quality* category concerns attention given to meeting users' needs and wishes in diverse contexts and tending to individuals' health (i.e. wellness) and behavior (i.e. social inclusion). The eight criteria can be described as follows based on information gathered from the studies analyzed in the literature review and the workshops:

- Usability: to use environments, facilities, and objects to ensure the comfort of different users (e.g. distance, dimension, weight, number of people, etc.). Usability includes accessibility, which is considered a pre-requisite;

Table 2. Proposed evaluation framework of Universal Design buildings' performance

Categories	Criteria	Indicators
1. Physical-spatial quality	1.2 Usability	Equal use of the environment
		Equal use of furniture
	1.3 Functionality	Flexibility/Personalization
		Low physical effort
		Flows/Distribution
	1.4 Safety/Security	Minimize risk situations
		Maximize security perception
2. Sensorial-cognitivequality	2.1 Wayfinding	Visual information (signs, colors, map, landmark)
		Perceptible information (tactile, sound)
	2.2 Understanding	Information easy to understand (symbols, language, color contrast)
		Communication (awareness, ICT)
	2.3 Environmental factors	Illumination (natural/artificial)
		Acoustics
		Thermal comfort
		Indoor air quality
3. Social quality	3.1 Well-being	Health promotion and Physical activity
		Hygienic conditions
		Aesthetic quality (color, materials)
	3.2 Social Inclusion	Cultural appropriateness
		Social relation (integration and privacy)
		Inclusive design process

- Functionality: to satisfy the preferences of different users through flexibility and adaptation of space and furniture in terms of use and time (i.e. maintainability);
- Safety/Security: to guarantee safety and security of different users in both emergency and common situations, by minimizing risks without stigmatized solutions;
- Wayfinding: to orientate users with visual, tactile, and verbal information to help them determine their own position in a space;
- Understanding: to communicate information in an effective and simple way through different methods, regardless of the environmental conditions or the cognitive and sensory abilities of users;

- Environmental Factors: to evaluate the indoor comfort conditions of a building's environment by analyzing air quality, thermal comfort, acoustics, and lighting;
- Well-being: to transfer positive emotions to different users through healthy behaviours, physical activity and the design of the environment and its soft qualities, pleasantness, and esthetics;
- Social Inclusion: to foster active participation of different users during the design process, guarantee the same experience for all users, reinforce the cultural values of any design project, and treat all groups with dignity and respect.

Finally, the indicators of Table 2 come from both the analysis of the literature and the information gathered with the different cognitive maps of the workshops. Each indicator is evaluated by the presence or absence of specific requirements, as a checklist, by means of a binary scale. In this way, a score is assigned to each indicator in relation to the characteristics' presence.

4 Discussions

The present work proposes a UD performance-based evaluation framework aimed at assessing the quality of the built environment to improve its usability and social inclusion for a wider number of users. According to the MCDA, the framework is composed of 21 indicators and eight main criteria (i.e. usability, functionality, safety/security, wayfinding, understanding, comfort, well-being, social inclusion) divided into three categories: physical-spatial quality, sensory-cognitive quality, and social quality.

The study represents a first attempt to investigates the actual meaning of UD criteria that, as showed by the analysis, still overlap or lack of clear features needed to assess the built environment in terms of usability and inclusion. In this sense, the literature review explored existing studies and provided the basic UD criteria, while the workshops with the cognitive mapping technique enabled the gathering of evidence regarding stakeholders' objectives through a participative approach.

The proposed framework can be considered an innovative approach in the field of accessible design, since it takes into account social factors, in addition to physical, sensorial and cognitive aspects, which are basically considered in different evaluation tools of accessible design. The framework can be used in practice as a decision support system (DSS) at the beginning of the design process. For example, the framework can be adopted for focus group discussions with different stakeholders as a reference to determine if the proposed design solution takes into account the different objectives of a UD project in relation to physical, sensory/cognitive, and social quality.

Nevertheless, this research has limitations. For instance, the workshop used to identify objectives and enhance knowledge from the literature review are limited in number. The validation of the framework can be an opportunity to expand the discussion by engaging more experts or conducting a focus group with different stakeholders in one meeting.

Furthermore, the analysis was conducted at criteria level, considering the environment as a whole, but deeper considerations can emerge when examining specific buildings spaces. One possibility is to experiment the framework proposed focusing on the

different building's areas considered in the evaluation (e.g. entrance, horizontal circulation, rooms, etc.). As such, a possible research line is the adoption of the evaluation framework to gather more information about each criterion by focusing on different space settings that characterize a typology of public building (e.g. schools, hospitals, workplaces, etc.).

5 Conclusions

The present study describes the development of a design evaluation framework, which can be considered a starting point when measuring UD building performance using a rating system. The system can help inform choices amid different alternatives and suggest interventions to increase buildings' usability and inclusion. Accordingly, a performance-based approach can prevent subjective evaluation and overcome prescriptive regulations, allowing the comparison of different building solutions.

In this regard, two main research lines can be followed: (1) developing a DSS to be used during the design process involving stakeholders to improve the usability and inclusion of new buildings and renovations and (2) developing a tool for POE to objectively define the priority of interventions in existing buildings. In both cases, the tool can produce new evidence-based design knowledge to suggest guidelines used from the beginning of the design process to support designers and avoiding extra time, extra costs, and disabling situations.

Acknowledgements. The authors of this paper want to show their great gratitude to all the participants to the workshops and people who supported the organization. In particular, the associations that made it possible to conduct this study are: Lega per i Diritti delle Persone con Disabilità (LEDHA) Milano, Unione Italiana Lotta alla Distrofia Muscolare (UILDM) Milano, Associazione Nazionale Subvedenti (ANS) Milano, Solidarietà in Rete (SIR), Associazione Italiana Sclerosi Multipla (AISM) Milano and Design for All Italia. The study is part of the doctoral research of E.M. at the Department of Architecture, Built environment and Construction engineering of Politecnico di Milano.

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