ISSN 2712-0554
Original Research

Heritage and Sustainable Development
Vol. 6, No. 1, June 2024, pp.379-394
https://doi.org/10.37868/hsd.v6i1.425

An LCIA-based model proposal for the selection of building interior finishing materials

Nil Kokulu[1*], Seden Acun Özgünler[2], Fethiye Ecem Edis[3], Saniye Karaman Öztaş[4]
[1,2,3] Department of Architecture, Istanbul Technical University, Turkey
[1] Department of Architecture, Antalya Bilim University, Turkey
[4] Department of Architecture, Gebze Technical University, Turkey

*Corresponding author E-mail: kokulu@itu.edu.tr

Received Mar. 2, 2024
Revised May. 16, 2024
Accepted May. 22, 2022

Abstract
The increasing environmental impacts of buildings highlight conscious material selection as a pivotal aspect of sustainable building design. Most current life cycle impact assessment (LCIA) models on material selection focus on the main construction or insulation materials while often neglecting the environmental effects of finishing materials. Hence, this study seeks to present an LCIA-based model for selecting finishing materials based on their environmental impacts. Environmental Product Declaration (EPD) as a data source for the mandatory steps of LCIA is recommended for the model since it provides fast, reliable, and equivalent data on the environmental impacts of the materials. The model is validated by assessing three wall finishing materials in hotel bedrooms- gypsum board, paint, and wood panel. Findings revealed that the model has the potential to mitigate the environmental effects by guiding decisions made during the finishing material selection phase.

Keywords: Life cycle impact assessment, Finishing material selection, Environmental product declaration, Sustainability, Environmental impact

1. Introduction

The contribution to sustainability by sectors producing goods and services requires improvements to functions protecting ecosystems functions, adapting to necessary regulations, progressing with technological advancements and cultural shifts within the environmental dimension [1]. The construction industry can significantly contribute to this transition by reducing greenhouse gas emissions, particularly carbon. The sector is the leading emitter, constituting 37% of global emissions [2]. Additionally, materials manufactured within the construction sector led to issues such as decreased biodiversity, depletion of energy, water, and raw material resources, and increased waste production [3].

Building materials are the essential components shaping a structure, and their selection significantly influences building properties. Conscious choices during the design stage are impactful in minimizing environmental effects. In discussions of building materials, finishing materials are often overlooked, yet they are instrumental in determining the overall sustainability of a construction project [4]. Durability, appearance, acoustics, and comfort are among the key parameters to consider when choosing finishing materials.

Additionally, environmental sustainability has become a crucial criterion since energy loads, raw materials, and water scarcity have been taken into attention.

Studies show that the choice of finishing materials significantly impacts the environment. Reference [5] stated that the parameters such as service life, maintenance, and effectiveness significantly affect the costs and environmental effects that will occur throughout the life cycle of the materials. Reference [6] found that ceramic floor tiles have 7.5 times higher water demand than ceramic roof tiles and bricks. Reference [7] highlighted how quality finishing materials are crucial for balancing indoor humidity and temperature, preventing energy losses. Reference [8] noted that pollutant emissions from finishing materials are often overlooked, posing risks to indoor air quality and residents' health. Reference [9] revealed that finishing materials constitute 24.26% of total construction waste in Iraq. Reference [10] found that finishing materials' waste can surpass that of structural materials.

The choice-making process of sustainable material selection is challenging because of the multitude of criteria, data, and impact categories [11]. Institutions and researchers have devised systematic methods to assess environmental impacts, aiding decision-makers in the material selection process. Life cycle assessment (LCA) has become a critical tool in this endeavor, comprising four main stages: goal and scope definition, inventory analysis, impact assessment, and interpretation. The third stage, known as the life cycle impact assessment (LCIA), concentrates on assessing potential environmental impacts across various categories. It includes mandatory components like impact category, category indicator, characterization model selection, classification, and characterization, as well as optional aspects such as normalization, grouping, and weighting [12].

Various LCIA models exist to evaluate finishing materials' environmental performance. BEES was developed by the EPA in 1996 [13]; BRE by the Construction Research Council in 1999 [14]; BPIC-ICIP for the international construction industry in Australia [15]; ATHENA by Athena Sustainable Materials Institute in 2002 [16]; BEPAS by the Construction Management Department of Tsinghua University in 2004 [17]; BELES by Tsinghua University Department of Building Sciences and Building Energy Research Center in 2004 [18]. Alternatively, practitioners may choose self-developed approaches [19], [20], [21]. While these LCIA methods facilitate finishing material evaluation, they also present specific drawbacks. Firstly, they can yield diverse results for the same material, leading to different decision-making scenarios. Variability arises from factors like substances considered, characterization factor values, impact categories, and emission values in inventories [22]. Users find it challenging to determine the optimal evaluation method for specific materials due to the scale of these approaches. Secondly, these methods tend to favor external normalization, which relies on reference data for regional and global resource comparisons, potentially containing errors from inventory inconsistencies [23], [24]. The changing nature of the emissions creates a requirement for the database to be updated periodically [25]. Lastly, a critical point involves the service life and renewal frequency of materials. Assessing a building's service life determines material renewal frequency and environmental impact recurrence, varying from 4% to 25%, depending on the impact category [26]. Reference [27] emphasized the significance of service life in environmental impact assessments, highlighting that LCIA methodologies often rely on fixed material and system replacement cycles.

According to [28], LCIA is one of the weakest parts of LCA due to variations in approaches. Conducting an LCIA study is difficult because it requires extensive collection, synthesis, and computation of data throughout its implementation. Data-gathering solutions involve the usage of various international databases such as GaBi, Impacts database, Ecoinvent, Synergia, and environmental product declaration (EPD) [29]. According to [30], the use of an EPD database offers a higher level of standardization compared to others. The International Life Cycle Data (ILCD) System advises using EPDs in LCA for consistency and quality [31].

EPD, established by EN 15804:2012+A1:2013, is an authenticated report providing clear and consistent evaluations of materials' environmental impact [32]. EPDs assess 13 core and 6 additional environmental impact categories [33]. They enable material evaluation across various scopes: cradle-to-gate, cradle-to-grave, and cradle-to-cradle scopes. As of January 2022, over 80,000 EPDs for construction products have been generated through 29 EPD programs, supporting comparative analyses [34]. Several studies use EPDs as a data source to conduct an LCIA on finishing materials [4], [35], [36]. The positive influence of EPD data on LCA results has been examined by various researchers [29], [37].

Finishing material selection methods are primarily grounded in the intended function of the space, the technical attributes of the material, or its aesthetic appearance. Decision-makers often lack awareness of finishing materials' environmental impacts [38]. To address this, this study introduces an LCIA-based model for environmentally conscious finishing material selection, distinguishing itself with three key features: (1) using EPD documents to enhance input-output calculations and appraise the environmental performance of materials on a one-to-one basis, (2) employing internal normalization for material comparison, and (3) independently evaluating material service life, considering renewals within the building's predetermined lifespan.

2. Research method

The current stage involves the following procedure: (1) the finishing material selection model development (2) functional unit conversion, (3) internal normalization - division by maximum approach, (4) environmental impact score calculation. The model flowchart is shown in Figure 1.

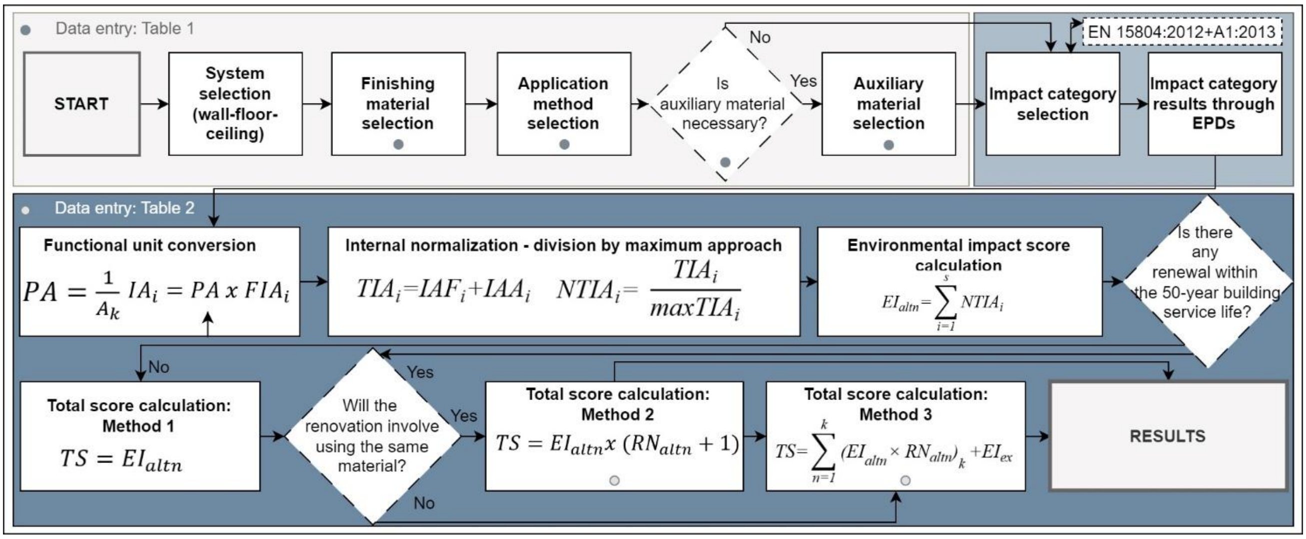

Figure 1. The model flowchart

2.1. The finishing material selection model development

Many finishing materials require auxiliary components. For instance, adhesives are used for installing carpets. For a comprehensive impact assessment, both the environmental effects of the finishing material and its auxiliary materials must be considered [39]. The need for auxiliary materials may differ based on the application method of the finishing materials. The finishing material options, application methods, and auxiliary materials were determined through a literature review (Table 1). The initial step in the model involves selecting finishing materials and, if applicable, auxiliary materials. For an impact assessment comparison through the model, at least two finishing materials must be selected within the specified wall, floor, or ceiling system. This model follows a problem-oriented midpoint approach, minimizing uncertainties compared to other methods [40]. The model has adopted EN 15804:2012+A1:2013 [33] for mandatory steps of LCIA. The model user selects impact categories using this standard, taking local parameters into account, and retrieves category results from the materials' EPD. The calculations to be performed after this selection are described in the following sections.

2.1.1. Functional unit conversion

EPDs are not directly comparable unless they share the same functional unit [36]. The model adopts a functional unit of 1 m^2. A specific formula, detailed in Equations 1 and 2 [35] is applied if the functional unit differs.

$$PA=\frac{1}{A_k} \tag{1}$$

Where PA: the amount of product in m^3 or kg required for 1 m^2 area; A_k: the surface area covered in m^2 by a product with a functional unit of 1 m^3 or kg.

$$IA_i=PA \times FIA_i \tag{2}$$

Where IA_i: environmental impact assessment score for different environmental impact categories of the amount of product required for 1 m^2 area; PA: the amount of product in m^3 or kg required for 1 m^2 area; FIA_i: impact assessment score for different environmental impact categories of the product with a functional unit of 1 m^3 or kg.

Table 1. Finishing materials, application methods, and auxiliary materials

System	Finishing material (F_m)	Application methods	Auxiliary materials (A_m)	Reference
Wall	Artificial stone	mechanical fixing with a structural system	-	[41]
	Ceramic	bonding	cementitious adhesive + joint filler	[42]
		mechanical fixing with a structural system	-	[43]
	Natural stone	metal clamping system	-	[42]
		bonding	polymer added cement mortar + joint filler	
	Paint	painting	primer + paste backfilling	
	Gypsum board	mechanical fixing with a structural system	plaster + paint +pastefilling	[41]
	Gypsum liquid	plastering	rough-cast	
	Polymer	bonding	adhesive	[43]
		mechanical fixing with a structural system	-	
	Wallpaper	gluing	adhesive	[41]
	Wood	paneling	-	[42]
Floor	Carpet	gluing	adhesive	[41]
		loose-laid	-	
	Ceramic	bonding	cementitious adhesive + joint filler	[42]
	Natural stone	bonding	polymer added cement mortar + joint filler	[41]
	Wood	gluing	adhesive	
		mechanical fixing with a structural system	-	
Ceiling	Paint	painting	primer + paste backfilling	[44]
	Gypsum board	(1) hanging with a rod (2) directly applied to the ceiling (3) mounted on a structural system	plaster + paint +pastefilling	
	Polymer		-	
	Wood		-	

2.1.2. Internal normalization - division by maximum approach

EPD documents present environmental impact scores that can't be directly summed due to unit variations. Standardizing units is crucial to calculate total environmental scores for each material, achievable through normalization. This step assesses indicator results against reference data for significance [45]. Normalization can be classified as internal and external. Compared to external normalization, internal normalization minimizes large-scale errors [46] and is recommended in regions lacking external data [24]. The division-by-maximum method is a commonly used internal normalization approach, enabling comparisons between alternatives [47]. In this approach, indicator results for different options get divided by the scores of the top-rated alternative in each impact category. This method was selected for the model to enable its use in countries lacking specific reference values. In this model stage, the initial step involves determining total scores for each material group (finishing + auxiliary) in each category using Equation 3, followed by applying internal normalization per Equation 4 [47].

$$TIA_i = IAF_i + IAA_i \tag{3}$$

Where TIA_i: the total impact assessment score for different environmental impact categories; IAF_i: the environmental impact assessment score for different environmental impact categories of the amount of the finishing material required for 1 m^2 area; IAA_i: the environmental impact assessment score for different environmental impact categories of the amount of the auxiliary material required for 1 m^2 area.

$$NTIA_i = \frac{TIA_i}{maxTIA_i} \tag{4}$$

Where $NTIA_i$: the normalized total impact assessment score for different environmental impact categories; TIA_i: the total impact assessment score for different environmental impact categories; and $maxTIA_i$: the maximum value of the total impact assessment score for different environmental impact categories.

2.1.3. Environmental impact score calculation

To calculate the environmental impact of the material, normalized indicator results need to be summed [45]. In this regard, the formula shown in Equation 5 can be used [13].

$$EI_{altn} = \sum_{i=1}^{s} NTIA_i \tag{5}$$

Where EI_{altn}: total environmental impact value for different material groups; s: number of environmental impact categories; $NTIA_i$: normalized total impact assessment score for different environmental impact categories.

In one study [35] study, rubber initially showed a 2.5 times higher environmental impact than ceramics, escalating to 5 times when considering renewals over a 100-year building lifespan. For a comprehensive environmental impact assessment, both building and material service life are crucial. ISO 16204:2012 sets the service life for buildings at 50 years [48], supported by studies like [49], and [50], thus adopted by the model. Calculating the total environmental impact involves considering finishing material renewals within this timeframe. A literature review determined the service life and renewal frequency for finishing materials in Table 2 within the 50-year building service life.

Three methods are suggested to calculate the overall environmental impact score. The first method, expressed in Equation 6, excludes renewal considerations.

$$TS = EI_{altn} \tag{6}$$

Where TS: total score; EI_{altn}: total environmental impact value for different material groups.

The second method can be applied when renovations involve using the same materials shown in Equation 7.

$$TS = EI_{altn} \times (RN_{altn} + 1) \tag{7}$$

Where TS: total score; EI_{altn}: total environmental impact value for different material groups; RN_{altn}: number of renewals in a 50-year building service life for different material groups.

The third method can be applied when renovations involve using different materials expressed in Equation 8.

$$TS=\sum_{n=1}^{k}(EI_{altn}\times RN_{altn})_k+EI_{ex} \quad (8)$$

Where TS: total score; EI_{altn}: total environmental impact value for different material groups; RN_{altn}: number of renewals in a 50-year building service life for different material groups; k: number of environmental impact value; EI_{ex}: environmental impact value for different existing material groups.

Table 2. Finishing materials' renovation frequencies in 50 years of building service life

System	F_m	Service life	Renovation frequency	Reference
Wall	Artificial stone	50	0	[51]
	Ceramic	50	0	
	Natural stone	50	0	
	Paint	10	4	
	Gypsum	27	1	[52]
	Polymer	27	1	
	Wallpaper	27	1	
	Wood	20	2	
Floor	Carpet	10	4	
	Ceramic	75	0	
	Natural stone	100	0	
	Wood	100	0	
Ceiling	Paint	10	4	
	Gypsum board	75	0	
	Polymer	30	1	
	Wood	20	2	

2.2. Case study - finishing material selection in hotel bedrooms

Hotels are considered the largest contributors to environmental pollution worldwide compared to other building types [53]. One of the primary reasons for this is that the finishing materials in hotel bedrooms undergo frequent renewal to ensure a consistently fresh and inviting atmosphere for incoming tourists. Turkey, with its top 5 positions in incoming tourists and 6th in global tourism income, holds a notable position in the tourism sector [54]. Antalya, a pivotal city in global and Turkish tourism, experiences high hotel usage rates [55]. In parallel with this trend, the Konyaaltı region in Antalya stands out for its frequent material renewal initiatives. The model's validation focuses on assessing the three most used finishing materials in hotel bedrooms located in Antalya's Konyaaltı region.

The first part of this research, conducted by [56], involved a survey study to identify the most used finishing materials and their renewal methods in bedrooms within this specific region. Following this research, this study focused on three preferred finishing materials within the wall system: wood, paint, and gypsum board. The auxiliary materials are selected according to Table 1. The model employed a cradle-to-gate approach and focused on environmental impact categories based on EN 15804:2012+A1:2013 [33] deemed important for Turkey (Figure 2). Previous studies conducted in Turkey [20], [28], [35] showed similarity in the chosen impact categories for the model.

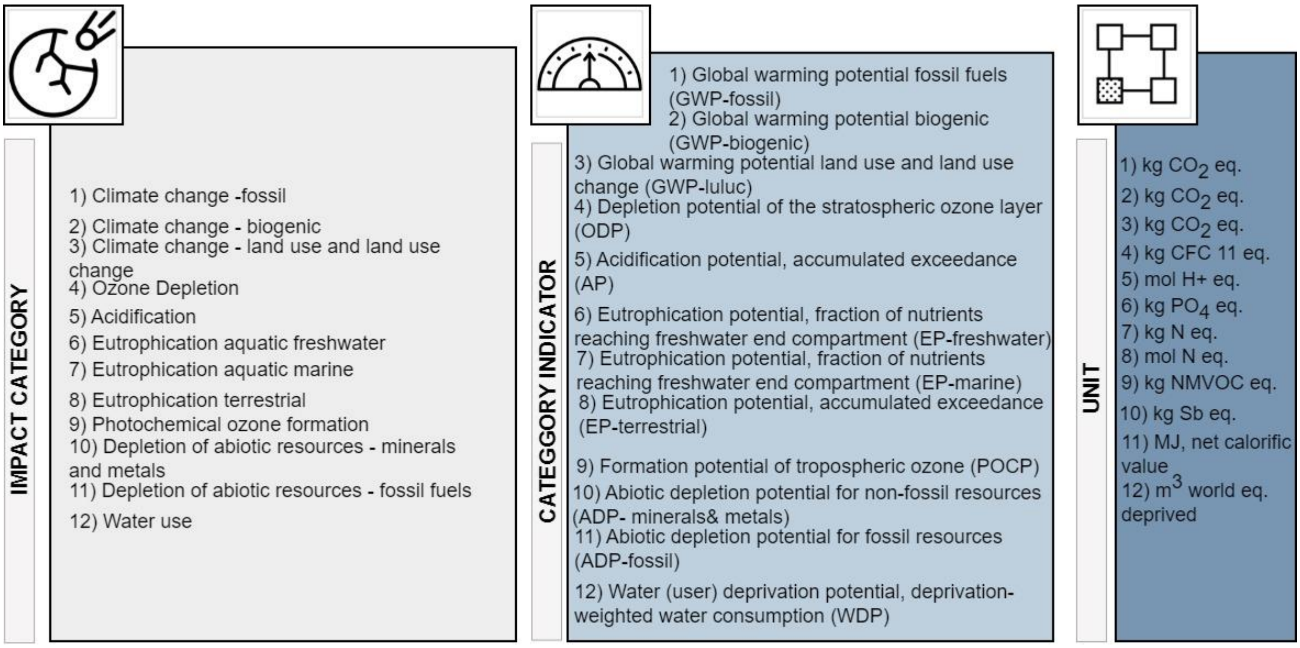

Figure 2. Important environmental impact categories of Turkey [33]

3. Results

Table 3 presents each material's EPD-documented impact category results. Tables 4 and 5 present the PA and IA_i values according to functional unit conversion calculations as outlined in section 2.1.1.

Table 3. Impact category results (A1, A2, A3 total) of each material

	F_m	A_m			F_m	A_m		F_m
	1 m^2 Gypsum board	1 kg Plaster	1 kg Paint	1 kg Paste backfilling	1 kg Paint	1 m^2 Primer	1 kg Paste backfilling	1 m^3 Wood panel
GWP-fossil	2.04	0.111	2.294	1.27E+00	2.294	6.86E-01	1.27E+00	515
GWP-biogenic	-0.283	0.001	0.024	2.16E-03	0.024	-1.58E-02	2.16E-03	-1164
GWP-luluc	0.008	1.86E-04	12E-3	9.17E-04	12E-3	5.08E-04	9.17E-04	1.29
ODP	6.08E-08	4.18E-09	231.1E-9	2.11E-07	231.1E-9	2.56E-08	2.11E-07	82.5E-6
AP	0.007	4.18E-04	0.013	6.59E-03	0.013	4.65E-03	6.59E-03	3.68
EP-freshwater	0.001	2.46E-05	0.002	1.13E-04	0.002	2.57E-05	1.13E-04	92.9E-3
EP-marine	0.003	9.71E-05	0.003	1.32E-03	0.003	5.87E-04	1.32E-03	677E-3
EP-terrestrial	0.022	1.08E-03	0.025	1.25E-02	0.025	6.35E-03	1.25E-02	10.7E+0
POCP	0.007	3.73E-04	0.008	3.92E-03	0.008	2.81E-03	3.92E-03	2.21
ADP-minerals and metals	2.12E-05	1.60E-07	17.6E-6	9.70E-06	17.6E-6	3.13E-06	9.70E-06	3.08E-3
ADP-fosil	30.2	1.56	38.35	2.19E+01	38.35	1.16E+01	2.19E+01	9269
WDP	1.077	0.02	1.593	1.52E-02	1.593	4.92E-01	1.52E-02	718
Reference	[57]	[58]	[59]	[60]	[59]	[61]	[60]	[62]

"E" serves as an abbreviation for scientific notation (E= x10^a). Example: 6.08E-08 =6.08x10^{-08} =0,0000000608

Table 4. PA values of the materials

	F_m	A_m			F_m	A_m		F_m
	1 m^2 Gypsum board	1 kg Plaster	1 kg Paint	1 kg Paste backfilling	1 kg Paint	1 m^2 Primer	1 kg Paste backfilling	1 m^3 Wood panel
A_k	-	1 m^2	10 m^2	2 m^2	10 m^2	-	2 m^2	30 m^2
PA	-	1 kg	0,1 kg	0,5 kg	0,1 kg	-	0,5 kg	0,033 m^2
Reference		[63]	[59]	[64]	[59]		[64]	[65]

Table 5. IA_i values of the materials

	Material groups (M)							
	M_1				M_2			M_3
	F_m	A_m			F_m	A_m		F_m
	1 m^2 Gypsumboard	Plaster (for 1m^2 area)	Paint (for 1m^2 area)	Paste backfilling (for 1m^2 area)	Paint (for 1m^2 area)	1 m^2 Primer	Paste backfilling (for 1m^2 area)	Wood panel (for 1m^2 area)
GWP-fossil	2.0400E+00	1.1100E-01	2.2900E-01	6.3500E-01	2.2900E-01	6.8600E-01	6.3500E-01	1.7000E+01
GWP-biogenic	-2.8300E-01	1.0000E-03	2.4000E-03	1.0800E-03	2.4000E-03	-1.5800E-02	1.0800E-03	-3.8400E+01
GWP-luluc	8.0000E-03	1.8600E-04	1.2000E-03	4.5900E-04	1.2000E-03	5.0800E-04	4.5900E-04	4.2600E-02
ODP	6.0800E-08	4.1800E-09	2.3100E-08	1.0600E-07	2.3100E-08	2.5600E-08	1.0600E-07	2.7200E-06
AP	7.0000E-03	4.1800E-04	1.3000E-03	3.3000E-03	1.3000E-03	4.6500E-03	3.3000E-03	1.2100E-01
EP-freshwater	1.0000E-03	2.4600E-05	2.0000E-04	5.6500E-05	2.0000E-04	2.5700E-05	5.6500E-05	3.0700E-03
EP-marine	3.0000E-03	9.7100E-05	3.0000E-04	6.6000E-04	3.0000E-04	5.8700E-04	6.6000E-04	2.2300E-02
EP-terrestrial	2.2000E-02	1.0800E-03	2.5000E-03	6.2500E-03	2.5000E-03	6.3500E-03	6.2500E-03	3.5300E-01
POCP	7.0000E-03	3.7300E-04	8.0000E-04	1.9600E-03	8.0000E-04	2.8100E-03	1.9600E-03	7.2900E-02
ADP-minerals and metals	2.1200E-05	1.6000E-07	1.7600E-06	4.8500E-06	1.7600E-06	3.1300E-06	4.8500E-06	1.0200E-04
ADP-fosil	3.0200E+01	1.5600E+00	3.8400E+00	1.1000E+01	3.8400E+00	1.1600E+01	1.1000E+01	3.0600E+02
WDP	1.0800E+00	2.0000E-02	1.5900E-01	7.6000E-03	1.5900E-01	4.9200E-01	7.6000E-03	2.3700E+01

Table 5 shows that, among finishing materials, the order from highest to lowest impact in all categories is wood panel, gypsum board, and paint except GWP-fossil and GWP-biogenic. The total environmental impact of the auxiliary materials in the M_2 group is higher than that of the M_3 group across all categories except EP-freshwater, GWP-biogenic, GWP-luluc, and ODP.

Table 6 presents the TIA_i, $NTIA_i$, and EI_{altn} values as per sections 2.1.2 and 2.1.3. It shows that, after the TIA_i calculation, the order from highest impact to lowest in almost all categories are wood panel, gypsum board, and paint (which is also applicable to EI_{altn} values). Following internal normalization, the rating remained consistent, with the only change observed occurring in the GWP-biogenic within the M_2 and M_3 groups. Pre-normalization, all materials appeared highest in the ADP fossil category; post-normalization, this shifted to GWP biogenic.

Following this stage, renewal frequencies for material groups within the 50-year building service life are incorporated. As per Table 1, the gypsum board undergoes no renovation, the paint is renewed every 10 years, and the wood panel every 20 years. Research [56] suggests that both paint and wood panels can be renewed with either the same or different materials, leading to alternative scenarios formulated for these materials (Table 7).

Table 6. TIA_i, $NTIA_i$, and EI_{altn} values of the materials

	TIA_i			$NTIA_i$		
	M_1	M_2	M_3	M_1	M_2	M_3
GWP-fossil	3.0200E+00	1.5500E+00	1.7000E+01	1.7700E-01	9.1200E-02	1.0000E+00
GWP-biogenic	-2.7900E-01	-1.2300E-02	-3.8400E+01	2.2600E+01	1.0000E+00	3.1200E+03
GWP-luluc	9.8500E-03	2.1700E-03	4.2600E-02	2.3100E-01	5.0900E-02	1.0000E+00
ODP	1.9400E-07	1.5500E-07	2.7200E-06	7.1400E-02	5.6900E-02	1.0000E+00
AP	1.2000E-02	9.2500E-03	1.2100E-01	9.9300E-02	7.6400E-02	1.0000E+00
EP-freshwater	1.2800E-03	2.8200E-04	3.0700E-03	4.1700E-01	9.1900E-02	1.0000E+00
EP-marine	4.0600E-03	1.5500E-03	2.2300E-02	1.8200E-01	6.9400E-02	1.0000E+00
EP-terrestrial	3.1800E-02	1.5100E-02	3.5300E-01	9.0200E-02	4.2800E-02	1.0000E+00
POCP	1.0100E-02	5.5700E-03	7.2900E-02	1.3900E-01	7.6400E-02	1.0000E+00
ADP-minerals and metals	2.8000E-05	9.7400E-06	1.0200E-04	2.7400E-01	9.5500E-02	1.0000E+00
ADP-fosil	4.6600E+01	2.6400E+01	3.0600E+02	1.5200E-01	8.6400E-02	1.0000E+00
WDP	1.2700E+00	6.5900E-01	2.3700E+01	5.3400E-02	2.7800E-02	1.0000E+00
EI_{altn}				2.4500E+01	1.7700E+00	3.1300E+03

High impact   Middle impact   Low impact

Table 7. TS values of the materials and ratings

Material group	Renovation method	Material groups used for renovation	TS	Impact Rating (1-Highest to 17-Lowest)			
				All scenarios	No renovation	Renovation with the same materials	Renovation with different materials
M_1	-		2.45E+01	15	2	2	13
M_2	-		1.77E+00	17	3		
	same materials	M_2+ M_2+ M_2+ M_2	8.83E+00	16		3	
	different materials	M_2+ M_2+ M_2+ M_1	3.16E+01	11			9
		M_2+ M_2+ M_1	2.98E+01	12			10
		M_2+ M_1	2.80E+01	13			11
		M_1	2.63E+01	14			12
		M_2+ M_2+ M_2+ M_3	3.13E+03	8			7
		M_2+ M_2+ M_3	3.13E+03	9			8
		M_2+ M_3+ M_2	3.13E+03	9			8
		M_2+ M_3+ M_3	6.26E+03	3			2
		M_2+ M_3+ M_1	3.16E+03	5			4
M_3	-		3.13E+03	10	1		
	same materials	M_3+ M_3	9.38E+03	1		1	
	different materials	M_3+ M_2	6.26E+03	4			3
		M_2+ M_2+ M_2	3.13E+03	9			8
		M_2+ M_3	6.26E+03	4			3
		M_3+ M_1	6.28E+03	2			1
		M_1	3.15E+03	7			6
		M_2+ M_1	3.15E+03	6			5
		M_2+ M_2+ M_1	3.16E+03	5			4

In all ratings, M_3 exhibits the highest environmental impact value. In ‘all scenarios’, the best alternative is M_2 without renovation. The rating appears to be the same for the ‘no renovation’and the ‘renovation with the same materials’ in renovation scenarios involving different materials, gypsum board appears to be the most favorable material.

4. Discussion

4.1. Evaluation of the case study

Within the scope of this study, a model for the selection of finishing materials was developed and validated using three wall materials commonly found in hotel bedrooms: paint, gypsum board, and wood panel. The results are presented below.

Table 5 reveals that, in some categories, auxiliary materials' environmental impact may exceed that of finishing materials. For example, in the POCP category, primer and paste backfilling, linked to paint usage, had a higher impact than the paint itself. This emphasizes the need to carefully consider choices regarding auxiliary materials. However, Table 6 shows that a finishing material with auxiliary material in a certain category might not surpass the environmental impact of the finishing material without auxiliary materials. For instance, despite lacking auxiliary materials, wood panel had a higher impact than gypsum board and paint. Thus, when selecting finishing materials, it's crucial to focus on the overall environmental impact rather than just the presence or quantity of auxiliary materials.

The choice of normalization method, as shown in the case study, is a key factor influencing environmental outcomes. [23] highlights limitations with internal normalization, including order alteration, specifically seen in the GWP-biogenic category. Before normalization, the order of impact, from highest to lowest, was M_2, M_1, M_3. However, after normalization, this order shifted to M_3, M_1, M_2. Another limitation is the loss of information about the magnitude of environmental impact [46], evident in identical scores for M_3 in all categories, except for GWP-biogenic. This is because M_3 attains the highest value in each category when the division-by-maximum approach is applied. This stresses the need for careful normalization method selection aligned with the study's specific purpose.

Table 7 demonstrates that renovation increases the environmental impact of material groups; for example, M_3's impact tripled after renovation with $M_{3+}M_3$. However, renewing a material group doesn't necessarily mean a higher impact; renewing M_2 with M_2+M_2+M_2+M_2 has a lower impact than non-renewed M_1. Similarly, the sequence of renovation in a material group may not alter its environmental impacts; renewing M_2 with M_2+M_3+M_2 shows no difference from renewing with M_2+M_2+$M_{3.}$ The renovation method significantly affects the material's environmental impact score; renewing M_2 with M_1 has a greater impact than renewing it with M_2 alone. However, the number of renewals may not follow the same trend; renewing M_2 with M_2+M_3+M_1 has a greater impact than renewing with M_2+M_2+M_2+$M_{3.}$ According to all this information, decision-makers should prioritize considering renewal and service life in the selection of finishing materials.

4.2. Evaluation of the model

In this model, EPDs are preferred for deriving finishing materials' environmental impact results compared to other approaches (ATHENA, BEES, BELES, BEPAS, BRE, BPIC-ICIP) due to three crucial reasons: (1) the EPD database enables quick and reliable finishing material selection, (2) more environmental impact categories can be assessed, and (3) EPDs are global, allowing easy data retrieval. While there are several reasons to favor EPDs, their incorporation into the model has introduced some limitations. The first constraint on this subject is that some finishing material companies lack EPD registration, leading to missing documentation for certain materials [66]. This issue became evident during the case study, as EPDs for paste backfilling and primer from local manufacturers were unavailable. In this scenario, alternative databases can be used but may introduce inconsistencies. EPD results may vary depending on factors such as the manufacturer, production processes, application method, and variations in Product Category Rules (PCRs) [36]. The second constraint is about the impact categories in EPD documents. While they assess more categories than other models, discussions in existing studies suggest the need to add more categories to the EN 15804:2012+A1:2013 [33] standard [29]. The absence of certain impact categories can lead to incomplete results, impacting the selection of finishing materials based on local environmental considerations. Additionally, some EPD documents combine category results, such as providing a GWP-total impact category instead of individual results for GWP-fossil, GWP-biogenic, and GWP-luluc. While this doesn't affect the model's calculation method, it may hinder a detailed examination of results in finishing material comparisons. The third limitation concerns the defined system boundaries for comparing finishing materials. EN 15804:2012+A1:2013 [33] mandates specific modules (A1-A3, C1-C4, and D) for every material, but EPDs often omit modules with significant environmental impacts, limiting comprehensive comparisons across all life cycle stages of finishing materials.

One other notable feature distinguishing this model from others is its reliance on internal normalization. Prevailing methods predominantly favor external normalization approaches. This method has been developed specifically for certain countries and these countries typically possess yearly updated national databases that facilitate the process of external normalization [25]. Depending on the normalization type, LCIA results may vary significantly, emphasizing the crucial choice of the appropriate method for the study's purpose. The decision to use internal normalization in this model has two key considerations: (1) it enables self-assessment without external data reliance, ensuring universal applicability for countries lacking databases (2) it aligns with the model's main purpose of selecting finishing materials with low environmental impact through material comparison.

In contrast to other methods, the model treats all chosen environmental impact categories equally. Weighting is an optional step of LCIA and consists of a potential risk that individuals may intentionally or unintentionally select specific weighting factors to influence the results [67]. While the model allows updates with local weighting coefficients, this may necessitate a reevaluation of the current normalization method. Reference [68] cautions against weighting in internal normalization, as it doesn't affect impact indicator scores.

Research indicates that some LCIA models do not account for renovation, while others assume that all materials have the same service life. Also, certain tools have a predetermined calculation period that users cannot alter [28]. One crucial feature that distinguishes this model is its capability to determine the service life of each finishing material, defining auxiliary materials and their effects on total environmental impact and underscoring the importance of renewal methods and frequency throughout the material selection process.

5. Conclusions

This study presents a systematic method for the selection of finishing materials according to various parameters. The developed model was tested using gypsum board, paint and wood panel, which are preferred in hotel bedrooms. The results of the study showed the importance of auxiliary materials, service life, normalization method and renewal methods and frequencies in the selection of finishing materials. It was shown that in some environmental impact categories, the environmental impact score of auxiliary materials is higher than that of the main material. This underscores the significant effects of auxiliary materials. However, it does not mean that a finishing material with auxiliary materials will have a greater environmental impact than one without. The study also observed that the choice of normalization method can alter the environmental impact ranking of materials. Particularly in methods using internal normalization, there may be changes in the environmental impact magnitude of materials. According to the study results, material renewal methods and frequencies are crucial in calculating the total environmental impact score. However, this does not mean that renewing a material has a higher environmental impact than a non-renewed material. Likewise, a material with a higher number of replacements may not have a higher environmental impact than a material with fewer replacements. As can be understood from this, the environmental impact results of materials may vary according to various criteria. Therefore, a holistic approach is necessary.

Although there are various methods for material selection in the literature, this study fills the gap by focusing only on the environmental impacts of finishing materials. The study also emphasizes the impact of the differences in the criteria in the selection process of each material on the environmental impact results. The model appears to be a promising alternative for those in the building materials industry to obtain reliable and rapid results by encouraging the use of EPDs. At the same time, it can be used as a method open to improvement with new data obtained.

Undoubtedly, a comprehensive assessment of finishing materials necessitates a broader consideration beyond solely environmental impact. Evaluating material properties and health effects from a holistic perspective is essential, and addressing these aspects in future studies is imperative. Additional research might involve integrating country-specific weight coefficients based on input from national experts, expanding evaluations to cover more life cycle stages, and encouraging the building materials sector to broaden the range and depth of available EPD documents.

Author Contribution

The contribution of Nil Kokulu: manuscript design, data collection, analyses, and writing; Seden Acun Özgünler: providing ideas, review, and editing; Fethiye Ecem Edis: methodology, analysis, providing ideas, evaluating results, improving the manuscript; Saniye Karaman Öztaş: methodology, analysis, providing ideas, evaluating results, improving the manuscript.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

Funding information

No funding was received from any financial organization to conduct this research.

Acknowledgements

We are grateful to İsmail Veli Sezgin, Tom, Eric & Sabrina Austin, and Colin Roskos for reading and commenting on the drafts of this paper.

References

[1] F. Findik, "Green concrete for structural buildings," *Heritage and Sustainable Development*, vol. 4, no. 1, pp. 67–76, Jun. 2022, doi: 10.37868/hsd.v4i1.84.

[2] UN Environment Programme, "Building materials and the climate: constructing a new future," United Nations Environment Programme. [Online]. Available: https://wedocs.unep.org/handle/20.500.11822/43293

[3] O. Ortiz, F. Castells, and G. Sonnemann, "Sustainability in the construction industry: A review of recent developments based on LCA," *Constr Build Mater*, vol. 23, no. 1, pp. 28–39, Jan. 2009, doi: 10.1016/j.conbuildmat.2007.11.012.

[4] R. N. Passarelli and B. J. Mouton, "Embodied life cycle impacts of lightweight building methods for affordable houses in the USA: Comparison of conventional, circular, and regenerative strategies," *Journal of Building Engineering*, vol. 77, p. 107513, Oct. 2023, doi: 10.1016/j.jobe.2023.107513.

[5] M. K. Dixit, S. Singh, S. Lavy, and W. Yan, "Floor finish selection in health-care facilities: a systematic literature review," *Facilities*, vol. 37, no. 13/14, pp. 897–918, Oct. 2019, doi: 10.1108/F-03-2018-0042.

[6] I. Zabalza Bribián, A. Valero Capilla, and A. Aranda Usón, "Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential," *Build Environ*, vol. 46, no. 5, pp. 1133–1140, May 2011, doi: 10.1016/j.buildenv.2010.12.002.

[7] Z. Z. Bako and M. M. Jusan, "Motivational factors influencing housing interior finish choice and preference," *Procedia Soc Behav Sci*, vol. 36, pp. 177–186, 2012, doi: 10.1016/j.sbspro.2012.03.020.

[8] S. Wi, Y. Kang, S. Yang, Y. U. Kim, and S. Kim, "Hazard evaluation of indoor environment based on long-term pollutant emission characteristics of building insulation materials: An empirical study," *Environmental Pollution*, vol. 285, p. 117223, Sep. 2021, doi: 10.1016/j.envpol.2021.117223.

[9] A. Hussain, “Evaluating waste material among construction project: identify reason waste and suggestion improvement designer, contractor and client practice,” *Journal of Korean Society of Environmental Engineers*, vol. 43, no. 6, pp. 453–460, Jun. 2021, doi: 10.4491/KSEE.2021.43.6.453.
[10] L. L. Ekanayake and G. Ofori, “Building waste assessment score: design-based tool,” *Build Environ*, vol. 39, no. 7, pp. 851–861, Jul. 2004, doi: 10.1016/j.buildenv.2004.01.007.
[11] M. F. Ashby and D. Cebon, “Materials selection in mechanical design,” in *Troisieme Conference Europeenne sur les Materiaux et les Procedes Avances*, Paris: Euromat ‘93, Jun. 1993. Accessed: May 12, 2022. [Online]. Available: https://studylib.net/doc/18201956/materials-selection-in-mechanical-design
[12] *Environmental management - Life cycle assessment - Principles and framework*, ISO Standard No 14040:2006, International Organization for Standardization, 2006. Accessed: Mar. 11, 2023. [Online]. Available: https://www.iso.org/standard/37456.html International Organization for Standardization
[13] B. C. Lippiatt, “BEES 4.0 Building for environmental and economic sustainability technical manual and user guide,” National Institute of Standards and Technology Building and Fire Research Laboratory. Accessed: Oct. 02, 2023. [Online]. Available: https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=860108
[14] N. Howard, S. Edwards, and J. Anderson, “Environmental profiles of construction materials, components and buildings,” Breglobal. Accessed: Oct. 02, 2023. [Online]. Available: https://files.bregroup.com/bre-co-uk-file-library-copy/filelibrary/greenguide/PDF/SD028-4_EnvironmentalProfiles_SchemeDocument.pdf
[15] J. Bengtsson and N. Howard, “A life cycle impact assessment model. Part 1: Classification and Characterisation.” BPIC/ICIP Life Cyce Inventory Project.: Building Products Innovation Council (BPIC) and AusIndustry, 2010.
[16] ATHENA, “Athena impact estimator for buildings V 4.5 users manual, software and database overview.” Accessed: Oct. 02, 2023. [Online]. Available: https://calculatelca.com/wp-content/uploads/2013/11/IE4B_User_Guide_Nov2013.pdf
[17] Z. Zhang, X. Wu, X. Yang, and Y. Zhu, “BEPAS—a life cycle building environmental performance assessment model,” *Build Environ*, vol. 41, no. 5, pp. 669–675, May 2006, doi: 10.1016/j.buildenv.2005.02.028.
[18] D. Gu, L. Gu, and Y. Zhu, “A life cycle assessment method for buildings,” in *Building Simulation 2007: 10th Conference of IBPSA*, China: International Building Performance Simulation Association, Jul. 2007, pp. 1595–1600. [Online]. Available: https://www.researchgate.net/publication/255613264_A_life_cycle_assessment_method_for_buildings
[19] V. Echarri-Iribarren, F. Echarri-Iribarren, and C. Rizo-Maestre, “Ceramic panels versus aluminium in buildings: Energy consumption and environmental impact assessment with a new methodology,” *Appl Energy*, vol. 233–234, pp. 959–974, Jan. 2019, doi: 10.1016/j.apenergy.2018.08.091.
[20] A. B. Gültekin, “Proposal of a model for assessment of the environmental impacts of construction products within the context of life cycle assessment methodology,” Ph.D. dissertation, Gazi University, Ankara, 2006. Accessed: Jan. 12, 2023. [Online]. Available: https://tez.yok.gov.tr/UlusalTezMerkezi/tezDetay.jsp?id=WZcX4jRt3Db28U11nzYurA&no=3K02v4G46XeA8moF_TzGqg
[21] K. Jaemoon, L. Duhwan, and N. Seunghoon, “Potential for environmental impact reduction through building LCA (Life Cycle Assessment) of school facilities in material production stage,” *Build Environ*, vol. 238, p. 110329, Jun. 2023, doi: 10.1016/j.buildenv.2023.110329.
[22] M. D. Bovea and A. Gallardo, “The influence of impact assessment methods on materials selection for eco-design,” *Mater Des*, vol. 27, no. 3, pp. 209–215, 2006, doi: 10.1016/j.matdes.2004.10.015.
[23] M. Pizzol, A. Laurent, S. Sala, B. Weidema, F. Verones, and C. Koffler, “Normalisation and weighting in life cycle assessment: quo vadis?,” *Int J Life Cycle Assess*, vol. 22, no. 6, pp. 853–866, Jun. 2017, doi: 10.1007/s11367-016-1199-1.

[24] S. R. Sousa, S. R. Soares, N. G. Moreira, R. M. Severis, and L. A. de Santa-Eulalia, “Internal normalization procedures in the context of LCA: A simulation-based comparative analysis,” *Environmental Modeling & Assessment*, vol. 26, no. 3, pp. 271–281, Jun. 2021, doi: 10.1007/s10666-021-09767-5.

[25] J. Bare, T. Gloria, and G. Norris, “Development of the method and U.S. normalization database for life cycle impact assessment and sustainability metrics,” *Environ Sci Technol*, vol. 40, no. 16, pp. 5108–5115, Aug. 2006, doi: 10.1021/es052494b.

[26] S. Junnila and A. Horvath, “Life-cycle environmental effects of an office building,” *Journal of Infrastructure Systems*, vol. 9, no. 4, pp. 157–166, Dec. 2003, doi: 10.1061/(ASCE)1076-0342(2003)9:4(157).

[27] A. Grant, R. Ries, and C. Kibert, “Life cycle assessment and service life prediction,” *J Ind Ecol*, vol. 18, no. 2, pp. 187–200, Apr. 2014, doi: 10.1111/jiec.12089.

[28] S. Karaman Öztaş, “A model proposal for life cycle impact assessment for the Turkish building materials sector,” Ph.D. dissertation, İstanbul Technical University, İstanbul, 2014. Accessed: Dec. 27, 2023. [Online]. Available: https://tez.yok.gov.tr/UlusalTezMerkezi/tezDetay.jsp?id=soWRh9bW77L6f-ji46JXfA&no=VVa9QcS_mIj3inNVs_iYBg

[29] S. Lasvaux, G. Habert, B. Peuportier, and J. Chevalier, “Comparison of generic and product-specific Life Cycle Assessment databases: application to construction materials used in building LCA studies,” *Int J Life Cycle Assess*, vol. 20, no. 11, pp. 1473–1490, Nov. 2015, doi: 10.1007/s11367-015-0938-z.

[30] M. Rangelov, H. Dylla, and N. Sivaneswaran, “Environmental product declarations (EPDs)/product category rules (PCRs) of waste plastics and recycled materials in roads,” in *Plastic Waste for Sustainable Asphalt Roads*, Elsevier, 2022, pp. 303–334. doi: 10.1016/B978-0-323-85789-5.00015-0.

[31] JCR European Commission, “ILCD handbook, general guide for life cycle assessment – detailed guidance.” Accessed: Oct. 02, 2023. [Online]. Available: https://eplca.jrc.ec.europa.eu/uploads/ILCD-Handbook-General-guide-for-LCA-DETAILED-GUIDANCE-12March2010-ISBN-fin-v1.0-EN.pdf

[32] *Environmental labels and declarations - Type III environmental declarations - Principles and procedures*. ISO Standard No: 14025:2006, International Organization for Standardization, 2006. Accessed: Mar. 10, 2023. [Online]. Available: https://www.iso.org/standard/38131.html

[33] *Sustainability of construction works – environmental product declarations – core rules for the product category of construction products*, EN Standard No 15804:2012+A1:2013, 2013. Accessed: Apr. 06, 2023. [Online]. Available: https://standards.iteh.ai/catalog/standards/cen/a7de5991-2e9f-4e93-b34c-f1d794cbca02/en-15804-2012a1-2013

[34] J. Anderson, “ConstructionLCA’s 2023 Guide to Environmental Product Declarations (EPD),” Infogram. Accessed: Oct. 02, 2023. [Online]. Available: https://infogram.com/constructionlcas-2023-guide-to-epd-1h0n25yvdgz7l6p?live

[35] N. Kalkan, “Evaluation of environmental impacts of finishing materials used in metro stations, based on production and use process energy: The case of Çırçır Station,” M.S. thesis, İstanbul Technical University, İstanbul, 2020. Accessed: Nov. 15, 2023. [Online]. Available: https://tez.yok.gov.tr/UlusalTezMerkezi/tezDetay.jsp?id=dxRERJExpsSzsNHqJUn68w&no=W7RDnRJ0XRP6fhQTf8Z8dA

[36] A. K. Abd El-Hameed, Y. M. Mansour, and A. A. Faggal, “Benchmarking water efficiency of architectural finishing materials based on a ‘cradle-to-gate’ approach,” *Journal of Building Engineering*, vol. 14, pp. 73–80, Nov. 2017, doi: 10.1016/j.jobe.2017.10.001.

[37] C. Strazza, A. Del Borghi, F. Magrassi, and M. Gallo, “Using environmental product declaration as source of data for life cycle assessment: a case study,” *J Clean Prod*, vol. 112, pp. 333–342, Jan. 2016, doi: 10.1016/j.jclepro.2015.07.058.

[38] D. Guerin and D. Ginther, “Designers’ knowledge of green design: What do we do now,” in *IDEC International Conference Abstracts*, Florida, 1999, pp. 50–51.

[39] B. Zhang, R. Zeng, and X. Li, “Environmental and human health impact assessment of major interior wall decorative materials,” *Frontiers of Engineering Management*, vol. 6, no. 3, pp. 406–415, Sep. 2019, doi: 10.1007/s42524-019-0025-4.

[40] J. C. Bare, P. Hofstetter, D. W. Pennington, and H. A. U. de Haes, “Midpoints versus endpoints: The sacrifices and benefits,” *Int J Life Cycle Assess*, vol. 5, no. 6, p. 319, Nov. 2000, doi: 10.1007/BF02978665.

[41] N. Toydemir, E. Gürdal, and L. Tanaçan, *Material in Building Element Design - Yapı Elemanı Tasarımında Malzeme*. İstanbul: Literatur Publication, 2000.

[42] G. Berkin, *Material and Detail in Interior Architecture - İç Mimarlıkta Malzeme ve Detay*. İstanbul: YEM Publication, 2022.

[43] S. Ergenç, “Product selection for interior wall coating,” M.S. thesis, Yıldız Technical University, İstanbul, 2007. Accessed: Aug. 08, 2023. [Online]. Available: https://tez.yok.gov.tr/UlusalTezMerkezi/TezGoster?key=ePX_SaJ0b35Gq45swKG3lCFyPU5ehB5BfB75FGf43dGSL26ZvoGHKY2mrqM4mlP4

[44] M. B. Güler and E. Kasapoğlu, “Suspended ceiling applications in interiors - İç Mekanlarda Asma Tavan Uygulamaları,” *Kocaeli Üniversitesi Mimarlık ve Yaşam Dergisi*, Mar. 2021, doi: 10.26835/my.709077.

[45] *Environmental management — Life cycle assessment — Requirements and guidelines*. ISO Standard No 14044:2006, International Organization for Standardization, 2006. Accessed: May 03, 2023. [Online]. Available: https://www.iso.org/standard/38498.html

[46] A. Roesch, S. Sala, and N. Jungbluth, “Normalization and weighting: the open challenge in LCA,” *Int J Life Cycle Assess*, vol. 25, no. 9, pp. 1859–1865, Sep. 2020, doi: 10.1007/s11367-020-01790-0.

[47] C. Ji and T. Hong, “Comparative analysis of methods for integrating various environmental impacts as a single index in life cycle assessment,” *Environ Impact Assess Rev*, vol. 57, pp. 123–133, Feb. 2016, doi: 10.1016/j.eiar.2015.11.013.

[48] *Durability-Service life design of concrete structures*. ISO 16204:2012, International Organization for Standardization, 2012. Accessed: Aug. 17, 2023. [Online]. Available: https://www.iso.org/standard/55862.html

[49] F. N. Rasmussen, R. K. Zimmermann, K. Kanafani, C. Andersen, and H. Birgisdóttir, “The choice of reference study period in building LCA – case-based analysis and arguments,” *IOP Conf Ser Earth Environ Sci*, vol. 588, no. 3, p. 032029, Nov. 2020, doi: 10.1088/1755-1315/588/3/032029.

[50] M. F. D. Morales, R. J. Ries, A. P. Kirchheim, and A. Passuello, “Comparison and analysis of product stage and service life uncertainties in life cycle assessment of building elements,” *Environmental Research: Infrastructure and Sustainability*, vol. 2, no. 3, p. 035001, Sep. 2022, doi: 10.1088/2634-4505/ac6d07.

[51] BBSR, “Service lives of components for life cycle analyze according to the Sustainable Building Assessment System (BNB) - Nutzungsdauern von Bauteilen für Lebenszyklusanalysen nach Bewertungssyem Nachhaltiges Bauen (BNB).” Accessed: Aug. 18, 2023. [Online]. Available: https://www.nachhaltigesbauen.de/fileadmin/pdf/baustoff_gebauededaten/BNB_Nutzungsdauern_von_Bauteilen__2011-11-03.pdf

[52] S. Lasvaux *et al.*, “DUREE Project, analysis of lifetimes of building elements in the literature and in renovation practices and sensitivity analyses on building LCA & LCC,” Swiss Federal Office for Energy SFOE. Accessed: Aug. 15, 2023. [Online]. Available: https://www.aramis.admin.ch/Default?DocumentID=67264&Load=true

[53] C.-C. Teng, J.-S. Horng, M.-L. (Monica) Hu, L.-H. Chien, and Y.-C. Shen, “Developing energy conservation and carbon reduction indicators for the hotel industry in Taiwan,” *Int J Hosp Manag*, vol. 31, no. 1, pp. 199–208, Mar. 2012, doi: 10.1016/j.ijhm.2011.06.006.

[54] UNTWO, “Global and regional tourism performance,” UN Tourism. Accessed: Aug. 11, 2023. [Online]. Available: https://www.unwto.org/tourism-data/global-and-regional-tourism-performance

[55] General Directorate of Investment and Enterprises, “Accommodation facility statistics by province İl bazında konaklama tesisi istatistikleri - 2022 Yılı Belediye Belgeli Konaklama İstatistikleri İl-İlçe Tablosu,”

TC Kültür ve Turizm Bakanlığı. Accessed: Aug. 11, 2023. [Online]. Available: https://yigm.ktb.gov.tr/TR-211090/yillik-il-ilce-konaklama-istatistikleri.html

[56] N. Kokulu and S. Acun Özgünler, "An investigation on the maintenance, repair, and renovation behaviors of finishing materials used in hotel bedrooms," in *III. International Architecture Symposium*, Diyarbakır: İksad Publishing, Nov. 2023, pp. 150–163. Accessed: Feb. 02, 2024. [Online]. Available: https://f0b47925-b258-4468-8ac3-68a0e42cc408.filesusr.com/ugd/d0a9b7_9eaad621d4a14ad69f6383d7f4bb9a67.pdf

[57] Aytaş Alçı, "Aypan White Type A EPD," The International EPD system. Accessed: May 05, 2023. [Online]. Available: https://api.environdec.com/api/v1/EPDLibrary/Files/82d4bdb1-2749-4635-53d0-08dbdfa90a02/Data

[58] Aytaş Alçı, "AYGIPS Quick Dry Bonding (Machine Spray) Plaster EPD," The International EPD system. Accessed: May 05, 2023. [Online]. Available: https://api.environdec.com/api/v1/EPDLibrary/Files/c8b9b774-7ea5-4fa5-5396-08dbdfa90a02/Data

[59] Dyo, "Dinamic Silicone Silk Matt Interior Wall Paint EPD," The International EPD System. Accessed: May 05, 2023. [Online]. Available: https://api.environdec.com/api/v1/EPDLibrary/Files/063c99d7-8327-40ed-18e3-08db312e2dc4/Data

[60] Beissier, "Agguaplast Fillers/Spachtelmasse EPD," The International EPD system. Accessed: May 05, 2023. [Online]. Available: https://api.environdec.com/api/v1/EPDLibrary/Files/d0920de3-4ffd-447b-0d1c-08dbae79b560/Data

[61] PPG, "Sigma S2U Nova Primer EPD," The International EPD system. Accessed: May 05, 2023. [Online]. Available: https://api.environdec.com/api/v1/EPDLibrary/Files/4341b058-b5ab-443a-fc01-08dbfcbc4c1b/Data

[62] Kastamonu Entegre, ""Melamine faced MDF EPD," The International EPD system. Accessed: May 05, 2023. [Online]. Available: https://epd.dijitalpanel.site/Upload/epdturkey.com/Products/Images/64df779234c05-2021%2004_Melamine%20Faced%20MDF.pdf

[63] Onat, "How many m2 does 1 bag of satin plaster cover? 1 torba saten alçı kaç m2 yer yapar?" Accessed: May 05, 2023. [Online]. Available: https://www.onpo.com.tr/tr/haber-detay/1-torba-saten-alci-kac-m2-yer-yapar-109

[64] Filli Boya, "Momento putty-filler and surface smoothing putty Momento macun-dolgu ve yüzey düzeltme macunu." Accessed: May 05, 2023. [Online]. Available: https://www.filliboya.com/uploads/Momento_Macun.pdf

[65] Vuspan, "Rabita 2nd class floorboard - Rabıta 2.sınıf döşeme tahtasi." Accessed: May 05, 2023. [Online]. Available: https://www.masifpanel.com.tr/tr/rabita-2.sinif#:~:text=1%20m3%20rab%C4%B1ta%20ortalama,finger%20joint)%20olarak%20da%20%C3%BC

[66] B. Soust-Verdaguer *et al.*, "The use of environmental product declarations of construction products as a data source to conduct a building life-cycle assessment in Spain," *Sustainability*, vol. 15, no. 2, p. 1284, Jan. 2023, doi: 10.3390/su15021284.

[67] E. Meijer, "Weighting: applying a value judgment to LCA results." Accessed: Feb. 01, 2023. [Online]. Available: https://pre-sustainability.com/articles/weighting-applying-a-value-judgement-to-lca-results/

[68] A. Laurent and M. Z. Hauschild, "Normalisation," 2015, pp. 271–300. doi: 10.1007/978-94-017-9744-3_14.