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Universal Design 2024: Shaping a Sustainable, Equitable and Resilient Future for All

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Wolfgang V. Leister
Juan Carlos Torrado Vidal

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Contents

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Universal Design 2024: Shaping a Sustainable, Equitable and Resilient Future for All
K.S. Fuglerud et al. (Eds.)

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Future-Proof Homes. Design Support System for Selecting Age-Adaptive Building Elements and Finishes

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Abstract. The paper illustrates the definition of a home adaptation design support tool for selecting interior finishes and partition systems based on multicriteria evaluations. In line with Universal Design principles, the selection criteria promote the creation of homes that respond to the changing needs of people over their life course, allowing for aging in place. Based on a literature review on the design of age-friendly living spaces, optimal requirements for safety, comfort, usability, management, environmental protection and integrability related to partitioning elements and interior finishes were identified. Then, through the multicriteria analysis technique of the Analytic Hierarchy Process, selection criteria were established, and weights were assigned to classify market-available products according to performance, thereby informing the choices of designers and end users.

Keywords. aging in place, lifespan housing, universal design, multicriteria analysis, finishes and partitions

1. Introduction

In the current context characterized by an aging population, the design of housing that can adapt to people's needs throughout their lifetimes is crucial for promoting aging in place and optimizing resource use by extending the operational life of buildings.

In response to these needs, living spaces, furnishings, and technological equipment must be designed according to Universal Design principles in order to support various levels of autonomy and be compatible with home care activities, a key node of the long-term care services network [1].

This paper aims to re-evaluate domestic spaces based on the performances of elements such as walls, floors, and ceilings, also considering the biopsychosocial ICF model [2], which emphasizes the active role of the physical environment in improving the quality of life through spatial, technological, and material features that can support functional limitations and facilitate caregiving activities.

Specifically, this study presents findings from research funded by Sapienza University of Rome, aimed at developing a multicriteria evaluation tool for selecting partition systems and interior finishes suitable for aging and varying abilities, from a life-course perspective.

First results of the same research have already focused on a multicriteria selection system of aging-friendly furnishings, including when home care is needed [3]. In order

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to consider other spatial and technological features, the study presented here addresses the selection of internal partitions and related finishes as key physical interfaces between the space and users.

Starting with a literature review, optimal requirements were identified, diversifying between those related to finishes and those related to interior partitions, and considering sustainability and the possibility of integrating "smart" Ambient Assisted Living (AAL) devices as necessary cross-cutting features.

Subsequently, through the multicriteria analysis technique of Analytic Hierarchy Process (AHP) [4], such requirements were transformed into selection criteria to which weights were assigned to classify market-available products based on performance, thereby informing the choices of designers and end users.

2. Methods

To study the characteristics of housing suitable for meeting people's changing needs across the lifespan, the first phase of the research involved a review of the gray and scientific literature within databases such as Google Scholar, PubMed and in specialized repositories such as The Centre for Health and Design.

From the review, optimal characteristics of age-friendly housing were identified, with a focus on requirements for interior finishes and partitions.

For the two different areas of observation (walls and ceilings; floors, wall finishes, and ceiling finishes), from the technical requirements identified in the first phase of the research, specific evaluation sub-criteria were defined, grouped into the following macro-categories of criteria: Safety; Comfort; Usability; Easy Management; Environmental protection; Integrability and installation/disassembly impact.

Then, in the second phase, referring to the AHP multicriteria evaluation technique, the following steps were performed: definition of markers for each evaluation sub-criterion; assignment of a weight to each sub-criterion and criterion; implementation of the evaluation tool through spreadsheets.

The third phase involved the application of the tool for the evaluation of commercially available products sourced through desk research.

3. Technical selection criteria

Selecting indoor finishing materials/products and flexible construction solutions is crucial in designing inclusive and supportive age-adaptive environments. Therefore, it is necessary to identify spatial, technological and material features that can compensate/support any functional limitations and facilitate future care activities within the home environment.

3.1. Floorings, Wall and ceiling finishes

Flooring features greatly affect the safety of users, even more so if they have mobility or cognitive difficulties. In this case, technical choices should favour non-slip materials in dry and wet conditions [5, 6].

For fire safety, flooring should have a low reaction to fire and limit smoke emission in case of burning. Also considering the health implications, choosing coatings that do not release pollutants or toxic substances is important.

Concerning visual comfort, reflective or highly shiny surfaces can cause glare and hide the presence of liquids on the floor, increasing the risk of slipping. Excessive contrast between two adjacent floors can also be mistaken for a step by people with visual or cognitive disabilities [7, 8]. Similarly, high-contrast patterns should be avoided because they can cause disorientation and prevent recognition of objects on the floor [9].

To ensure good usability by all, the flooring components should be firmly fixed, flat, with minimum joints and projections.

Regarding acoustic comfort, soft coverings with high sound-absorbing power should be preferred. However, opting for carpeting, for example, would prevent easy use of movement aids [8] and cause difficulties in cleaning operations. In fact, flooring characteristics also affect the ease of space management. Floors must be stain-resistant and allow easy cleaning [10] by choosing nonporous and nonabsorbent materials. They must also be resistant to wear and tear and hard enough not to be nicked or marked by the passage of carts, removable furniture or wheelchairs.

Wall and ceiling finishings also play an essential role in facilitating aging in place.

To maximize natural and diffuse lighting, it is preferable to use light colors with a high reflection coefficient [11], reducing reflections so as not to cause visual discomfort.

Regarding aesthetic-perceptual characteristics, it has been shown in the literature that bold and repetitive patterns can cause illusions, restlessness and confusion in people with dementia [8]. Therefore, soft or pastel-colored upholstery is recommended [12].

In addition, combining user- and environment-focused design approaches and adhering to circular economy principles, using natural, non-toxic, and recyclable materials and systems that allow replacement parts to improve performance potential and reusability while maintaining aesthetic and sensory quality is a priority.

The aforementioned has been systematized in Table 1, which shows the set of technical criteria categories, sub-criteria and related indicators of success.

For each sub-criterion, a specific marker expressing the degree of satisfaction of the performance requirement was defined. Therefore, a scale of discrete values that allows for a score of 0 in the case of an unmet requirement, 0.5 in the case of a partially met requirement, and 1 in the case of a fully met requirement was defined.

Table 1. Criteria, sub-criteria, marker and score ranges for coating materials

Criteria	Sub-criteria	Applicability	Marker	Low score (0)	Medium score (0.5)	High score (1)
1. Safety	1a. Low reaction to fire	Fc/Wc/Cc	Reaction to fire	Highly flammable	/	incombustible
	1b. Low VOC emission	Fc/Wc/Cc	VOC certificate	High emission	/	Low emission
	1c. Non-slip surface	Fc	Friction coefficient (μ) (or equivalent)	μ<0.4	μ 0.4-0.6	μ >0.6
	1d. Visual uniformity	Fc/Wc/Cc	Presence of pattern/textures	Surface with patterns	/	Monochromatic surface
2. Comfort	2a.Sound absorption	Fc/Wc/Cc	Sound absorption coefficient (α)	α <0.4	α 0.4-0.8	α >0.8

3. Usability	2b. Pleasant to touch	Fc	Thermal conductivity (W/mK)	>1	0.1-1.0	<0.1
	2c. Light reflectance and contrast	Fc Wc Cc	Light reflectance value (LRV)	<0.3 <0.6 <0.8	/ / /	0.3-0.5 0.6-0.8 0.8-0.9
	2d. No shiny/ no glare	Fc/Wc/Cc	Sheen/ Glossiness	Sheen >70%	Sheen 25-70%	Sheen <25%
	3. Flat without joints	Fc	Installation without joints or projections	Joints > 5mm projections > 2mm	/	Joints < 5mm and projections <2 mm
4. Easy Management	4a. Resistance to scratch and wear	Fc	Resistance to wear / Hardness	Prone to wear	Medium resistant	Hard / Resistant
	4b. Easy to clean	Fc/Wc	Stain resistance / Low porosity	High porosity	/	ceramic tiles >ClassIV; low porosity
5. Env. Protection	5a. Recyclability	Fc/Wc/Cc	Recyclability certification	Without certification	/	With certification
	5b. Recycled content	Fc/Wc/Cc	Certified recycled content	<10%	10-50%	>50%
	5c. Sustainable manufacturing	Fc/Wc/Cc	Sustainabilit y certifications	Without certification	/	With certification
	5d. low transportation impact	Fc/Wc/Cc	Distance	>500km	150-500km	<150km
6. Integrability	6a. Ease of replacement	Fc/Wc/Cc	Separability	Non-separable	Partially separable	Separable
	6b. Removability	Fc/Wc/Cc	Dry installation	Wet installation	/	Dry installation
	6c. Impact construction work for installation	Fc/Wc/Cc	Installation	Work involves building elements	work involves only finishings	No work required

Cc= ceiling coating material; Fc= floor coating material; Wc= wall coating material.

3.2. Internal Walls and Ceilings

Adopting solutions for interior partitioning from a perspective that anticipates future needs will save time and costs due to subsequent home modifications.

To promote interior flexibility, it is advisable to use movable partitions consisting of sliding panels that are preferably soundproof, lightweight, easily maneuverable, and have no floor rails so that they do not constitute an obstacle and avoid dirt accumulation.

As an alternative to movable partitions, drywall solutions should be favored, organizing structural frames to facilitate strategically placed openings, expand existing rooms, or allow the removal of the portion of the wall above the doors for the passage of a ceiling hoist. Another preventive approach is to choose partition walls with adequate mechanical properties to allow the installation of grab bars. [13].

To encourage flexible use of space and increase its potential to accommodate different functions, it is essential to provide walls and ceilings for the passage of cables and to facilitate the incorporation of assistive ICT devices [5]. To this end, the choice of drywall systems with adequately sized cavities is a preferable solution also to facilitate their inspectability, taking care, however, to ensure adequate sound insulation to benefit from a quiet environment [13].

In accordance with circular economy instances, it is preferable that products result from recycled processes or are highly recyclable and come from factories near the construction site. The construction system chosen should also favor disassemblability of components to facilitate their replacement and/or removal.

The set of technical criteria categories, sub-criteria and related success indicators for internal partitions are shown in Table 2.

Table 2. Criteria, sub-criteria, marker and score ranges for walls and ceilings

Criteria	Sub-criteria	Applicability	Marker	Low score (0)	Medium score (0.5)	High score (1)
1. Safety	1a. Low reaction to fire	W/C	Reaction to fire	Highly flammable	/	Incombustible
	1b. High resistance to fire	W	Fire resistance	<EI30	/	>EI60
2. Comfort	2a. Sound insulation	W/C	Sound insulation (Rw)	<25	30-50	>50
3. Easy Management	3a. Mechanical strength	W/C	Load resistance	<50kg	50-250kg	>250kg
	3b. Impact resistance	W	Impact resistance	Not compliant	/	Compliant with impact from a hard and soft body
	3c. Flexibility	W	Movability	fixed	/	Easy to move
4. Environmental Protection	4a. Recyclability	W/C	Recyclability certification	Without certification	/	With certification
	4b. Recycled content	W/C	Certified recycled content	<10%	10-50%	>50%
	4c. Sustainable manufacturing	W/C	Sustainability certifications	Without certification	/	With certification
	4d. low transportation impact	Fc/Wc/Cc	Distance	>500km	150-500km	<150km
5. Integrability	5a. easy plant integration	W/C	Presence of cavities	Wall without cavity	/	Wall providing cavity
	5b. Removability	W/C	Dry installation	Wet installation	/	Dry installation
	5c. Impact construction work for installation	W/C	Installation	Work involves building elements	Work involves only finishings	No work required

C= ceilings; W= internal walls

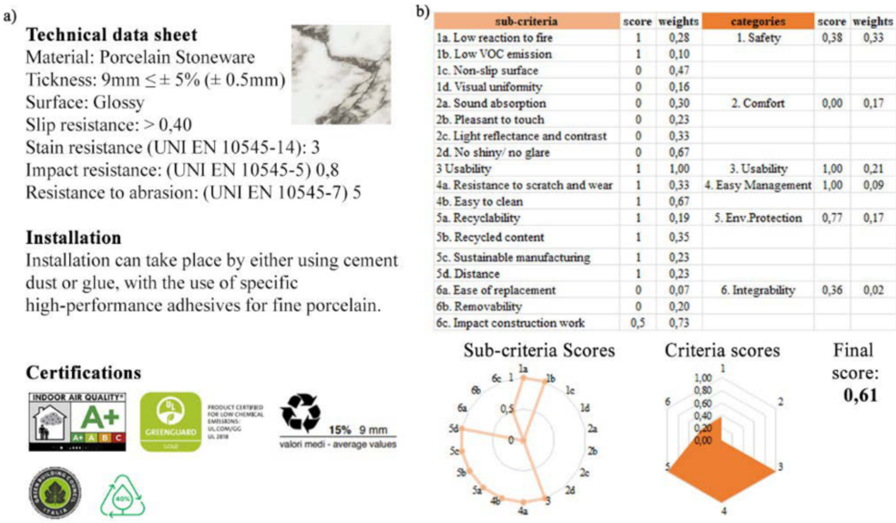
The assignment of weights for both criterion categories and sub-criteria was done using the value scale proposed by Saaty [14]. The final score given to a product (finishing or partition) is obtained from the weighted sum of the partial scores for each criterion, which are obtained from the weighted sum of the scores for each sub-criterion.

Due to a lack of space, Tables with weights are available in Appendix A.

4. Results

The proposed multicriteria evaluation tool was tested for selecting a new flooring and inserting a new interior partition, simulating the renovation of an apartment in Rome, Italy.

The technical information about a flooring was retrieved from the data sheets provided by the manufacturer (Figure 1a) and, through the indicators defined in Table 1, discrete scores were assigned and entered into the prepared spreadsheet. The spreadsheet returns within two polar graphs the partial scores related to the satisfaction of each sub-criterion, the partial scores for each criterion, and an overall score (Figure 1 b).

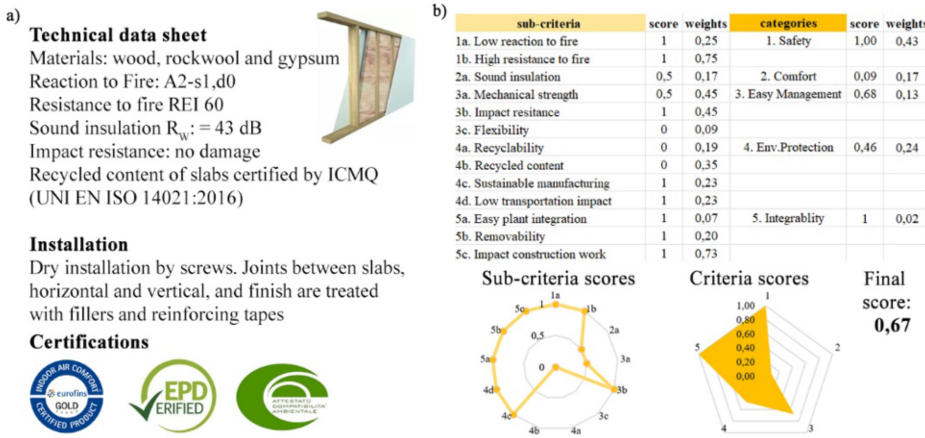


sub-criteria	score	weights	categories	score	weights
1a. Low reaction to fire	1	0,28	1. Safety	0,38	0,33
1b. Low VOC emission	1	0,10			
1c. Non-slip surface	0	0,47			
1d. Visual uniformity	0	0,16			
2a. Sound absorption	0	0,30	2. Comfort	0,00	0,17
2b. Pleasant to touch	0	0,23			
2c. Light reflectance and contrast	0	0,33			
2d. No shiny/ no glare	0	0,67			
3 Usability	1	1,00	3. Usability	1,00	0,21
4a. Resistance to scratch and wear	1	0,33	4. Easy Management	1,00	0,09
4b. Easy to clean	1	0,67			
5a. Recyclability	1	0,19	5. Env.Protection	0,77	0,17
5b. Recycled content	1	0,35			
5c. Sustainable manufacturing	1	0,23			
5d. Distance	1	0,23			
6a. Ease of replacement	0	0,07	6. Integrability	0,36	0,02
6b. Removability	0	0,20			
6c. Impact construction work	0,5	0,73			

Figure 1. a) data retrieval from the technical sheets provided by the flooring manufacturer.; b) outcome of multicriteria evaluation

Likewise, a solution for the construction of an internal partition was evaluated (Figure 2). By repeating the evaluation for other finishes and partitions, the tool allows the comparison of different alternatives, making objective conformity of their performance with the fulfillment of Universal Design principles translated into selection criteria. The tool is intended to be used by the designer, as it requires technical expertise in interpreting product data sheets and using spreadsheets. However, by highlighting the objective conformity of different alternatives to predetermined requirements, the user participates more consciously in the decision-making process.

Using the proposed tool, the designer can also consider, along with the results, other factors that determine the final choice, such as possible user preferences, costs, and other technical constraints determined by the specific context of intervention.



sub-criteria	score	weights	categories	score	weights
1a. Low reaction to fire	1	0,25	1. Safety	1,00	0,43
1b. High resistance to fire	1	0,75			
2a. Sound insulation	0,5	0,17	2. Comfort	0,09	0,17
3a. Mechanical strength	0,5	0,45	3. Easy Management	0,68	0,13
3b. Impact resitance	1	0,45			
3c. Flexibility	0	0,09			
4a. Recyclability	0	0,19	4. Env.Protection	0,46	0,24
4b. Recycled content	0	0,35			
4c. Sustainable manufacturing	1	0,23			
4d. Low transportation impact	1	0,23			
5a. Easy plant integration	1	0,07	5. Integrablity	1	0,02
5b. Removability	1	0,20			
5c. Impact construction work	1	0,73			

Figure 2. a) data retrieval from the technical sheets provided by the manufacturer; b) outcome of multicriteria evaluation

Currently, the tool supports the evaluation and comparison of isolated products. However, future research developments intend to include in the evaluation system the mutual compatibility of multiple compliant solutions, as well as their compatibility with respect to other contextual constraints.

Furthermore, in future advancements of the study the observed aspects will be considered along with the spatial configuration and other building elements (doors, windows, lighting, etc.) by taking advantage of the digitization of technical information using Building Information Modeling methodologies .

5. Conclusions

To meet people's living needs, it is necessary to promote an approach to design that moves from a dogmatic attitude built on regulations and standards to one focused on the selection of materials and components based on their performance. According to these assumptions, the paper outlines a multicriteria evaluation system to support the designer in selecting interior partitioning elements and related finishes that comply with Universal Design principles [15].

Such principles, when considered as one of the filters for selection, along with eco-friendly features, can help achieve full social and environmental sustainability of housing adaptation interventions for aging in place.

Considering the principle of *Equitable use*, the selection criteria promote finishing products according to the logic of inclusion and design for all.

Preferable solutions for partitions adapt to how people use them according to their different conditions, meeting the principle of *Low physical effort* and *Flexibility in use* of spaces, ensuring through the facilitation of different configurations the appropriate *Size and Space for Approach and Use.* Moreover, by allowing the harmonious integration of systems and any assistive technologies, they promote *Simple and intuitive use* of spaces, leaving the routine of daily life unaffected. The joint control of finishes' technical and sensory performance makes the home more communicative, in line with the principle of *Perceptible information*.

Finally, in terms of *Error Tolerance*, the system rewards solutions that minimize the risks and negative consequences of installation errors, assembly of drywall components and their connections.

Through tools that facilitate the identification and choice of such solutions, an adaptive pathway that pursues the concept of progressive accessibility can be promoted. Therefore, it is important to know the optimal performance for the user's preventive choices and lifelong planning. It is equally useful to have tools, such as the one proposed, that facilitate this anticipatory approach to incorporate universally designed age-friendly features, which can then save costs of tailored interventions when needed. By guiding choices and controlling costs, this could also provide useful input to the housing construction industry and direct market innovations toward more inclusive solutions.

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