Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 55 (2024) 127–134

Structural Integrity Procedia

www.elsevier.com/locate/procedia

ESICC 2023 – Energy efficiency, Structural Integrity in historical and modern buildings facing Climate change and Circularity

The TEnSE approach to assess the nudge of stakeholders in the choice of thermal insulation materials

Francesca Frasca[a,b,*], Beatrice Bartolucci[c], João Luis Parracha[d,e], Ozge Ogut[f,g], Maria Paula Mendes[d], Anna Maria Siani[a,b], Julia Neritzia Tzortzi[f], Chiara Bertolin[g], Ines Flores-Colen[d]

[a]*Department of Physics, Sapienza University of Rome, P.le A. Moro 5, Rome 00185, Italy*
[b]*CIABC Research Center, Sapienza University of Rome, P.le A. Moro 5, Rome 00185, Italy*
[c]*Department of Earth Sciences, Sapienza University of Rome, P.le A. Moro 5, Rome 00185, Italy*
[d]*CERIS, Department of Civil Engineering, Architecture and Environment, Instituto Superior Técnico, Universidade de Lisboa, Av. RoviscoPais, 1, Lisbon 1049-001, Portugal*
[e]*LNEC, Department of Buildings, National Laboratory for Civil Engineering, Av. do Brasil 101, Lisbon 1700-066, Portugal*
[f]*Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Via G. Ponzio 31, Milan 20133, Italy*
[g]*Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology, Richard Birkelands vei 2B, Trondheim 7491, Norway*

Abstract

The buildings' energy efficiency and the energy poverty can be improved through the implementation of active and/or passive retrofit solutions. The thermal insulation of building envelope is one of the most employed retrofit solutions. Several thermal insulation materials are currently available in the building market. However, the choice of a specific material can depend on an ensemble of requirements ascribed to four domains – Technical (T), Environmental (En), Safety (S) and Economic (E). The TEnSE approach is here proposed to investigate the influence of specific stakeholders or nudgers in the selection of thermal insulation materials for building retrofit. It is a three-step approach, that starts from a) the identification of a set of alternatives and decision criteria, b) the assignation of parameters and their normalization, and c) the definition of a weights' matrix and calculation of the Stakeholders' Score. As an example, here, the TEnSE is used to study the influence of stakeholders in the choice of the most used thermal insulation materials in three countries of the European Economic Area. The TEnSE approach can be used beyond a

* Corresponding author. Tel.: +39 06 4991 3479.
E-mail address: f.frasca@uniroma1.it

Peer-review under responsibility of the ESICC 2023 Organizers
10.1016/j.prostr.2024.02.017

products' score tool, as experts in social sciences and climate/energy policies could depict what are the decisional patterns of public, private, and people to enhance the green awareness and fill the legislative and political gap towards this topic.

Keywords: TEnSE approach; building retrofit; stakeholder influence; sustainability; EFFICACY

1. Introduction

The European (EU) Directive 2018/844 brings about defining strategies aimed at decreasing the energy demand of existing buildings together with the improvement in the energy performance to reduce carbon dioxide emissions from the building sector by more than half by 2030 and close to zero by 2050. Indeed, about 75% of existing buildings in Europe are energy inefficient and more than 90% of these buildings will still exist in 2050 (Sandberg et al., 2016). Consequently, there is a pressing need to carry out the maintenance, refurbishment, and retrofit of these buildings. However, approximately 8% of Europeans, predominantly in southern and eastern EU countries (Recalde et al., 2019; Sánchez-Guevara Sánchez et al., 2017), have difficulties of accessing to essential energy products and services in their buildings due to Energy Poverty (EP) thus limiting the decarbonization process and the energy efficiency. Both short-term and long-term measures can be implemented to reduce the disparities among Europeans in EP. Short-term measures is mainly driven by political decisions, long-term measures by the improvement of the energy efficiency of buildings through active and passive solutions (Directive 2010/31/EU). The thermal insulation of building envelopes is one of the most applied passive solutions and it is witnessed by the increase (around 3.5% of Compounded Average Growth Rate - CAGR) of the demand for thermal insulation materials in building applications. The building market includes a large variety of thermal insulation products, and for this reason, several methods have been developed to help identifying the best possible alternative among items or systems or processes based on the decision-makers' preferences and priorities. These methods are commonly called Multi-Criteria Decision Making (MCDM) methods. Although the performance of MCDM methods was successfully tested in a wide range of applications (Balali et al., 2020; Mahmoudkelaye et al., 2018; Milani et al., 2013; Parece et al., 2022; Sharma et al., 2023; Zagorskas et al., 2014), one of their limitations is the coupling between a criterion and its relative importance which may vary case-by-case depending on the professional priorities of single experts (Laguna Salvadó et al., 2022). However, it was possible to categorise these criteria into four domains (economic, social, technological, and environmental) representing the pillar of sustainability and to identify the most popular criterion within each domain (Siksnelyte-Butkiene et al., 2021). Another limitation of MCDM methods is related to the validation of outputs that can be proven mainly through practice (Zakeri et al., 2023). Currently, to the best of authors' knowledge, no study has been conducted to understand whether the selection of thermal insulation materials for building retrofit has been influenced by specific stakeholders or nudgers.

In this paper, we describe a straightforward approach to better understand the influence of specific stakeholders or nudgers in the selection of thermal insulation materials for building retrofit under various contexts. The approach is called TEnSE as it considers four objective domains – Technical (T), Environmental (En), Safety (S) and Economic (E). The TEnSE makes it possible a comparison on preferences at different regional scale. Here, we provide an example in the application of TEnSE in three countries of the European Economic Area.

Nomenclature

A	alternative
DC	decision criteria
E	economic domain
En	environmental domain
EPD	environmental product declaration
p	parameter
p'	normalized parameter
S	security domain

StS	stakeholder score
T	technical domain

2. Methodology: TEnSE approach

Nowadays, the selection of the most suitable thermal insulation material for building retrofit should involve an ensemble of requirements rather than only the thermal performance of the material itself (Al-Homoud, 2005). These requirements can be ascribed to four domains – Technical (T), Environmental (En), Safety (S) and Economic (E) – as demonstrated in the literature (Antwi-Afari et al., 2023; Hatefi et al., 2021; Moussavi Nadoushani et al., 2017; Parracha et al., 2023; Siksnelyte-Butkiene et al., 2021).

The TEnSE approach was developed in the framework of the EEA grants EFFICACY (Energy eFFiciency building and CirculAr eConomY for thermal insulating solutions), whose overall objective is to provide a comprehensive database contributing to the New European Bauhaus. The TEnSE can be classified as an inverse decision-making approach (Jern et al., 2017), as it allows to objectively compare data and metadata of a set of alternatives of a given item or system or process (in this study thermal insulation materials) and to identify the underlying influences behind the selection of specific alternative in a country or in a region. The TEnSE is based on the schematic workflow in Fig. 1 and structured in three steps briefly described in the following subsections.

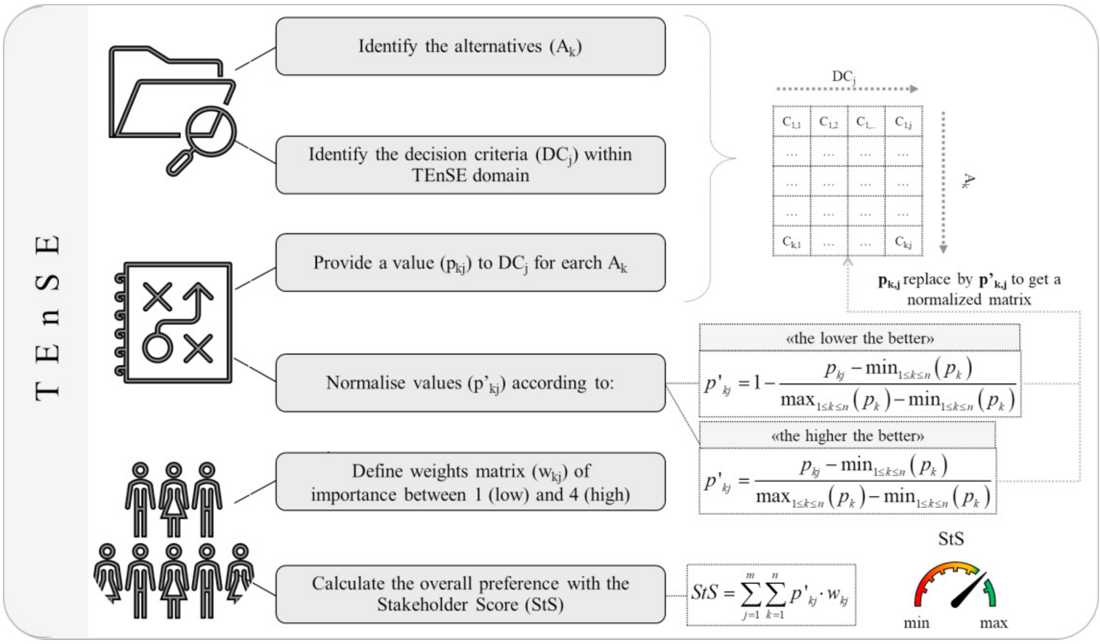

Fig. 1. Schematic workflow of the TEnSE approach.

2.1. Identification of alternatives and decision criteria

This step allows to define the input matrix, based on a set of alternatives (A), among items or systems or processes, that can be employed in a specific context, such as the thermal insulation materials for building retrofit. After that, one or more decision criteria (DC) are selected for each domain considering a set of quantitative and measurable parameters (p). In this way, it is possible to define the input matrix, where each row corresponds to an alternative (A_k) and each column to a decision criterion (DC_j). For thermal insulation materials, Siksnelyte-Butkiene et al. (2021) provided an overview of DC commonly considered in the scientific literature corresponding to TEnSE domains.

2.2. Assignation of parameters and parameters' normalization

In this step, p values for the selected DC_j in T, En and S domains can be gathered from the Environmental Product Declarations (EPD, in accordance with EN 15804:2012+A2:2019 and ISO 14025:2006) of each alternative (A_k) and, in the case of E domain, from the national/international price lists. Data (p_{kj}) feed the input matrix defined in the previous step.

For each DC_j along A_k, parameters (p_{kj}) are linearly normalized between 0 and 1 (p'_{kj}), where 0 corresponds to the worst case and 1 to the best case among the alternatives. The normalization considers the rules: *"the lower the better"* if the best case corresponds to low values of the parameter; and *"the higher the better"* if the best case corresponds to high values of the parameter. The main advantage to normalize p values relies on analyzing dimensionless criteria without the influence of different units and ranges of measure (Felinto De Farias Aires and Ferreira, 2022; Zakeri et al., 2023). The p_{kj} matrix is replaced by the new p'_{kj} matrix.

2.3. Definition of a weights' matrix and calculation of the Stakeholders' Score (StS)

The construction of weights associated with stakeholders are commonly defined via surveys or questionnaire filled in by specific experts (Siksnelyte-Butkiene et al., 2021). This can be responsible for a biased evaluation on the reason behind the choice of thermal insulation materials, as it would depend on the expertise of the stakeholders involved. To consider the relative importance of stakeholder within each domain, twenty-four scenarios, corresponding to a set of six permutations for each domain, are defined by associating a weight (w) – from 1 (low importance) to 4 (high importance). The w matrix is reported in Table 1.

The Stakeholders' Score (StS) is computed by multiplying p' and w matrices. According to this formulation, StS can only range between 0 (no influence by any stakeholder) and 10 (strong influence by specific stakeholders).

StS can be globally visualized via stoplight charts: green indicates the highest preferred solution (StS > 5) and red the less preferred solution (StS < 5) by one or more stakeholders.

Table 1. Permutations of weights (w) to compute Stakeholders' Score (StS) according to TEnSE approach from 1 (low importance) to 4 (high importance).

Domain (parameter)	**Weights (w) for Stakeholders**																							
	Technical expertise						**En**vironmental expertise						**S**afety expertise						**E**conomical expertise					
	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*	*n*	*o*	*p*	*q*	*r*	*s*	*t*	*u*	*v*	*w*	*x*
Technical	4	4	4	4	4	4	1	1	2	2	3	3	1	1	2	2	3	3	1	1	2	2	3	3
Environmental	1	1	2	2	3	3	4	4	4	4	4	4	2	3	1	3	1	2	2	3	1	3	1	2
Safety (social issues)	2	3	1	3	1	2	2	3	1	3	1	2	4	4	4	4	4	4	3	2	3	1	2	1
Economic	3	2	3	1	2	1	3	2	3	1	2	1	3	2	3	1	2	1	4	4	4	4	4	4
Total	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**

3. Application to the most used thermal insulation materials

The TEnSE was here tested to objectively identify whether specific stakeholders have oriented the choice of the most used thermal insulation materials in Italy, Norway, and Portugal. These countries belong to the European Economic Area but significantly differ in terms of Energy Poverty (Ogut et al., 2023) as well as of environmental and legislative fields.

Following the three-step procedure of TEnSE, we identified the set of alternatives in the building market, i.e., the thermal insulation materials commonly used in the three countries, from the surveys conducted by market research for Norway and by the Erasmus Plus project OERCO2 (Open Educational Resource) for Italy and Portugal (Fig. 2). Then, we considered the following decision criteria for each TEnSE domain:

- T: thermal conductivity as the parameter to evaluate the thermal performance of the material because it is independent from the application thickness.

- En: amount of the equivalent carbon dioxide ($CO_{2,eq}$) emissions per 1 m^2 of the material in the cradle-to-gate approach to consider the Global Warming Potential (GWP) before its application in the retrofit.
- S: fire reaction according to EN 13501-1:2018 so to pay attention to the safeguard of the intervention and use (e.g., smoke release).
- E: price of the thermal insulation material per 1 m^2 (€ m^{-2}) per the whole thickness range to pay attention to the influence of the market on the selection of a thermal insulation material.

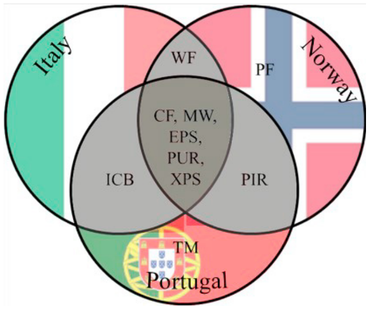

Fig. 2. Thermal insulation materials commonly used in Italy, Norway, and Portugal. CF = Cellulose fibre; ICB = Expanded cork agglomerate; WF = Wood fibre; MW = Mineral wool; TM = Thermal mortars; EPS = Expanded polystyrene; PF = Phenolic foam; PIR = Polyisocyanurate; PUR = Polyurethane foam; XPS = Extruded polystyrene.

After the extraction of data from the EPD and the national price lists reported in the footnotes of Table 2, it was applied the rule *"the lower the better"* for each parameter to compute the normalized matrix p' reported in Table 2.

Table 2. p' matrix on the most used thermal insulation materials in Italy, Norway, and Portugal, constructed on data retrieved from EPD (in footnotes) and national price lists.

Thermal insulation material based on EPDs	T	En	S	E		
				Italy	*Norway*	*Portugal*
Cellulose fibre (CF) (1)	0.24	0.05	0.8	0.85	n.a	0.62
Expanded cork agglomerate (ICB) (2)	0.08	1.00	0.2	0.71	0.00	0.35
Wood fibre (WF) (3)	0.32	0.11	0.2	0.89	0.90	0.61
Mineral wool (MW) (4)	0.52	0.03	1.0	0.44	0.90	0.37
Thermal mortars (TM) (5)*	0.00	0.00	1.0	0.65	1.00	0.00
Expanded polystyrene (EPS) (6)	0.28	0.00	0.2	0.41	0.96	1.00
Phenolic foam (PF) (7)	0.96	0.01	0.6	0.00	n.a	n.a
Polyisocyanurate (PIR) (8)**	0.88	0.03	0.8	0.24	0.77	0.77
Polyurethane foam (PUR) (9)	1.00	0.01	0.2	1.00	0.70	0.29
Extruded polystyrene (XPS) (10)	0.44	0.02	0.2	0.52	0.92	0.88

(1) CAPEM, (2) Amorim Cork Insulation, (3) IBU – Institut Bauen und Umwelt e.V., (4) KnaufInsulation, (5) DIASEN srl, (6) Finja, (7) Kingspan, (8) Europerfil, (9) Polyurethan dammt besser, (10) DANOSA
*Thermo-renderecological thermal and breathable, formulated with cork, natural hydraulic lime, clay and diatomaceous powders.
**Fire reaction of PIR varies according to additives (from B,s2-d0 to F). In this study, B,s2-d0 was considered as it was the most occurred. It is worth noticing that in this paper the criterion is related to safety of households, although it could be considered as a technical parameter.
Unit Cost Italy: https://prezziario.regione.veneto.it/, https://www.regione.lazio.it/cittadini/lavori-pubblici-infrastrutture/tariffa-prezzi-lavori-pubblici
Unit Cost Norway: https://www.xl-bygg.no/, https://www.obsbygg.no/, https://www.byggmakker.no/, https://www.kork24.no/shop/11-lyd-og-varme-kork-isolasjonsplater/, https://isotech.no/isokit/
Unit Cost Portugal: http://www.geradordeprecos.info/

Per each country, we computed the StS matrix by multiplying the w matrix (Table 1) with the p' matrix (Table 2). It is evident that there is not an evident underlying aspect behind the selection of thermal insulation materials in the three countries as the StS ranges between 2 and 7 (Fig. 3). In Norway and Portugal, the choice of PIR could be driven by the attention devoted to the low thermal conductivity and the high reaction to fire. The latter would play a key for

Norwegian experts in safety when it comes to retrofitting wooden dwellings that are very numerous in the country. In Italy, the selection of ICB could be driven by environmental experts and in less extent by economic experts, that could drive the preference towards a local raw material (Italy is the 5th cork producer in the world). Environment-oriented Portuguese stakeholders would influence the choice of ICB, as Portugal is the first producer of cork in the world. The main difference among countries is due to the E domain, although the global market is moderately competitive due to many suppliers in the building sector.

Thermal insulation materials		Technical expertise						Environmental expertise						Safety expertise						Economic expertise					
		a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**	**u**	**v**	**w**	**x**
Italy	CF	5	5	4	4	4	4	5	5	4	4	3	3	6	5	6	5	6	5	6	5	6	5	6	5
	ICB	4	3	5	4	5	4	7	6	6	5	6	5	5	5	4	5	3	4	6	6	5	6	4	5
	WF	4	4	4	3	4	3	4	3	4	3	3	3	4	3	4	3	4	3	5	5	5	5	5	5
	MW	5	6	4	6	4	5	4	5	3	5	4	4	6	5	6	6	6	6	5	4	6	4	5	4
	TM	4	4	3	4	2	3	4	4	3	4	2	3	6	5	6	5	5	5	6	5	6	4	5	4
	EPS	3	3	3	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2	3	2	3	2	3	3
	PF	5	6	4	6	4	5	2	3	3	4	4	4	3	3	4	4	5	5	3	2	4	3	4	4
	PIR	6	6	5	6	5	5	3	4	3	5	4	5	5	5	6	5	6	6	4	4	5	4	5	4
	PUR	7	7	7	6	6	5	4	4	5	4	5	4	5	4	6	4	6	5	6	5	7	6	7	7
	XPS	4	3	4	3	3	3	2	2	3	2	3	2	3	2	3	2	3	3	3	3	4	3	4	4
		a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**	**u**	**v**	**w**	**x**
Norway	CF																								
	ICB	2	2	3	3	4	4	4	5	4	5	4	5	3	4	2	4	2	3	3	3	2	3	2	2
	WF	5	4	4	3	4	3	4	3	4	3	3	3	4	3	4	3	4	3	5	5	5	5	5	5
	MW	7	7	6	6	5	5	5	5	5	5	4	5	7	6	8	6	7	7	7	6	8	6	7	6
	TM	5	5	4	4	3	3	5	5	4	4	3	3	7	6	7	5	6	5	7	6	7	5	6	5
	EPS	4	4	4	3	3	2	4	3	4	2	3	2	4	3	4	2	4	3	5	5	5	5	5	5
	PF																								
	PIR	7	7	7	7	6	6	5	5	5	5	5	5	6	6	7	6	7	7	6	6	7	6	7	7
	PUR	7	6	6	5	6	5	4	3	4	3	5	4	4	3	5	4	5	5	4	4	5	5	6	6
	XPS	5	4	5	3	4	3	4	3	4	2	3	3	4	3	4	3	4	3	5	5	5	5	5	5
		a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**	**u**	**v**	**w**	**x**
Portugal	CF	4	5	4	4	3	3	4	4	3	4	3	3	5	5	6	4	5	5	5	4	5	4	5	4
	ICB	3	3	4	3	4	4	6	5	5	5	5	5	4	5	3	4	3	3	4	5	3	5	3	4
	WF	4	3	4	3	3	3	3	3	3	2	3	2	3	3	3	2	3	3	4	3	4	4	4	4
	MW	5	6	4	6	4	5	4	4	3	5	3	4	6	5	6	6	6	6	5	4	6	4	5	4
	TM	2	3	1	3	1	2	2	3	1	3	1	2	4	4	4	4	4	4	3	2	3	1	2	1
	EPS	5	4	4	3	3	3	4	3	4	2	3	2	4	3	4	2	4	3	5	5	5	5	5	5
	PF																								
	PIR	7	7	7	7	6	6	5	5	5	5	5	5	6	6	7	6	7	7	6	6	7	6	7	7
	PUR	5	5	5	5	5	5	2	2	3	3	4	4	3	2	4	3	4	4	3	3	4	3	5	4
	XPS	5	4	5	3	4	3	4	3	4	2	3	3	4	3	4	3	4	3	5	4	5	5	5	5

Fig. 3. Stoplight charts of Stakeholders' Score (StS) where the influence in the selection of each thermal insulation material is rated as low (red), neutral (white) or high (green). Grey areas indicate thermal insulation materials where E domain is missing (Table 2).

4. Conclusion

The TEnSE approach lays its foundation upon the fact that when we make a decision, our expertise and experience affect that decision. The TENSE first gives the idea that the optimal solution should cover higher expectations for a high number of stakeholders and should not be focus on only one perspective. One of the limitations of the TEnSE is the dependency on environmental product declarations and price lists that can be specific of an area. Notwithstanding the TEnSE approach has the potential to become more than a products' score tool. In fact, experts in social sciences and climate and energy policies, analyzing the TEnSE scores in specific countries could depict the decisional patterns of public, private, and people when dealing with the selection of thermal insulation materials. In addition, from the scores analysis they could gain targeted feedback to enhance 1) the social awareness and social acceptability of greener and more sustainable thermal insulation solution; and 2) to fill the existing gaps in the legislation or in the guidelines, in a way that the next directives will be closer to the real understanding and needs of citizens. These TEnSE hidden potentialities have the capability of influencing the two missing domains, i.e., the social and the legislative/political. Since the TEnSE approach has exhibited significant promise, could yield valuable insights in various contexts.

Further research will be developed to understand the relationship of the stakeholder's score with the climate and legislative contexts of specific geographical areas. Indeed, it would allow to understand how the role of stakeholders can affect the development and implementation of solutions in areas that will be differently impacted by the ongoing climate change.

Acknowledgements

F. Frasca acknowledges fellowship funding from MUR (Ministero dell'Università e della Ricerca) under PON "Ricerca e Innovazione" 2014-2020 (ex D.M. 1062/2021). I. Flores-Colen and C. Bertolin and all the authors are grateful to the EEA Granted EFFICACY project (Efficacy project - Energy eFFiciency building and CirculAr eConomY for thermal insulating solutions, grant n. FBR_OC1_114) that has funded this research within the scope of bilateral fund. I. Flores-Colen and M. P. Mendes acknowledge the Portuguese Foundation for Science and Technology (FCT) and research unit CERIS (UIDB/04625/2020). J. Parracha also acknowledges FCT for the Ph.D. scholarship 2020.05180.BD.

References

Al-Homoud MS. Performance characteristics and practical applications of common building thermal insulation materials. Build Environ 2005;40:353–66. https://doi.org/10.1016/j.buildenv.2004.05.013.

Antwi-Afari P, Ng ST, Chen J. Determining the optimal partition system of a modular building from a circular economy perspective: A multicriteria decision-making process. Renewable and Sustainable Energy Reviews 2023;185. https://doi.org/10.1016/j.rser.2023.113601.

Balali A, Valipour A, Zavadskas EK, Turskis Z. Multi-criteria ranking of green materials according to the goals of sustainable development. Sustainability (Switzerland) 2020;12:1–18. https://doi.org/10.3390/su12229482.

EN 13501-1:2018: Fire classification of construction products and building elements. Part 1: Classification using data from reaction to fire tests. 2018.

EN 15804:2012+A2:2019. Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products n.d.

Felinto De Farias Aires R, Ferreira L. A New Multi-Criteria Approach for Sustainable Material Selection Problem. Sustainability 2022. https://doi.org/10.3390/141811191.

Hatefi SM, Asadi H, Shams G, Tamošaitienė J, Turskis Z. Model for the sustainable material selection by applying integrated dempster-shafer evidence theory and additive ratio assessment (Aras) method. Sustainability (Switzerland) 2021;13. https://doi.org/10.3390/su131810438.

ISO 14025:2006. Environmental labels and declarations - Type III environmental declarations - Principles and procedures 2006.

Jern A, Lucas CG, Kemp C. People learn other people's preferences through inverse decision-making. Cognition 2017;168:46–64. https://doi.org/10.1016/j.cognition.2017.06.017.

Laguna Salvadó L, Villeneuve E, Masson D, Abi Akle A, Bur N. Decision Support System for technology selection based on multi-criteria ranking: Application to NZEB refurbishment. Build Environ 2022;212. https://doi.org/10.1016/j.buildenv.2022.108786.

Mahmoudkelaye S, Taghizade Azari K, Pourvaziri M, Asadian E. Sustainable material selection for building enclosure through ANP method. Case Studies in Construction Materials 2018;9. https://doi.org/10.1016/j.cscm.2018.e00200.

Milani AS, Shanian A, Lynam C, Scarinci T. An application of the analytic network process in multiple criteria material selection. Mater Des 2013;44:622–32. https://doi.org/10.1016/j.matdes.2012.07.057.

Moussavi Nadoushani ZS, Akbarnezhad A, Ferre Jornet J, Xiao J. Multi-criteria selection of façade systems based on sustainability criteria. Build Environ 2017;121:67–78. https://doi.org/10.1016/j.buildenv.2017.05.016.

Ogut O, Bartolucci B, Parracha JL, Bertolin C, Tzortzi JN, Frasca F, et al. Energy poverty in Portugal, Italy, and Norway: Awareness, short-term driving forces, and barriers in the built environment. IOP Conf Ser Earth Environ Sci, vol. 1176, 2023. https://doi.org/10.1088/1755-1315/1176/1/012023.

Parece S, Rato V, Resende R, Pinto P, Stellacci S. A Methodology to Qualitatively Select Upcycled Building Materials from Urban and Industrial Waste. Sustainability (Switzerland) 2022;14. https://doi.org/10.3390/su14063430.

Parracha JL, Bartolucci B, Boccacci G, Ogut O, Bartels G, Siani AM, et al. A dataset of criteria on the use of thermal insulation solutions in building facades located in Norway, Portugal and Italy. Data Brief 2023:109622. https://doi.org/10.1016/J.DIB.2023.109622.

Recalde M, Peralta A, Oliveras L, Tirado-Herrero S, Borrell C, Palència L, et al. Structural energy poverty vulnerability and excess winter mortality in the European Union: Exploring the association between structural determinants and health. Energy Policy 2019;133. https://doi.org/10.1016/j.enpol.2019.07.005.

Sánchez-Guevara Sánchez C, Mavrogianni A, Neila González FJ. On the minimal thermal habitability conditions in low income dwellings in Spain for a new definition of fuel poverty. Build Environ 2017;114:344–56. https://doi.org/10.1016/j.buildenv.2016.12.029.

Sandberg NH, Sartori I, Heidrich O, Dawson R, Dascalaki E, Dimitriou S, et al. Dynamic building stock modelling: Application to 11 European countries to support the energy efficiency and retrofit ambitions of the EU. Energy Build 2016;132:26–38. https://doi.org/10.1016/j.enbuild.2016.05.100.

Sharma V, Zivic F, Adamovic D, Ljusic P, Kotorcevic N, Slavkovic V, et al. Multi-Criteria Decision Making Methods for Selection of Lightweight Material for Railway Vehicles. Materials 2023;16. https://doi.org/10.3390/ma16010368.
Siksnelyte-Butkiene I, Streimikiene D, Balezentis T, Skulskis V. A systematic literature review of multi-criteria decision-making methods for sustainable selection of insulation materials in buildings. Sustainability (Switzerland) 2021;13:1–21. https://doi.org/10.3390/su13020737.
Zagorskas J, Zavadskas EK, Turskis Z, Burinskiene M, Blumberga A, Blumberga D. Thermal insulation alternatives of historic brick buildings in Baltic Sea Region. Energy Build 2014;78:35–42. https://doi.org/10.1016/j.enbuild.2014.04.010.
Zakeri S, Chatterjee P, Konstantas D, Ecer F. A decision analysis model for material selection using simple ranking process. Sci Rep 2023;13. https://doi.org/10.1038/s41598-023-35405-z.