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PSAT: A knowledge-based decision support tool for selecting passive energy consumption optimisation strategies in buildings ☆

Amirhossein Balali, Akilu Yunusa-Kaltungo *

School of Engineering, Faculty of Science and Engineering (FSE), The University of Manchester, Manchester M13 9PL, United Kingdom

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ABSTRACT

Achieving net-zero energy targets is closely linked to the optimisation of building-related activities, given their significant share in global energy consumption (approximately 40%) and greenhouse gas emissions (around 33%). The substantial energy demands of active systems, such as energy recovery ventilation systems for heating and cooling, have increasingly directed research efforts towards the investigation of passive design strategies in recent years. Selecting the most sustainable passive energy consumption optimisation strategy for buildings is a complex and challenging task for practitioners, as it requires the consideration of multiple criteria, including technical, economic, and social factors. Therefore, this study aims to develop a knowledge-based decision support tool titled the PSAT for the selection of passive strategies for buildings. Initially, drivers and barriers to the adoption of passive strategies, the criteria involved in the selection of passive strategies, and the existing passive strategies were identified. This was followed by generating a novel multiple criteria decision-making (MCDM) algorithm by hybridising evaluation based on distance from average solution (EDAS) and criteria importance through inter criteria correlation (CRITIC) methods. Then, graphical user interface (GUI) was developed for the PSAT using CustomTkinter, an innovative and customisable Python UI library which allows for the design of modern interfaces, providing a more user-friendly environment for decision-makers. The PSAT was then validated by experts and obtained the efficiency score of 4.76 out of 5. Finally, a thematic analysis was performed to identify the key themes within the suggestions provided by the validating experts regarding future development of the PSAT. This tool can considerably facilitate the selection of passive strategies for practitioners, consequently enhancing the realisation of critical Sustainable Development Goals (SDGs), especially “Sustainable Cities and Communities”.

1. Introduction

Buildings are major contributors to climate change and environmental problems [1,2]. More specifically, the building sector is responsible for consuming over 40 % of the total produced energy [3,4], 30 % of the total global resources [5], 70 % of the electricity generated [6], as well as accounting for 40 % of greenhouse gas (GHG) emissions [7]. It is therefore imperative to deduce apt solutions for reducing the detrimental effects of buildings on the environment [8]. Moreover, recent reports published by EU Commission suggests that approximately 37.4 million people within Europe were unable to warm their homes [9] due to the continuously increasing prices of energy [10], which further buttresses the necessity of energy efficient buildings.

Energy efficient buildings can contribute to the achievement of multiple Sustainable Development Goals (SDGs) [11]. For example, energy efficient buildings emit significantly less GHGs during heating and cooling, thereby contributing to the realisation of Climate Action (SDG 13) [12]. This also results in the optimisation of resource consumption (mainly fossil fuel) which is directly associated with Sustainable Consumption and Production (SDG 12) [13]. Furthermore, energy

Abbreviations: AHP, Analytical hierarchy process; ANP, Analytical network process; CRITIC, Criteria importance through inter criteria correlation; EDAS, Evaluation based on distance from average solution; ES, Efficiency score; GHG, Greenhouse gas; GUI, Graphical user interface; IAQ, Indoor air quality; KB-DST, Knowledge-based decision support tool; MCDM, Multiple criteria decision-making; PCM, Phase changing material; PSAT, Passive strategy assessment tool; SDG, Sustainable development goal; TOPSIS, Technique for order of preference by similarity to ideal solution.

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* Corresponding author.
E-mail addresses: amirhossein.balali@manchester.ac.uk (A. Balali), akilu.kaltungo@manchester.ac.uk (A. Yunusa-Kaltungo).

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Table 1
Summary of the investigated previous studies.

Code	Author	Year	Journal	Focus of the study	Programming tool	Location covered	MCDM technique used	Research gap	Ref
LR1	Sadeghi et al.	2024	Journal of Safety Research	Development of a knowledge-based decision support system for automated safety risk assessment	MATLAB	Hong Kong	Fuzzy AHP-TOPSIS	• Not focusing on building energy context. • Consideration of a specific geographical area. • Adoption of dated MCDM techniques. • Inability to consider specific factors selected by users.	[39]
LR2	Tabatabaee et al.	2021	Journal of Building Engineering	Development of an MCDM assessment tool for the adoption of building information modelling	Microsoft Visual Basic for Applications (VBA) within Microsoft Excel	Malaysia	DEMATEL-ANP	• Not focusing on building energy context. • Consideration of a specific geographical area. • Adoption of dated MCDM techniques. • Inability to consider specific factors selected by users.	[45]
LR3	Alshamrani and Alshibani	2020	Building and Environment	Development of an automated decision support system for selecting the envelope and structural systems for educational buildings	Microsoft Visual Basic for Applications (VBA) within Microsoft Excel	Saudi Arabia	AHP- MAUT	• Lack of information regarding the drivers and barriers to the adoption of the investigated systems. • Consideration of a specific geographical area. • Adoption of dated MCDM techniques. • Inability to consider specific alternatives and selection criteria indicated by users. • Consideration of limited number of selection criteria. • Not considering uncertainty.	[46]
LR4	Mahdiyar et al.	2019	Sustainable Cities and Society	Development of a prototype decision support system for green roof type selection	Microsoft Visual Basic for Applications (VBA) within Microsoft Excel	Malaysia	Fuzzy ANP	• Lack of information regarding the drivers and barriers to the adoption of investigated systems. • Consideration of a specific geographical area. • Adoption of dated MCDM technique. • Inability to consider specific alternatives and selection criteria indicated by users.	[47]
LR5	Hwang et al.	2018	Automation in Construction	Development of a knowledge-based decision support tool for prefabricated prefinished volumetric construction	Microsoft Visual Basic for Applications (VBA) within Microsoft Excel	Singapore	SWM	• Consideration of a specific geographical area. • Adoption of dated MCDM technique. • Inability to consider specific alternatives and selection criteria indicated by users. • Not focusing on building energy context. • Not considering uncertainty.	[41]

efficient buildings ease the pathways towards transforming current cities into greener and more sustainable ones, leading to the achievement of Sustainable Cities and Communities (SDG 11) [14].

Previous research indicate that over 40 % of the existing buildings within Europe were built prior to the 1960 s, when there were no stringent regulations governing the energy consumption of buildings [15]. On the other hand, there are strict regulations in countries such as the UK (e.g., Town and Country Planning Act 1990 [16]) regarding the protection of historical buildings due to their vital role in preserving history for the next generation [17]. This further complicates the selection of energy consumption optimisation strategies for buildings, as such solutions need to satisfy all the existing regulations and simultaneously lead to the UK's plan to achieve net-zero emissions by 2050 (The Climate Change Act [18]).

Further information on different types of energy consumption optimisation strategies in buildings is provided in Section 1.1, followed by more elaboration on the criteria involved in sustainable selection of passive energy consumption optimisation strategies for buildings in Section 1.2. Previous studies in this domain, along with an analysis of their limitations, are investigated in Section 1.3. Finally, Section 1.4 outlines the aim of this study and highlights its unique contributions to the existing body of knowledge.

1.1. Energy consumption optimisation strategies in buildings

Energy consumption optimisation strategies for buildings fall into two categories [19]. The first category consists of strategies that employ mechanical or electrical appliances to reduce the demand of fossil fuels for buildings and are referred to as active strategies [20]. Sustainable strategies within this category rely on using the existing renewable energy sources rather than fossil fuels. Examples of such strategies include, but not limited to, photovoltaic (PV) panels [21], combined heat and power (CHP) systems [22], and mechanical ventilation with heat recovery (MVHR) [23]. Strategies within the second category, however, rely on the buildings' structure, as well as the natural properties of the environment, to optimise energy consumption in buildings. In other words, no electrical or mechanical appliances are used in optimising the energy consumption of buildings through passive means, making them significantly environmentally friendly. Utilisation of green roof/façades [24], optimisation of the insulation layers of buildings [25], decreasing the airtightness of buildings [26] and using phase changing materials (PCMs) [27,28] are examples of passive energy consumption optimisation strategies. Considering the previous discussion regarding the preservation of historical buildings, coupled with the considerable costs associated with active strategies (i.e., initial cost and operation and maintenance (O&M) cost), passive strategies can be suggested as apt, green, sustainable, and environmentally friendly alternatives.

1.2. Criteria involved in selecting passive strategies for buildings

Selection of passive energy consumption optimisation strategies for buildings involves the consideration of various sustainability criteria, which span across social, technological, and economic domains, if a truly sustainable selection is desired. These criteria include, but not limited to, compatibility with climate [29], reduction of energy consumption [30], reduction of GHG emissions [31], initial installation time [32], job creation [19], and occupant wellbeing [33]. However, the consideration of multiple criteria further sophisticates the selection of passive strategies. Multiple criteria decision-making (MCDM) techniques have proven useful for addressing challenges related to the optimisation of numerous attributes and/or criteria [34] and are therefore relevant to the selection of passive strategies for buildings [35,36].

1.3. Previous studies

Some studies already exist within the current body of knowledge in which MCDM techniques were used for passive strategy-related research within the wider area of building energy. For example, Balali et al. [19] utilised a hybrid of step-wise weight assessment ratio analysis (SWARA) and complex proportional assessment (COPRAS) methods for the selection of suitable passive energy consumption optimisation strategies for Iranian residential buildings. Cao et al. [37] focused on the identification of integrated solutions for heating and cooling of residential buildings in China using technique for order of preference by similarity to ideal solution (TOPSIS) method. The same technique was used by Tariq et al. [38] to optimise a naturally ventilated façade with phase change material (PCM) in Mexico. Although the contributions of the mentioned studies to the relevant body of knowledge cannot be contested, the adopted methodologies are very time-consuming and complicated, which may impede their adoption and utilisation by practitioners for real-life building projects. Therefore, there is an urgent need to develop a decision support tool which can facilitate the selection of passive strategies for practical uses. Knowledge-based decision support tools (KB-DSTs) are apt solutions to facilitate solving MCDM problems within the built environment discipline and beyond, as suggested by [39].

KB-DST is a hybridisation of decision support system (DSS) and expert system (ES) [40]. The former consists of the integration of personal knowledge, database, and documents which can aid decision-makers in solving complex situations [41]. The latter involves transferring specific human knowledge to a computer, enabling the program to make inferences based on the knowledge base which is achieved by mimicking the decision-making process of human experts [42–44]. Therefore, KB-DST is a desirable tool that offers valuable information to decision-makers and simultaneously facilitates the decision-making process in a user-friendly environment [39].

There are a number of studies within the existing body of knowledge focusing on the development of MCDM-based KB-DSTs within the area of built environment. These studies are elaborated as follows. Sadeghi et al. [39] developed a KB-DST for automated safety risk assessment within the construction industry. They developed the tool in MATLAB and utilised a hybridisation of analytical hierarchy process (AHP) and TOPSIS methods for constructing the decision-making algorithm. Tabatabaee et al. [45] hybridised decision making trial and evaluation laboratory (DEMATEL) and analytical hierarchy process (ANP) within Microsoft Visual Basic for Applications (VBA) to develop an MCDM assessment tool for the adoption of building information modelling within the construction industry. Alshamrani and Alshibani [46] developed an automated decision support system for selecting the envelope and structural systems for educational buildings in which a hybridisation of AHP and multi attribute utility theory (MAUT) methods was used. Mahdiyar et al. [41] developed a prototype decision support system for green roof type selection in Malaysia, and used fuzzy ANP as the MCDM algorithm. Hwang et al. [41] developed a KB-DST for prefabricated prefinished volumetric construction in Singapore and developed the tool in VBA using summative weight method (SWM) as the MCDM algorithm. A summary of the investigated studies (denoted by LR1-LR5) is presented in Table 1.

Based on the conducted literature review, authors observed six major shortfalls within the previous studies which are highlighted as follows:

- Very few studies focused on building energy context, especially on passive energy consumption optimisation strategies.
- Specific geographical areas were considered, making it unsuitable for other regions due to the nature of passive strategies (which are climate-dependant).
- None of the studies included the drivers and barriers to the adoption of passive strategies for buildings, which are necessary information for decision-makers in this area and may alter their decisions.
- None of the KB-DSTs were able to consider specific selection criteria and/or attributes selected by users. Considering that each building project may have its own specific conditions, it is a necessity for the KB-DST to possess this feature.
- Dated MCDM techniques (e.g., AHP, ANP, and TOPSIS) were mainly used, which resulted in neglecting novel and powerful MCDM tools that are far more efficient in their accommodation of extensive inputs, data processing speed, and simplicity.
- Most of the studies used crisp versions of MCDM techniques (e.g., crisp versions of AHP, ANP, TOPSIS, and DEMATEL) which are limited in their capability to address uncertainties, thereby leading to ambiguities in solving MCDM problems.

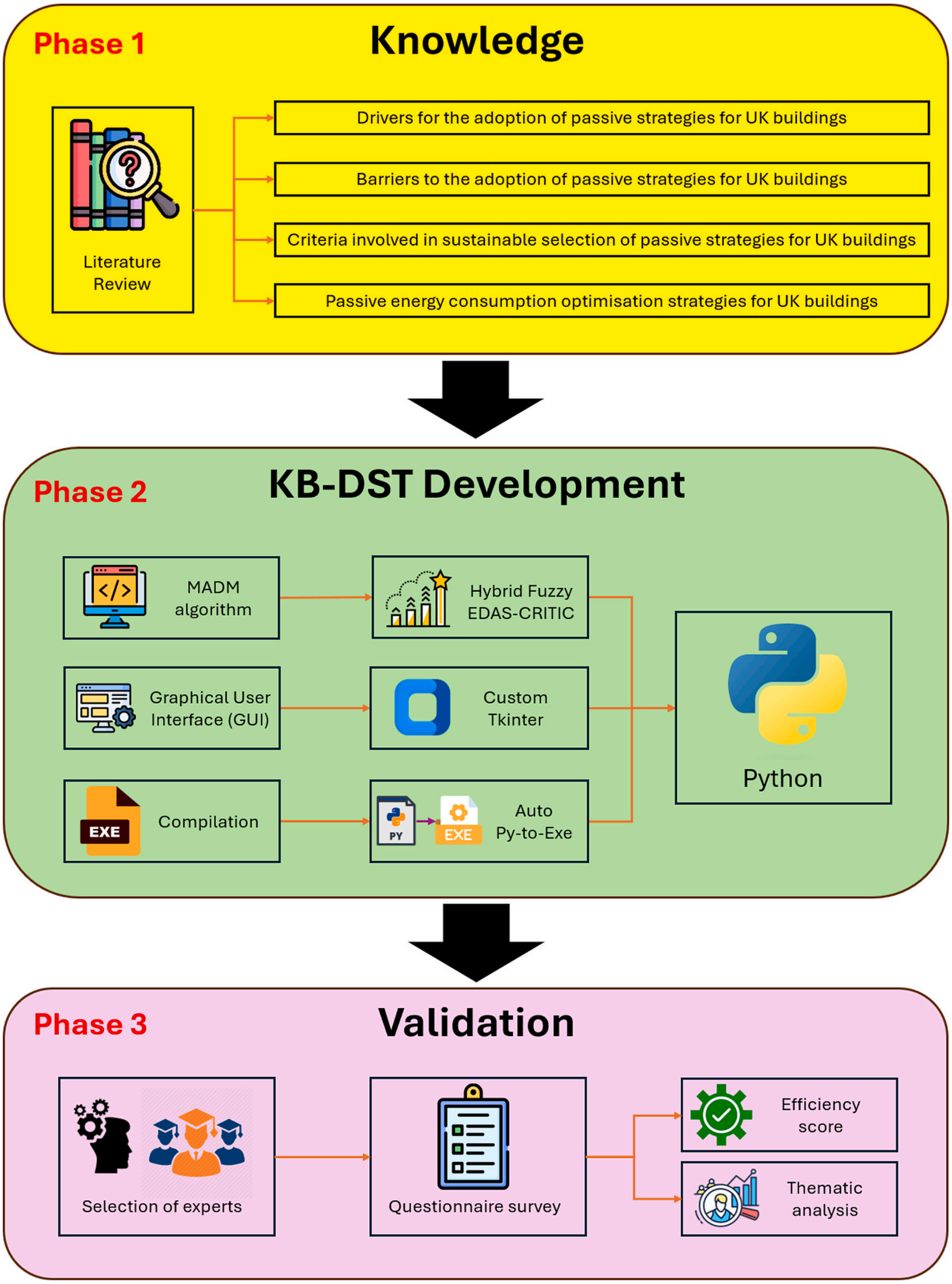


Fig. 1. Research framework.

Table 2
Keywords classification for the first search.

Keywords Class	Description
1	"Driver*" OR "Enabler*" OR "Barrier*" OR "Deterrent*" OR "Hindrance*" OR "Obstacle*"
2	"Passive*" OR "Passive Strateg*" OR "Passive Measure*"
3	"Energ*" OR "Energy Consum*" OR "Energy Optim*" OR "Energy Reduc*"
4	"Building*"

1.4. Aim of the study

In Europe, the building sector accounts for over 50 % of total energy consumption, more than 33 % of water usage, approximately 50 % of raw material extraction, and nearly 40 % of greenhouse gas (GHG) emissions [48]. To mitigate the mentioned environmental impacts, several countries, including the United Kingdom (UK), have implemented stringent building regulations. The UK, for instance, has set a target of achieving net-zero emissions by 2050 under the framework of The Climate Change Act [49]. However, a study by Liang et al. [50] highlights concerning statistics regarding the performance of existing

Table 3
Keywords classification for the second search.

Keywords Class	Description
1	"Multiple Criteria Decision Making OR Multi-Criteria Decision Making OR Multi-Criteria Decision-Making OR MCDM OR Multiple Criteria Decision Making OR Multi-Criteria Decision Analysis OR Multi-Criteria Decision-Analysis OR MCDA OR Rank* OR Prioriti*
2	"Passive*" OR "Passive Strateg*" OR "Passive Measure*"
3	"Energ*" OR "Energy Consum*" OR "Energy Optim*" OR "Energy Reduc*"
4	"Building*"

Table 4
Comparative analysis of MCDM techniques.

Technique	Ability to handle a large number of criteria/ alternatives	Ease of data collection	Ease of data analysis	Speed of data analysis
EDAS	H	H	M	H
Technique for order of preferences by similarity to ideal solution (TOPSIS)	H	M	L	M
Decision making trial and evaluation laboratory (DEMATEL)	H	M	M	H
Analytic Hierarchy Process (AHP)	L	L	H	L
Elimination et choix traduisant la realité (ELECTRE)	M	L	M	L
VIekriterijumsko KOmpromisno Rangiranje (VIKOR)	L	L	L	L
multi-objective optimization on the basis of ratio analysis (MOORA)	L	M	M	M

Table 5
Linguistic terms and their corresponding trapezoidal fuzzy numbers.

Linguistic term	Code	Trapezoidal fuzzy number
Very Low	VL	(0, 0, 0.1, 0.2)
Low	L	(0., 0.2, 0.2, 0.3)
Medium low	ML	(0.2, 0.3, 0.4, 0.5)
Medium	M	(0.4, 0.5, 0.5, 0.6)
Medium high	MH	(0.5, 0.6, 0.7, 0.8)
High	H	(0.7, 0.8, 0.8, 0.9)
Very high	VH	(0.8, 0.9, 1,1)

buildings in the UK, where over 30 % of generated energy and carbon emissions remain unaddressed.

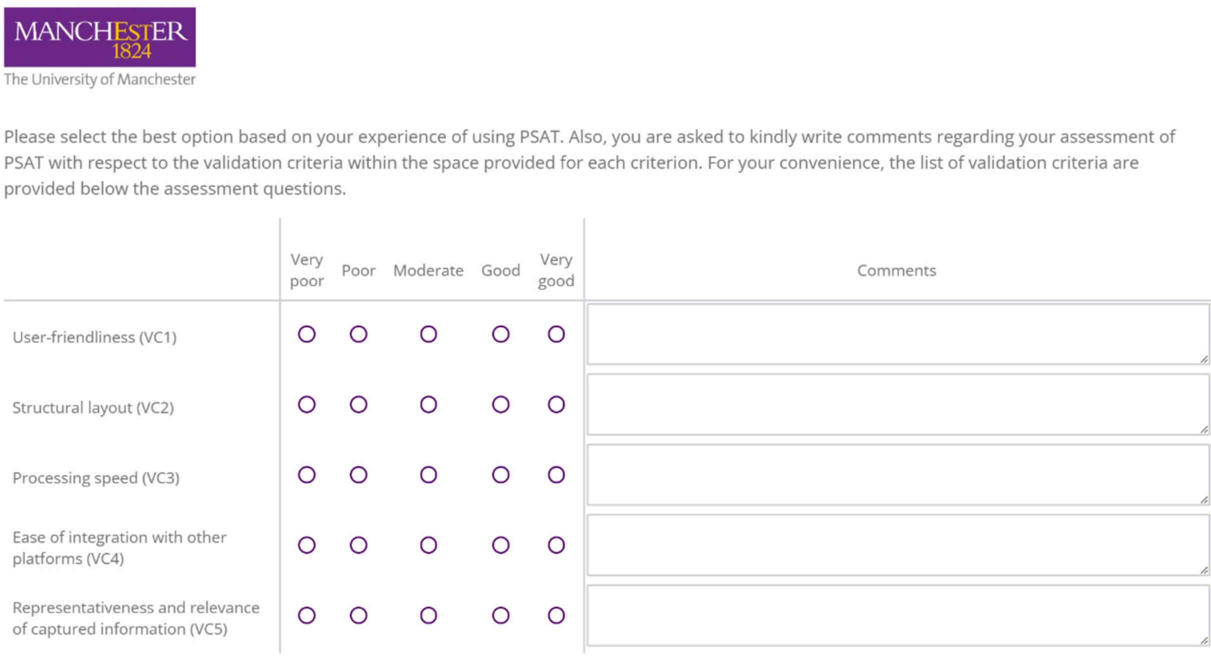
Based on the mentioned points, as well as the shortcomings identified from the previous studies, the overarching aim of this study is to develop a KB-DST for the selection of passive energy consumption optimisation strategies for UK buildings by hybridising fuzzy extensions of criteria importance through inter criteria correlation (CRITIC) and evaluation based on distance from average solution (EDAS) methods using Python, which includes a comprehensive information bank required for conducting the decision-making. Countries with climatic conditions similar to the United Kingdom (UK) can also utilise the findings of this study to inform their building strategies and sustainability initiatives. The contributions of this study to existing body of knowledge are:

Table 6
PSAT validation criteria.

Code	Validation criteria	Description
VC1	User-friendliness	VC1 refers to the ability of the PSAT to support the efficient and effective completion of specified tasks. It focuses on whether the platform meets all the users' functional requirements.
VC2	Structural layout	VC2 mainly refers to the overall appearance of the platform and the convenience with which users can navigate the different aspects.
VC3	Processing speed	VC3 refers to how quickly the user can input data, rank parameters, and generate results.
VC4	Ease of integration with other platforms	Most organisations would have already invested funds into other systems (e.g., building energy management systems, facilities management systems, building information models, computerised maintenance systems, etc.) that enable them to monitor building performance and compliance with regulations. Therefore, VC4 is a measure of the ease of integrating the PSAT with other existing building management platforms or systems.
VC5	Representativeness and relevance of captured information	VC5 is a measure of how well the recorded information reflect real-life scenarios.

- Identification of the criteria required for selecting passive energy consumption optimisation strategies for buildings, especially within the social, technical, and economic domains, which would be beneficial for future research within this discipline.
- Identification of the existing passive strategies for buildings, which will also serve as a vital baseline upon which future research activities can be developed.
- Identification of the drivers for adopting passive energy consumption optimisation strategies for UK buildings, which is necessary to further promote the use of passive strategies within the UK building sector.
- Identification of the barriers to adopting passive energy consumption optimisation strategies for UK buildings, which is required for future policymaking in this area.
- Creation of a novel algorithm for selecting passive strategies for UK buildings in Python, by hybridising fuzzy extensions of CRITIC and EDAS methods, which can be used to solve similar MCDM problems in the future, irrespective of the research discipline.
- Development of a user-friendly KB-DST featuring information regarding the drivers and barriers to the adoption of passive energy consumption optimisation strategies for UK buildings, the criteria involved in this selection, and the relevant passive strategies. This tool is titled passive strategy assessment tool (PSAT) and can considerably facilitate the selection of passive strategies in practice.

The remainder of the study is structured as follows. Section 2 provides information regarding the adopted methodology. Results of the study are provided from Section 3, where the knowledge involved in the PSAT is explained. Section 4 explains how the PSAT is developed in Python and demonstrates its menus and tabs. A sample case is presented in Section 5 to further guide the readers on how the PSAT works. Information regarding the validation of the PSAT, as well as the corresponding thematic analysis, is provided in Section 6. Finally, Section 7 concludes the study, identifies the limitations, and suggests future research pathways.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The University of Manchester

Please select the best option based on your experience of using PSAT. Also, you are asked to kindly write comments regarding your assessment of PSAT with respect to the validation criteria within the space provided for each criterion. For your convenience, the list of validation criteria are provided below the assessment questions.

	Very poor	Poor	Moderate	Good	Very good	Comments
User-friendliness (VC1)	○	○	○	○	○	
Structural layout (VC2)	○	○	○	○	○	
Processing speed (VC3)	○	○	○	○	○	
Ease of integration with other platforms (VC4)	○	○	○	○	○	
Representativeness and relevance of captured information (VC5)	○	○	○	○	○	

Fig. 2. PSAT validation questionnaire.

2. Research methodology

The suggested methodology for this study consists of three phases including knowledge, KB-DST development and validation, as illustrated in Fig. 1. Further information regarding each phase is provided within the following subsections.

2.1. Knowledge

A comprehensive literature review was initially conducted to identify a) drivers and barriers to the adoption of passive energy consumption optimisation strategies for UK buildings, b) sustainability criteria involved in the selection of passive energy consumption optimisation strategies, and c) the existing passive energy consumption optimisation strategies. Six popular databases were used to conduct the literature review, including Web of Science (WoS), Scopus, Compendex, Inspec, GEOBASE, and GeoRef. Two different searches were run to gather the required information (one for drivers/barriers, and the other for selection criteria/passive strategies), and the keywords used are shown in Tables 2-3, respectively. Four classes of keywords were used for each search, and the entries within each class were separated by "OR" operator since they represent variations of one another. Individual classes, however, were separated by "AND" operator.

The obtained results of this literature review formed the knowledge section of the PSAT, which is further discussed in Section 3.0.

2.2. KB-DST development

2.2.1. Selection of MCDM approach

There are numerous MCDM techniques within the existing body of knowledge [51], each having specific advantages and disadvantages [52]. Therefore, the selection of suitable technique for solving an MCDM problem severely depends on the problem type, as asserted by [35,53]. Balali and Yunusa-Kaltungo [36] investigated multiple MCDM methods and assessed their suitability for selecting passive energy consumption optimisation strategies, and considered four distinct assessment criteria including a) ability to handle a large number of criteria/alternatives, b) ease of data collection, c) ease of data analysis, and d) speed of data analysis. Based on their results, fuzzy EDAS was suggested as the best MCDM method for selecting passive strategies for buildings. In order to further illustrate the superiority of EDAS over other MCDM techniques, Table 4 evaluates multiple MCDM techniques with respect to the mentioned assessment criteria [36], whereby L, M, and H denote low, medium, and high ability of the MCDM technique, respectively. Readers are referred to [36] for further comparison of the MCDM techniques, i.e., expert-based comparative analysis.

According to Table 4, EDAS is superior in comparison to other MCDM techniques. However, subjective weights of the selection criteria are not considered in fuzzy EDAS approach. This study fulfils this gap and the suggested MCDM approach for the PSAT utilises a hybridisation of fuzzy EDAS and fuzzy CRITIC. The advantages of this hybridisation are a) consideration of both subjective and objective weights of the criteria, which can be obtained using EDAS and CRITIC methods, respectively, b) incorporation of fuzzy logic into the solution of an MCDM problem which improves the ability to deal with ambiguity in subjective opinions as well as the uncertainties that may exist within the mathematical formulations, and c) ease of data collection in comparison to dated MCDM techniques. The procedure of applying hybrid EDAS-CRITIC on an MCDM problem is explained as follows [54,55]:

Let the fuzzy performance value of i th alternative $(i = 1, 2, 3, \cdots, n)$ be represented by $\widetilde{x}_{ij} = (x_{ij1}, x_{ij2}, x_{ij3}, x_{ij4})$, where $j = 1, 2, 3, \cdots, n$, n indicates the total number of alternatives, N indicates the set of non-beneficial criteria, B denotes the set of beneficial criteria, and $(\widetilde{w}_j^0 = w_{j1}^0, w_{j2}^0, w_{j3}^0, w_{j4}^0)$ represents the fuzzy objective weight of the j th criterion.

Stage 1: Average decision matrix (X) is constructed as follows:

$$X = [\widetilde{x}_{ij}]_{n\times m} \tag{1}$$

$$\widetilde{x}_{ij} = \frac{1}{k}\oplus_{p=1}^{k}\widetilde{x}_{ij}^{p} \tag{2}$$

where the performance value of alternative A_i $(1 \le i \le n)$ with respect to criterion c_j $(1 \le j \le m)$ based on the opinion of the p th expert $(1 \le p \le k)$ is shown by $\widetilde{x}_{ij}^{p}$.

Stage 2: Subjective weights of the criteria are constructed as follows:

$$W^s = [\widetilde{w}_j^s]_{1\times m} \tag{3}$$

Table 7
Drivers for the adoption of passive strategies for UK buildings.

Category	Code	Driver	Explanation
Economic drivers	D1	Reduced whole lifecycle cost of building	Passive strategies are more cost-effective compared to active cooling and heating methods, leading to a lower overall lifecycle cost for buildings.
	D2	Increased property value	Passive strategies enhance the quality of buildings compared to traditional methods, which can result in higher property sale or rental rates.
Environmental drivers	D3	Reduced energy demand of building	Passive strategies substantially lower the heating and cooling demands of buildings.
	D4	Environmental protection	Implementing passive strategies will lead to a decrease in greenhouse gas emissions, particularly the oxides of carbon, thereby helping to combat climate change.
Technical drivers	D5	Improved occupants' health, wellbeing, and satisfaction	Passive strategies enhance occupants' health by preventing the growth of mould that can cause respiratory diseases. Additionally, they allow for larger windows due to the absence of thermal bridges, contributing to overall wellbeing. These strategies also improve occupant satisfaction by minimising temperature variations between rooms.
	D6	Improved building structure	Passive strategies reduce damage to a building's structure. For example, using a vapor-tight layer prevents moisture from moving from the interior to the building's structure, thereby avoiding potential damage from condensation.
	D7	Longer lifespan of passive strategies	Passive strategies typically have a longer lifespan compared to active heating and cooling systems.
	D8	Strong supply chain of passive means	Passive heating and cooling methods are readily available in the UK market, with detailed information accessible through certified institutes, e.g., the Passive House Institute (PHI).
	D9	Availability of simulation tools	Simulation tools for passive strategies are available to improve theoretical understanding of their key characteristics. A prominent example of these tools is the Passive House Planning Package (PHPP).

$$\widetilde{w}_j^s = \frac{1}{k} \oplus_{p=1}^{k} \widetilde{w}_j^p \tag{4}$$

where the weight of criterion c_j $(1 \le j \le m)$ based on the opinion of the p th expert $(1 \le p \le k)$ is denoted by $\widetilde{w}_j^p$.

Stage 3: Objective weights of the criteria (W_j^0) are formed [56].

Stage 4: Aggregated weights of the criteria are calculated by

Table 8
Barriers to the adoption of passive strategies for UK buildings.

Category	Code	Driver	Explanation
Economic barriers	B1	Insufficient economic incentives for end-users and developers	Currently, there are inadequate economic incentives for end-users and developers in the UK.
	B2	Capitalism	This barrier pertains to the 'Profit First' mentality, where many companies prioritise minimising construction costs to maximise their profits. Consequently, these companies may forgo adequate insulation and airtight layers in their buildings.
Legislative barriers	B3	Lack of strict legislation	Currently, there is a lack of stringent legislation regarding the use of passive strategies in buildings.
	B4	Methodological challenges	Passive strategies must be implemented with precision; otherwise, the anticipated outcomes may not be realised. For example, improper installation of insulation layers can lead to issues such as thermal bridges and inadequate airtightness.
Professional/ Technical barriers	B5	Lack of adequate research and development	Currently, the number of research studies and development projects focusing on passive strategies is insufficient to effectively demonstrate their benefits for buildings.
	B6	Lack of skilled workers with prior expertise	At present, there is a shortage of professionals with expertise in passive strategies, including both designers and skilled workers. This issue has been exacerbated following Brexit.
	B7	Difficulty of applying passive strategies on old buildings	Implementing certain passive strategies can be challenging in older buildings, particularly in listed historic structures. For example, regulations often prohibit the installation of naturally ventilated envelopes in such historic buildings.
	B8	Dependency on climate	Passive strategies are highly dependent on the climate, meaning that a strategy effective in one climate may not be suitable for another.
	B9	Unpredictability of the occupants' behaviour	Passive strategies rely more on occupant behaviour compared to active strategies. For example, if an occupant frequently keeps windows open for fresh air, mechanical ventilation can provide the necessary cooling or heating much more quickly than passive methods.

Table 9
Criteria involved in sustainable selection of passive energy consumption optimisation strategies for buildings.

Code	Criterion	Description
SC1	Compatibility with climate	Assessing the compatibility of a passive strategy involves considering the specific climate in which it is applied.
SC2	Reliability	The characteristic of being reliable or consistently delivering high performance.
SC3	Durability	Having the ability to endure over time without sustaining damage
SC4	Flammability	The potential of a material or substance to ignite, burn, or undergo combustion.
SC5	Feasibility	The ease with which a passive strategy can be installed.
SC6	Reduction of energy consumption	The extent to which energy can be reduced through the application of a passive strategy.
SC7	Reduction of GHGs emissions	The effectiveness of a passive strategy in lowering greenhouse gas emissions from a building.
SC8	Improvement of indoor air quality (IAQ)	The capacity of a passive strategy to enhance indoor air quality within the building.
SC9	Being environmentally friend	Having no adverse impact on the environment.
SC10	Capital Investment cost	The cost associated with acquiring and implementing a passive strategy.
SC11	O&M cost	The expenses related to operating and maintaining a passive strategy.
SC12	Payback period	The duration needed for an investment to recoup its initial expenditure.
SC13	Initial Installation time	The duration needed to install the passive strategy for the first time.
SC14	Availability	The accessibility of a passive strategy in the local market (purchasing the strategy from another country diminishes the value of this criterion).
SC15	Job creation	How effective a passive strategy can be in terms of generating new jobs to enhance employment opportunities.
SC16	Occupant wellbeing	The extent to which a passive strategy enhances the occupants' wellbeing.
SC17	Aesthetics	The aesthetic impact of a building following the implementation of a passive strategy.

obtaining the average of subjective and objective weights as follows:

$$\widetilde{w}_j = \frac{1}{2}(\widetilde{w}_j^0 \oplus \widetilde{w}_j^s) \tag{5}$$

Stage 5: Matrix of average solution is obtained as follows:

$$AV = [\widetilde{av}_j]_{1\times m} \tag{6}$$

$$\widetilde{av}_j = \frac{1}{n}\oplus_{i=1}^{n}\widetilde{x}_{ij} \tag{7}$$

Stage 6: Calculation of the matrices of positive and negative distances from average, denoted by *PDA* and *NDA*, respectiverly, as follows:

$$PDA = [\widetilde{pda}_{ij}]_{n\times m} \tag{8}$$

$$\widetilde{pda}_{ij} = \begin{cases} \dfrac{\psi(\widetilde{x}_{ij} \ominus \widetilde{av}_j)}{\kappa(\widetilde{av}_j)} ifj \in B \\ \dfrac{\psi(\widetilde{av}_j \ominus \widetilde{x}_{ij})}{\kappa(\widetilde{av}_j)} ifj \in N \end{cases} \tag{9}$$

$$NDA = [\widetilde{nda}_{ij}]_{n\times m} \tag{10}$$

Table 10
Passive energy consumption optimisation strategies for buildings.

Code	Passive strategy	Example(s) of application
PSB1	Optimum design of building's insulation layer	• Determining the optimum location of the insulation layer. • Determining the optimum thickness of the insulation layer.
PSB2	Thermal mass improvement of building's envelope	• Water walls. • Phase changing materials (PCMs).
PSB3	Thermal bridge reduction of building's envelope	• External thermal insulation composite systems (ETICS). • Aerogel inserts. • Structural modifications.
PSB4	Vapour tightness improvement of building	• Vapour barriers. • Moisture-resistant materials.
PSB5	Air tightness improvement of building	• Air retarders. • Sealing existing gaps and cracks in the envelopes of buildings.
PSB6	Utilising naturally ventilated envelope	• Trombe walls. • Solar chimneys. • Sunspaces (conservatories) multiple skin facades such as DSF (double skin façade); • Direct gain (DG). • Roof pond.
PSB7	Taking advantage of natural daylighting	• Light pipes. • Mirror systems. • Prismatic systems. • Lens systems. • Holographic diffracting systems. • Light shelves.
PSB8	Utilising sun shading devices	• Venetian blinds. • Projecting eaves. • Louvres.
PSB9	Fenestration improvement of building	• Utilising suitable glazing (e.g., tinted glazing, coated glazing, or laminated glazing). • Utilising the most efficient ratio for windows and walls. • Utilising efficient framing material for windows.
PSB10	Optimising the orientation of building	• Optimising the orientation of buildings.
PSB11	Minimising heat absorption from the building's façade	• Utilising light colours in colouring building façades.
PSB12	Utilising green envelope	• Garden roof. • Green wall. • Green façade.

$$\widetilde{nda}_{ij} = \begin{cases} \dfrac{\psi(\widetilde{av}_j \ominus \widetilde{x}_{ij})}{\kappa(\widetilde{av}_j)} ifj \in B \\ \dfrac{\psi(\widetilde{x}_{ij} \ominus \widetilde{av}_j)}{\kappa(\widetilde{av}_j)} ifj \in N \end{cases} \tag{11}$$

where $\widetilde{pda}_{ij}$ and $\widetilde{nda}_{ij}$ are the positive and negative performance values of i th alternative from the average solution with respect to the j th criterion, respectively. Also, if $\widetilde{G} = (g_1, g_2, g_3, g_4)$, $\kappa\left(\widetilde{G}\right)$ and $\psi\left(\widetilde{G}\right)$ are computed as follows:

$$\kappa\left(\widetilde{G}\right) = \frac{1}{3}(g_1 + g_2 + g_3 + g_4 - \frac{g_3g_4 - g_1g_2}{(g_3 + g_4) - (g_1 + g_2)} \tag{12}$$

$$\psi\left(\widetilde{G}\right) = \begin{cases} \widetilde{G} if \kappa\left(\widetilde{G}\right) > 0 \\ 0 if \kappa\left(\widetilde{G}\right) \le 0 \end{cases} \tag{13}$$

Stage 7: Weighted sum of the positive and negative distances of alternatives, denoted by $\widetilde{sp}_i$ and $\widetilde{sn}_i$, respectively, are calculated as follows.

$$\widetilde{sp}_i = \oplus_{j=1}^{m}(\widetilde{w}_j \otimes \widetilde{pda}_{ij}) \tag{14}$$

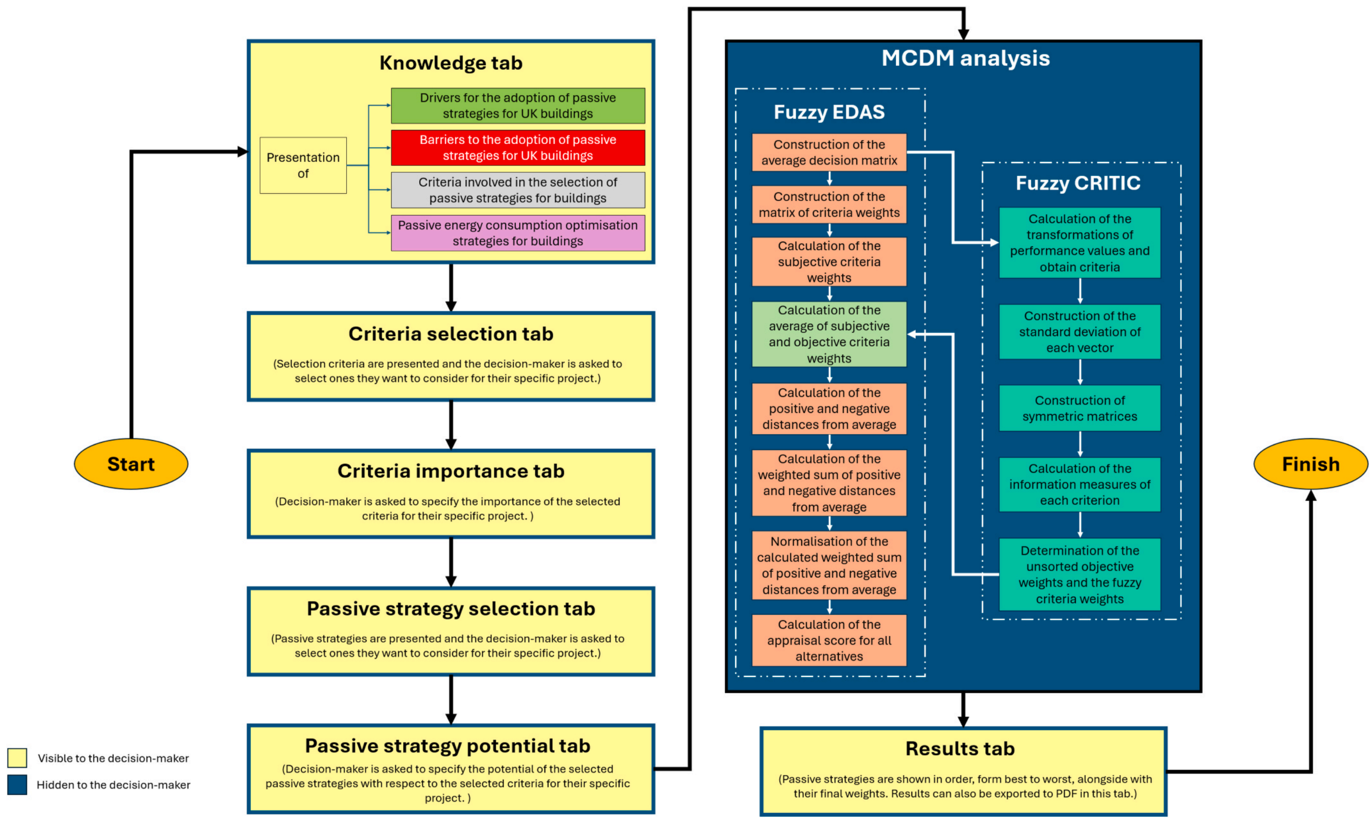


Fig. 3. Architecture of the PSAT.

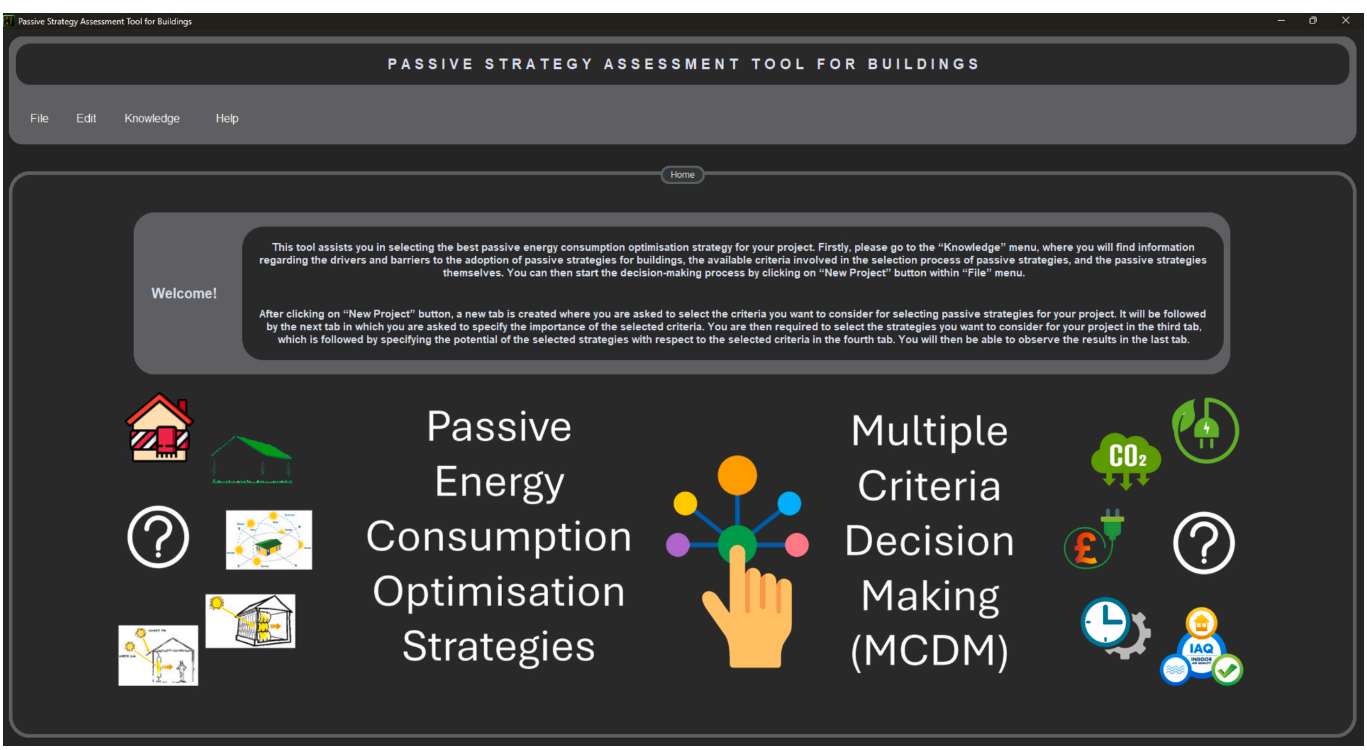


Fig. 4. Welcome page of the PSAT.

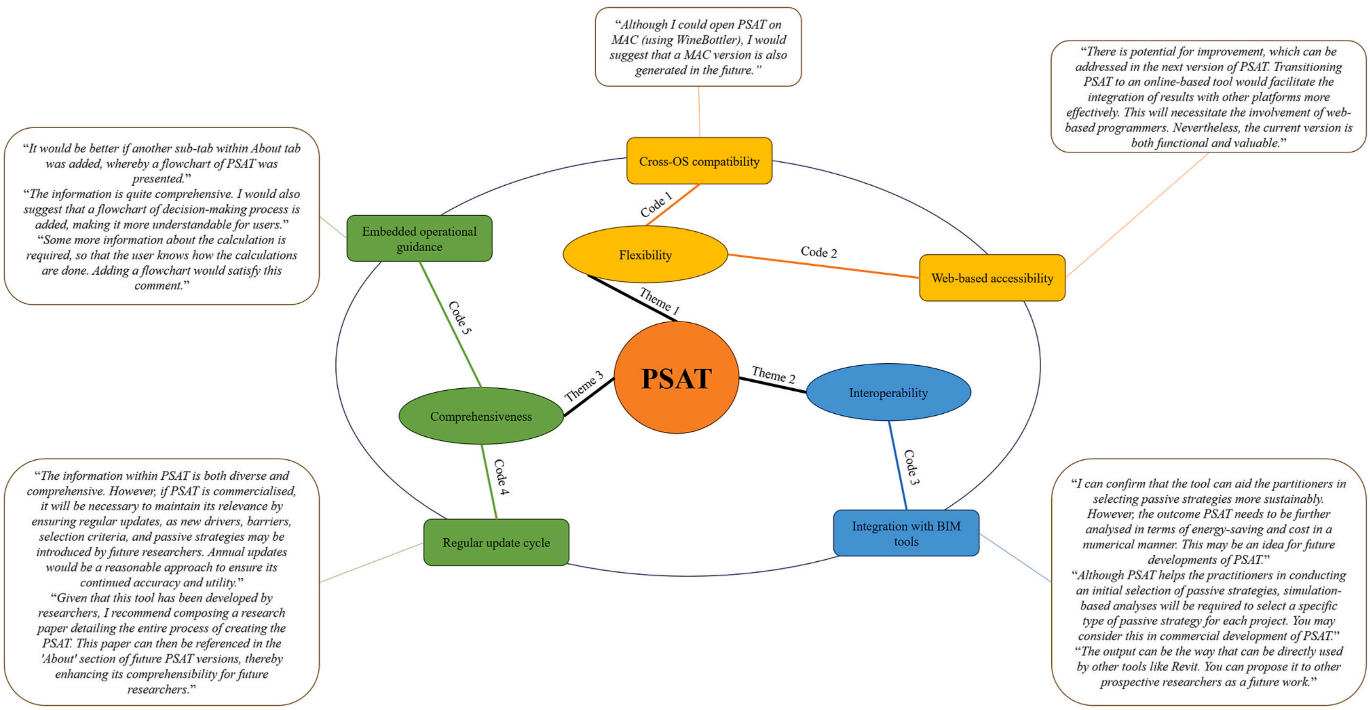


Fig. 5. Thematic network of the suggestions regarding the future development of the PSAT.

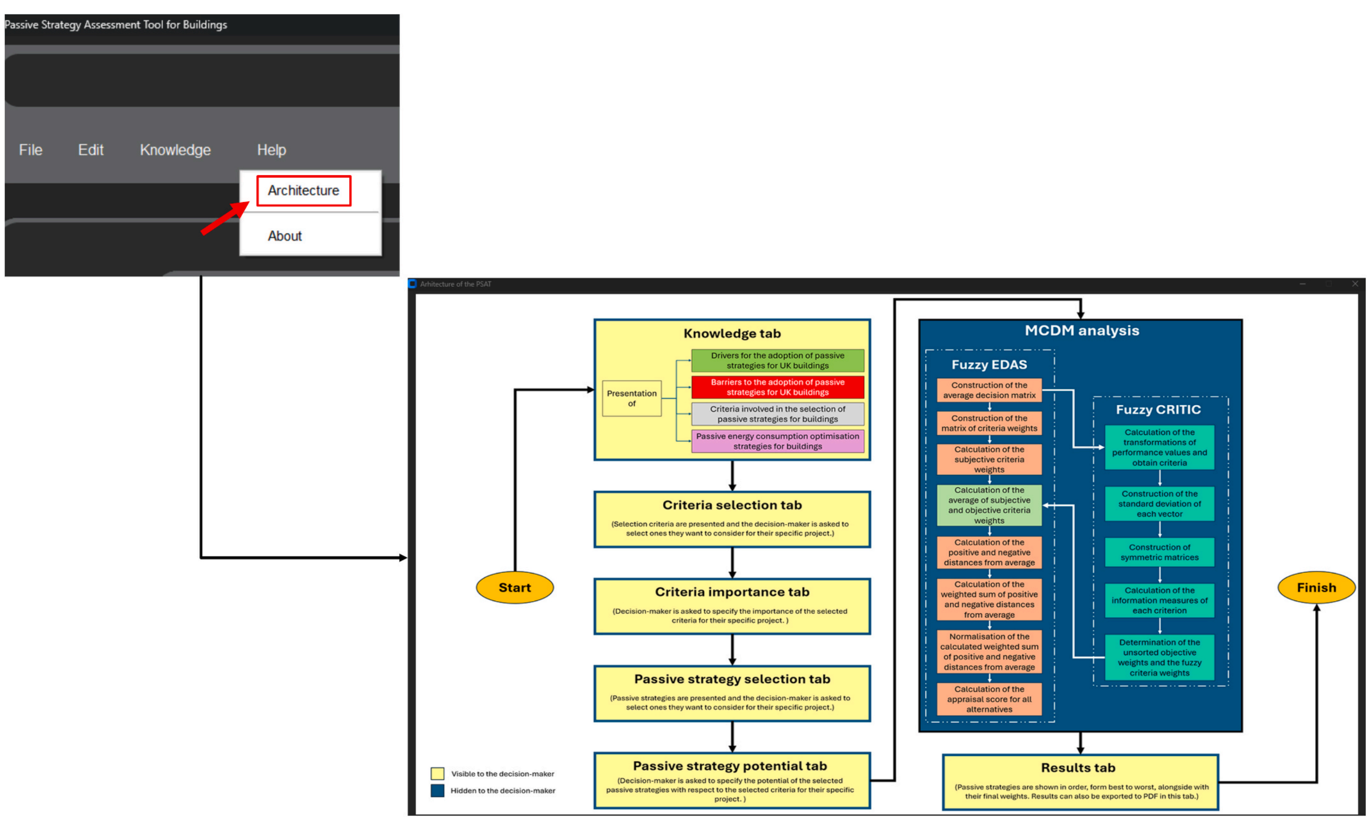


Fig. 6. Included architecture sub-menu of PSAT based on free text comments during the validation process.

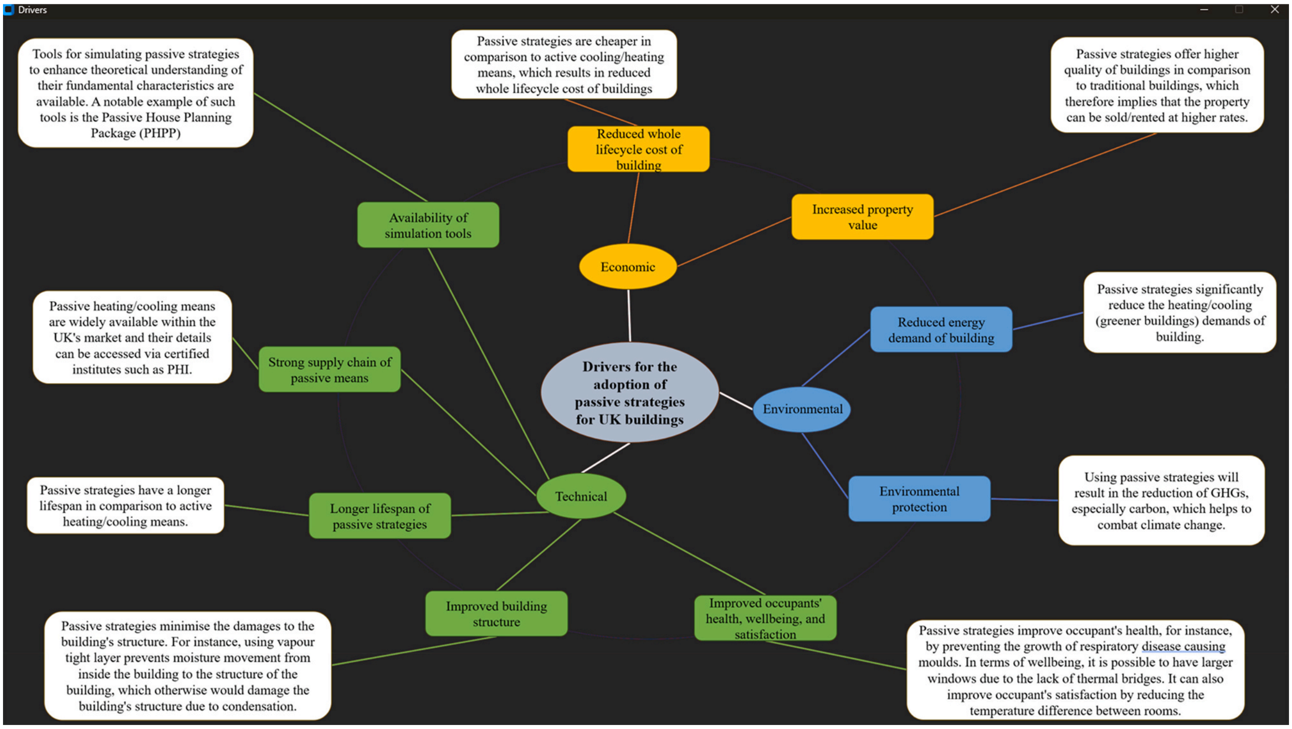


Fig. A1. Drivers for the adoption of passive strategies for UK buildings within the PSAT.

Table 11
Hypothetical potential of the passive strategies with respect to the criteria.

Passive energy consumption optimisation strategies	Passive strategy selection criteria for MCDM	
	Compatibility with climate	Improvement of indoor air quality (IAQ)
Utilising naturally ventilated envelope	Very high	Medium
Utilising sun shading devices	Low	Very high

Table 12
Information regarding the recruited experts for validating of the PSAT.

Category	Classification	Number	Percentage
Occupation	Academic	8	33.3 %
	Designer	10	41.7 %
	Construction manager	1	4.2 %
	Contractor	2	8.3 %
	Others	3	12.5 %
Years of experience	6–10	2	8.3 %
	11–15	3	12.5 %
	16–20	4	16.7 %
	21–25	3	12.5 %
	26–30	4	16.7 %
	31–35	5	20.8 %
	36–40	1	4.2 %
	41–45	2	8.3 %
Educational qualification	Doctorate degree	10	8.3 %
	Postgraduate degree	11	45.8 %
	Bachelor's degree	2	16 %
	Others	2	4.2 %
Area of professional expertise	Architecture	10	41.7 %
	Civil Engineering	5	20.8 %
	Mechanical Engineering	1	4.2 %
	Building Services Engineering	6	25.0 %
	Construction Engineering and Management	2	8.3 %

Table 13
Validation scores of the PSAT against the pre-defined criteria.

	VC1	VC2	VC3	VC4	VC5
Average score	4.71	4.79	4.88	4.63	4.79
Efficiency score (ES)	**4.76**				

Table 14
Themes/codes regarding future development of the PSAT.

Theme	Code	Suggestion
Flexibility	C1	Cross-operating systems (OS) compatibility
	C2	Web-based accessibility
Interoperability	C3	Integration with BIM tools
Comprehensiveness	C4	Regular update cycle
	C5	Embedded operational guidance

$$\widetilde{sn}_i = \oplus_{j=1}^{m} \left(\widetilde{w}_j \otimes \widetilde{nda}_{ij}\right) \tag{15}$$

Stage 8: The values of $\widetilde{sp}_i$ and $\widetilde{sn}_i$ for all alternatives, denoted by $\widetilde{nsp}_i$ and $\widetilde{nsn}_i$, respectively, are normalised as follows:

$$\widetilde{nsp}_i = \frac{\widetilde{sp}_i}{\max_i\left(\kappa\left(\widetilde{sp}_i\right)\right)} \tag{16}$$

$$\widetilde{nsn}_i = 1 - \frac{\widetilde{sn}_i}{\max_i\left(\kappa\left(\widetilde{sn}_i\right)\right)} \tag{17}$$

Step 9: Appraisal scores ($\widetilde{as}_i$) for alternatives are calculated as follows:

$$\widetilde{as}_i = \frac{\widetilde{nsp}_i \oplus \widetilde{nsn}_i}{2} \tag{18}$$

This research employed trapezoidal fuzzy numbers, which offer an improved approach over triangular fuzzy numbers for capturing the

Table 15
Positive free text comments on PSAT from experts during validation.

Validation criteria	Comments
VC1	*"Tasks are completed easily and effectively."* *"I have a strong feeling that PSAT satisfies the practitioners' expectations in a functional and effective way."* *"As an architect who has always dealt with multiple criteria decision-making, I can confirm that PSAT is among very few tools that consider social selection criteria within the calculation. This shows that researchers are focusing more on all the aspects of sustainability. Good job."* *"Simultaneous quantification of social criteria along with other types of selection criteria is of high importance and PSAT considers all criterion types effectively."*
VC2	*"Brilliant, much better than the old versions used in many tools."* *"The layout sounds logical."* *"PSAT makes a convenient environment for the user."* *"I appreciate the option to select between light and dark modes in PSAT."* *"The design of PSAT evokes the look of Windows 11. It is highly appreciated that PSAT has adopted modern themes."*
VC3	*"PSAT is extremely fast. This processing speed is a driver for promoting PSAT within the UK building sector."* *"PSAT is sufficiently fast."* *"The speed of PSAT is plausible."*
VC4	*"It will be very easy for PSAT to be integrated with other platforms considering that it has been developed in Python. For this purpose, there are multiple useful libraries for further development of PSAT in the future."*
VC5	*"Great job, especially for the drivers and barriers. It gives the user a more comprehensive view before the selection process."* *"PSAT provides comprehensive information before the decision-making stage which is an advantage in comparison to similar tools."* *"The information is quite comprehensive."*

uncertainty in experts' ratings, as suggested by [57]. Details of the linguistic terms and their associated trapezoidal fuzzy numbers are presented in Table 5.

2.2.2. Graphical user interface and compilation

The graphical user interface (GUI) for the PSAT was developed using the CustomTkinter library within Python [58]. This innovative and customisable Python UI library allows for the design of modern interfaces, providing a more user-friendly environment for decision-makers. To the best of authors' knowledge, this is the first research study which has used CustomTkinter for GUI development.

Additionally, the Auto-Py-to-Exe [59] library was utilised to create an executable file for the PSAT. This step is crucial as practitioners might not be well-versed in Python programming. Furthermore, even those with coding experience could find navigating through thousands of lines of code overwhelming and confusing.

2.3. Validation

According to [6], experts from both academia and industry are required to validate any decision support system if a truly comprehensive validation is desired. Therefore, this study considered experts from both professional facets for the validation process. Having at least five years of experience and being domiciled within the UK were considered as the inclusion criteria for the identification of both groups of experts. However, specific criteria for academic and industrial experts include having publications related to passive energy consumption optimisation strategies and holding a valid passive house designer (PHD) certificate, respectively. The identified experts were contacted via their publicly available email addresses (e.g., contact details of corresponding authors of published related articles and institutional websites). Volunteering participants were then sent the relevant information, including a short video that succinctly guides first time users around the different functions of the PSAT. They were then asked to watch the tutorial video, work with the PSAT, and finally validate the PSAT by completing a questionnaire developed in Qualtrics platform [60].

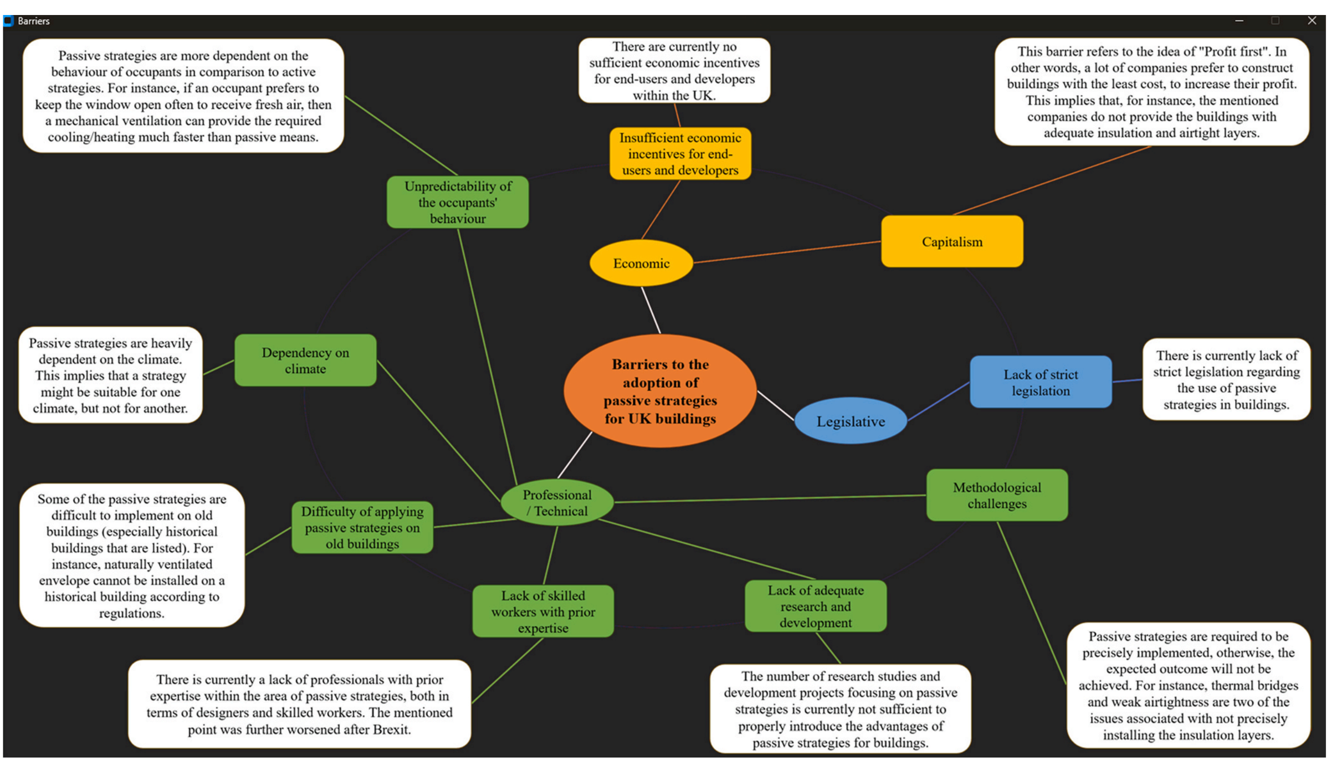


Fig. A2. Barriers to the adoption of passive strategies for UK buildings within the PSAT.

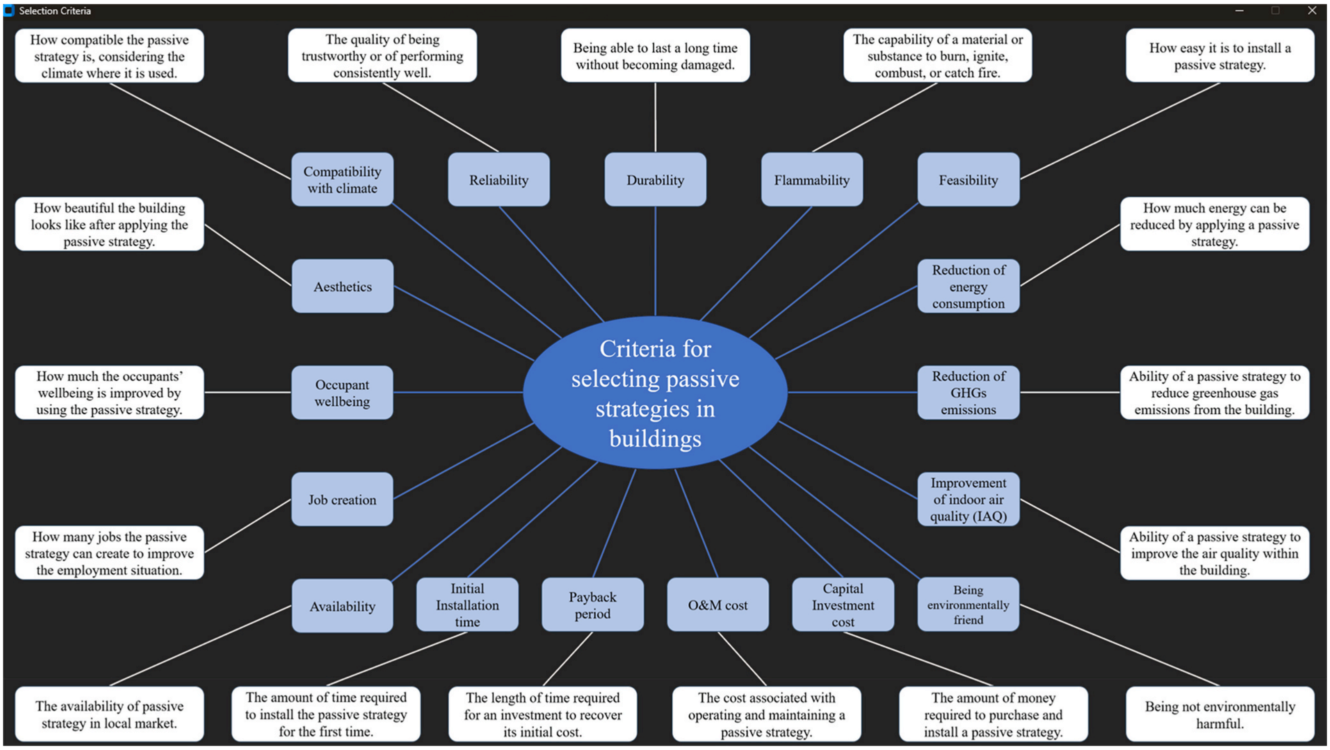


Fig. A3. Criteria involved in the selection of passive strategies for buildings within the PSAT.

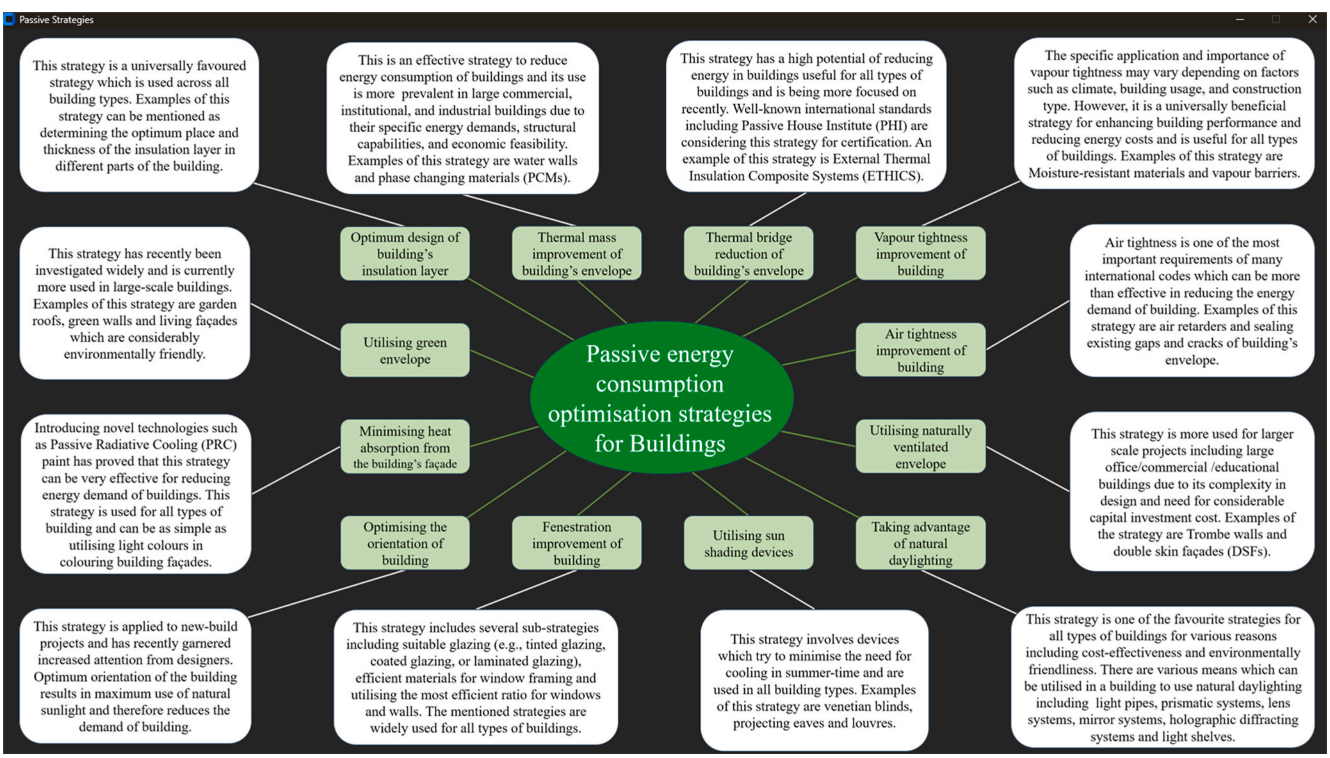


Fig. A4. Passive energy consumption optimisation strategies for buildings within the PSAT.

Questionnaire was employed as the data collection method in this study due to its alignment with the proposed methodology, the accessibility of the identified experts, and the simplicity of its implementation, as suggested by [61,62], and 24 experts completed the questionnaire. According to Balali and Yunusa-Kaltungo [63], 3–24 experts were used in previous relevant studies (e.g., [64–66]). Therefore, the number of experts in this study sounds reasonable.

The validation questionnaire consisted of two sections. The first section focused on collecting demography and background information of experts including years of experience, role, qualification, and professional experience. This was followed by section two, where the experts were asked to validate the PSAT against five pre-defined validation

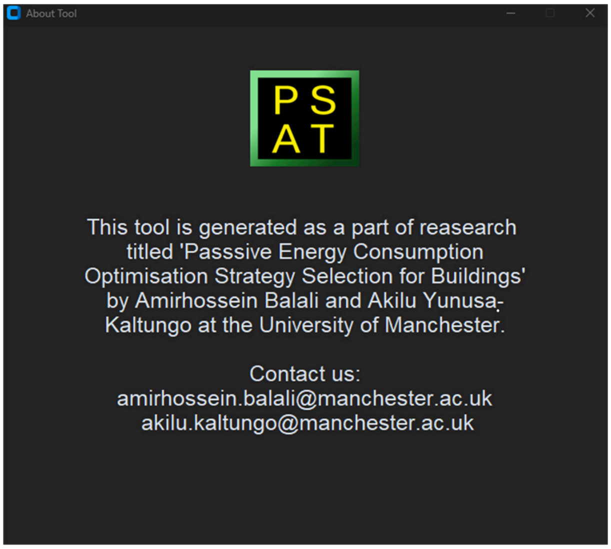


Fig. A5. "About" tab within the PSAT.

criteria. The validation criteria, alongside their descriptions, are presented in Table 6. Also, Fig. 2 illustrates the corresponding section of the validation questionnaire.

According to Fig. 2, an initial five-point linguistic scale, consisting of very poor, poor, moderate, good, and very good, was employed, which was later converted to numerical values of one, two, three, four, and five, respectively, to translate the qualitative data into quantitative form. Based on a study by Sadeghi et al. [39], validation efficiency score (ES) is defined as the average of the obtained validation scores against all the validation criteria, and a KB-DST is considered valid if the scores are higher than four.

Moreover, experts were asked to provide comments regarding their selections, as well as adding suggestions for further improvement of the PSAT. This was followed by a thematic analysis to identify key themes for future development of the PSAT, based on the experts' suggestions. According to the guidelines provided by [67], an in-depth examination of the comments was initially conducted multiple times to enhance familiarity with the data. This was followed by the generation of initial codes, which served as the basis for identifying preliminary themes. Themes, which represent patterns within the codes that share common characteristics, highlight significant insights within the data [68]. In the fourth stage, the identified themes were reviewed to ensure the accurate grouping of codes into appropriate themes. The fifth stage involved refining and defining the themes, culminating in the final stage where the thematic network was summarised. Results of the validation is discussed in Section 6.0.

3. Knowledge

As explained in Section 2.1, the information required for the knowledge section of the PSAT was identified through a comprehensive literature review. Tables 7-10 illustrate the identified drivers for the adoption of passive strategies for UK buildings (denoted by D1-D9), barriers to the adoption of passive strategies for UK buildings (denoted by B1-B9), criteria involved in the sustainable selection of passive strategies (denoted by SC1-SC17), and the existing passive energy consumption optimisation strategies (denoted by PSB1-PSB9) along with their corresponding descriptions.

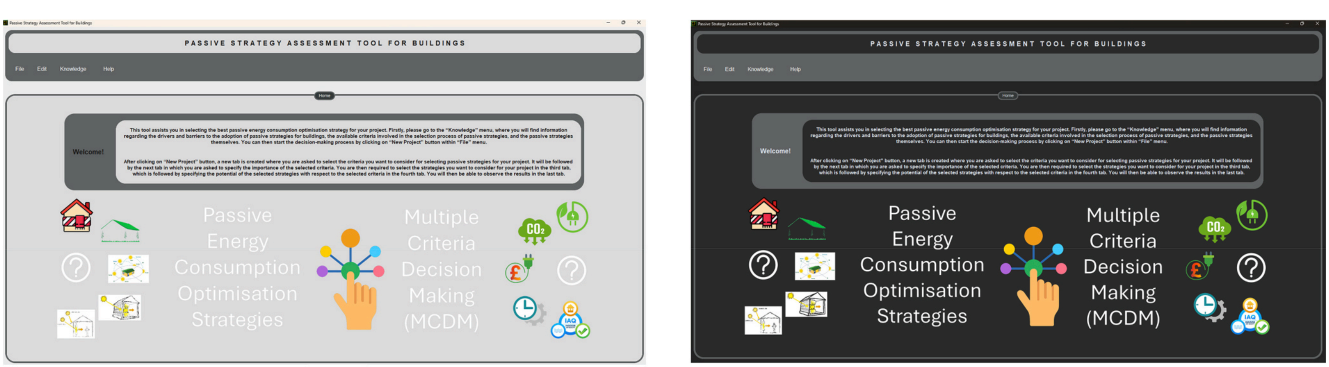
The identified knowledge is considered as the necessary information which must be presented to the decision-maker prior to the selection of passive strategies for buildings, as it is directly associated with the quality of decisions. For instance, understanding the drivers and barriers to the adoption of passive strategies can aid the decision-maker in developing a thorough understanding from both theoretical and practical perspectives. This approach helps bridge, or at least narrow, the gap that often exists between academic researchers and industry professionals. Therefore, all the mentioned information is available within the knowledge section of PSAT, which is further explained in Section 4.

4. Development of the PSAT

The architecture of the PSAT is presented in Fig. 3, with further details discussed as follows. The first page of the PSAT is a welcome page, summarising information about the PSAT and its application procedure for the decision-maker. This page is illustrated in Fig. 4. It is noteworthy to mention that the libraries used for developing the PSAT include NumPy [69], CustomTkinter [70], Tkinter [71], and Pillow (PIL Fork) [72]. According to Fig. 4, the PSAT consists of four menus (located on the top lefthand side of the PSAT), i.e., "File", "Edit", "Knowledge", and "Help". As mentioned previously, the decision-maker is suggested to initially explore the "Knowledge" menu to obtain a comprehensive information regarding the selection of passive strategies for buildings. This menu includes four sub-menus that can be accessed via a single click. Figs. A1-A4 (Appendix) illustrate the drivers for the adoption of passive strategies for UK buildings, barriers to the adoption of passive strategies for UK buildings, the criteria involved in the selection of passive strategies and the existing passive energy consumption optimisation strategies for buildings, respectively.

The "Help" menu includes general information regarding the PSAT, as shown in Fig. A5. The "Edit" tab provides the opportunity to vary the contrast of the PSAT between dark and light modes, which has been described as a powerful means to overcome contextual interaction challenges [73]. Fig. A6a and A6b illustrate the PSAT in light and dark modes, respectively.

A new project is created by clicking on the "New project" sub-menu from the "File" menu. The first tab illustrates the passive strategies



a b

Fig. A6. Appearance of the PSAT in light (a) and dark (b) modes.

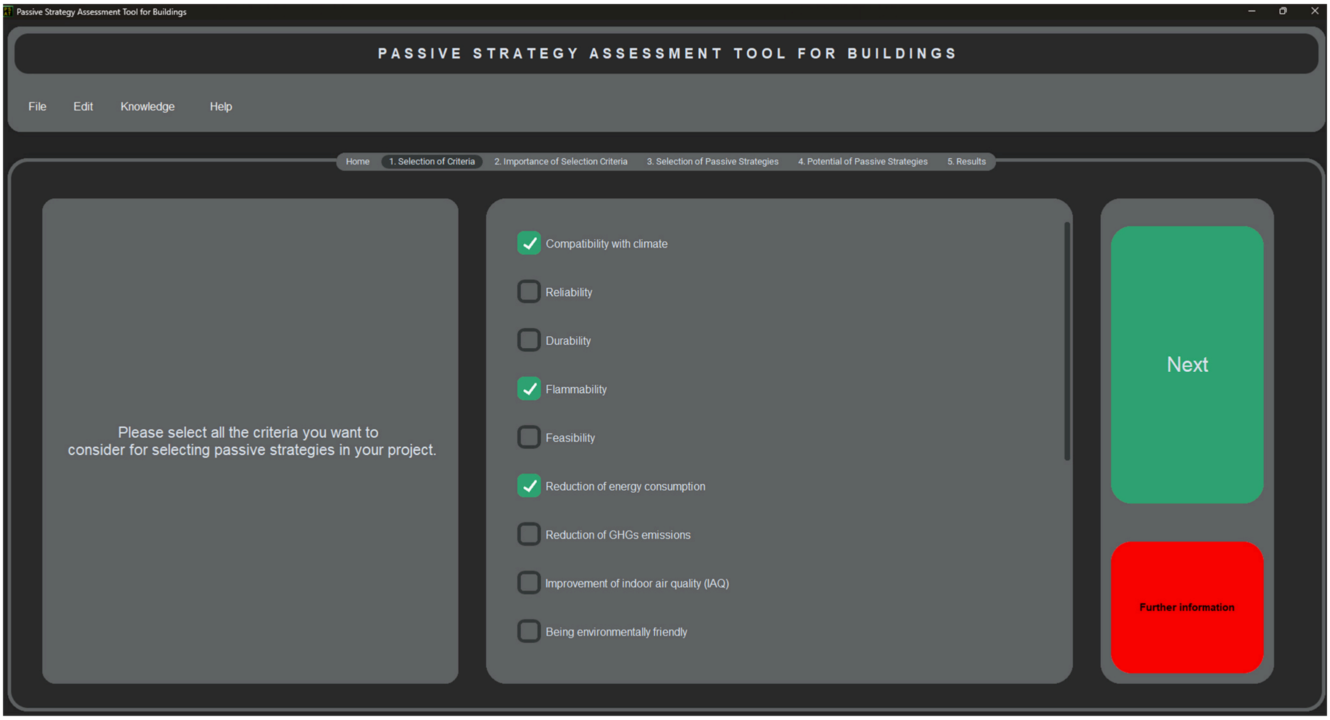


Fig. A7. Criteria selection tab within the PSAT.

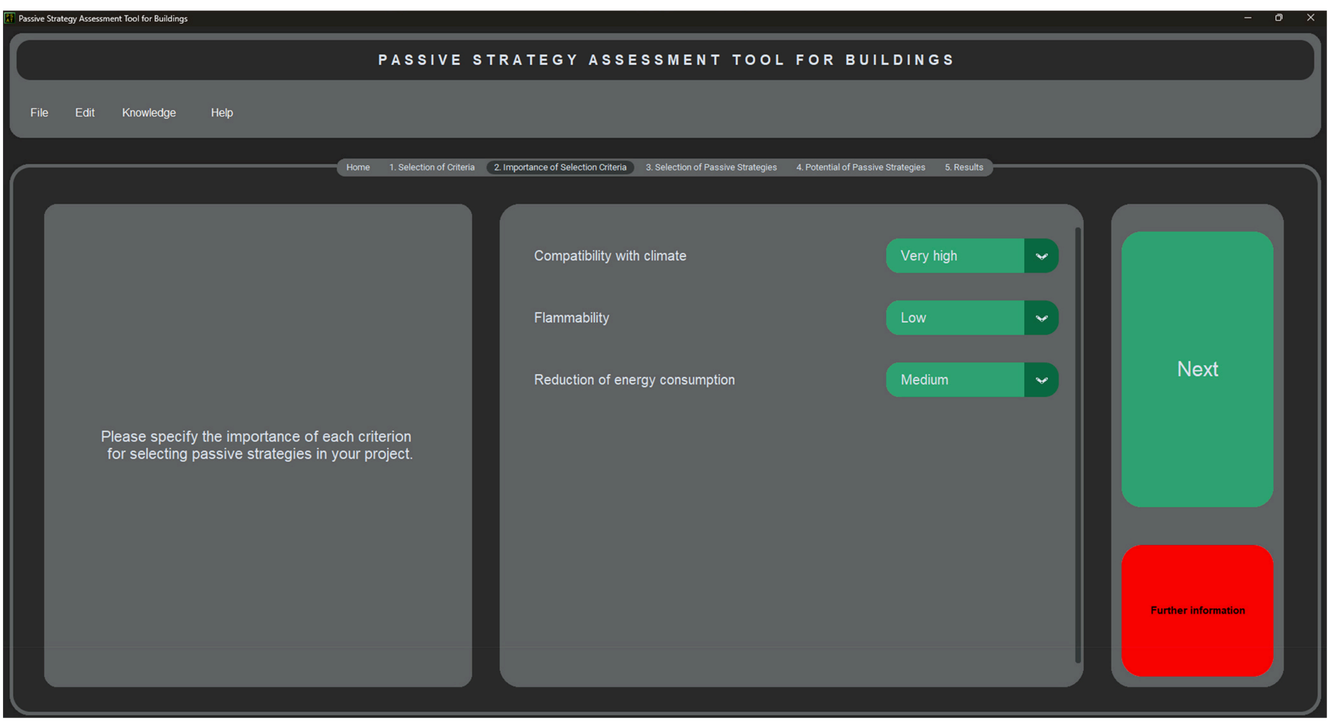


Fig. A8. Criteria importance tab within the PSAT.

selection criteria for buildings, whereby the decision-maker is asked to select the desired ones based on the specific requirements of their project, as shown in Fig. A7. It is noteworthy to mention that "Further information" button is available in all stages, thereby providing the relevant knowledge information if the decision-maker needs to check the information once more. By clicking on the "Next" button, the second tab is displayed, where the decision-maker is asked to specify the importance of the criteria selected in the previous stage, as shown in Fig. A8. Then, the decision-maker is directed to the third tab, where they need to select the desired passive energy consumption optimisation strategies for their specific project, as illustrated in Fig. A9. This is then followed by the fourth tab in which the decision-maker needs to specify the potential of the selected passive strategies with respect to the selected criteria, as shown in Fig. A10. Upon completion of the specifications, the user needs to click the "Submit" and "Generate result" buttons and all the MADM analysis is conducted automatically. The

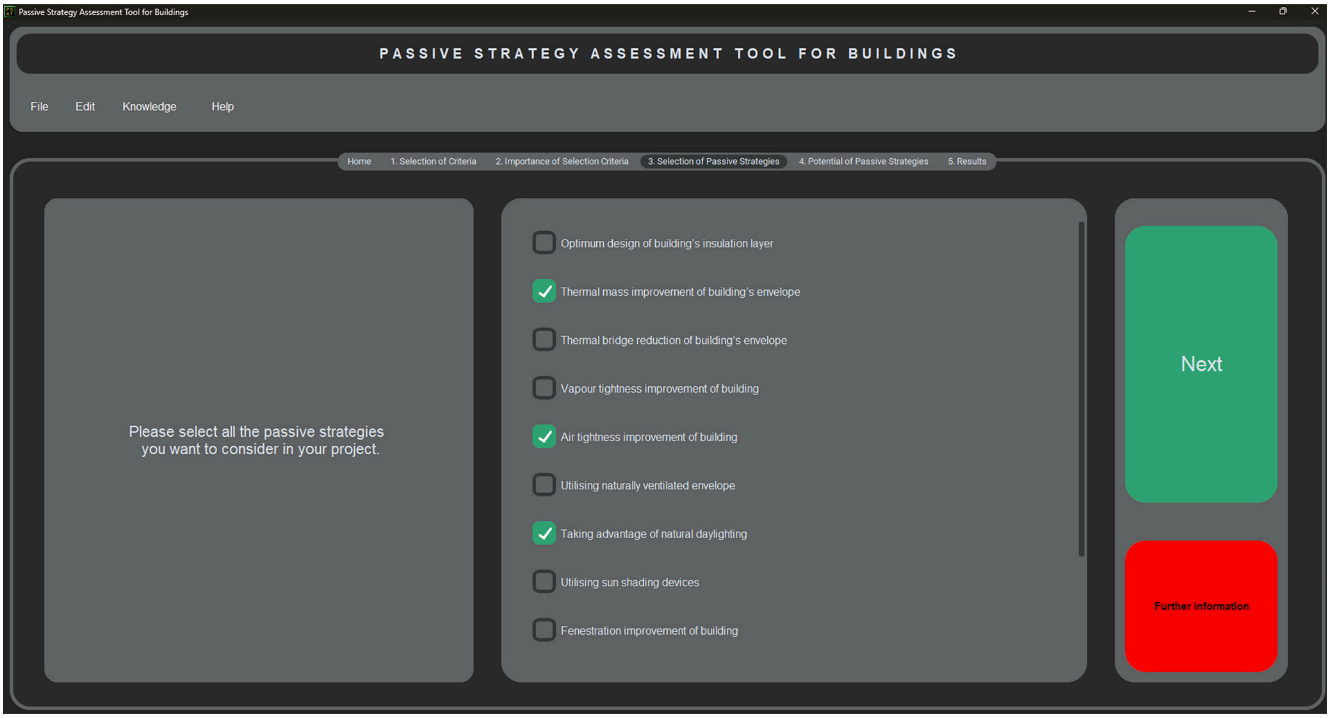


Fig. A9. Passive strategy selection tab within the PSAT.

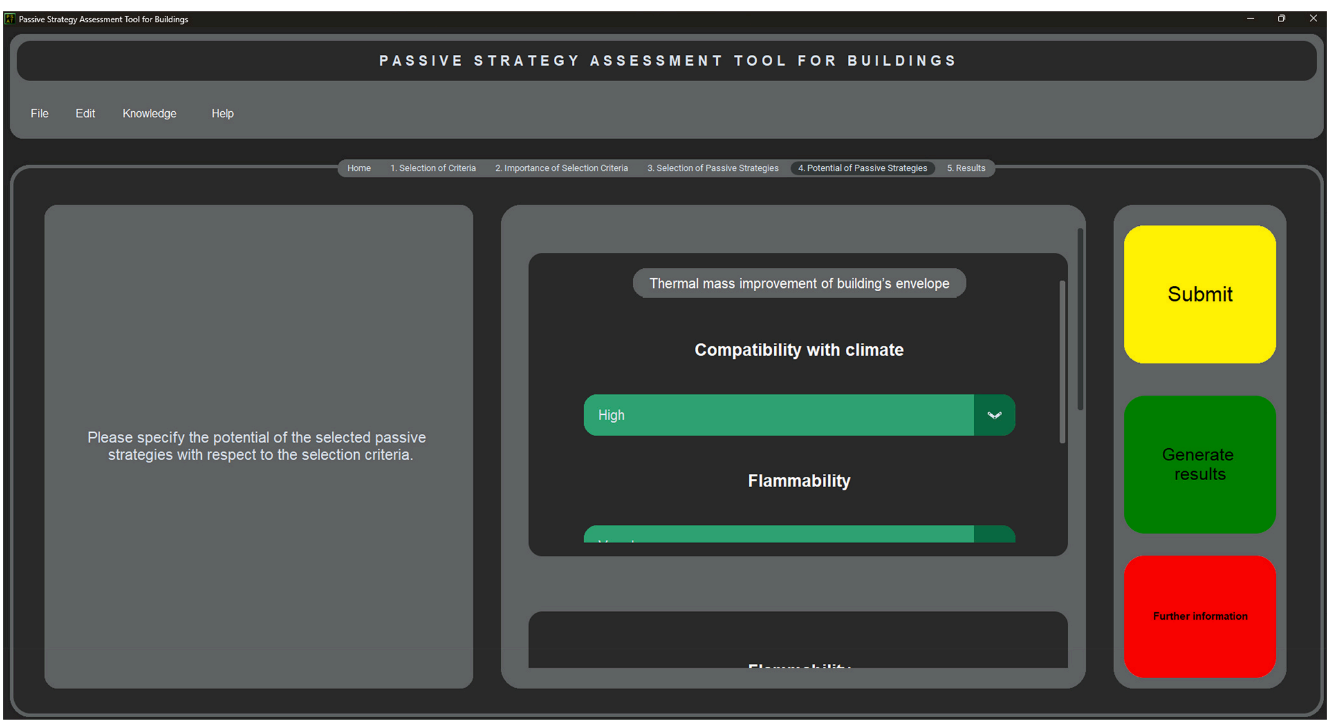


Fig. A10. Passive strategy potential tab within the PSAT.

decision-maker is then directed to the fifth tab, where the final weights of the passive strategies are shown. Within this tab, the selected passive strategies are ranked from top to button and are also distinguished by different colours for easier comprehension of the ranking. More specifically, the best and worst passive strategies, based on the selections of the decision-maker, are shown in green and red colours, respectively (as visible in Fig. A11). The obtained results can also be exported to PDF by clicking on the "Export to PDF" button

5. Sample case

This section provides a hypothetical example to further explain the application process of the PSAT to readers. Let's assume that a building designer or architect intends to decide on the best passive energy consumption optimisation strategy for a specific building project. The following steps can be implemented via the PSAT to realise this objective:

Fig. A11. Results tab within the PSAT.

Step 1: As mentioned in Section 4.0, the first step after creating a new project is to select the criteria to be considered during the MCDM analysis. For this example, let's assume that the desired selection criteria are "compatibility with climate" and "improvement of indoor air quality (IAQ)". The decision-maker therefore selects these criteria in the first tab, as illustrated in Fig. A12a. This information is stored within a Python Numpy list titled "selected_criteria" as follows:

selected_criteria = [['Compatibility with climate', ' Improvement of indoor air quality (IAQ)']]

Step 2: The second step is to specify the importance of the selected criteria. In this example, let's assume that the importance of "compatibility with climate" and "improvement of indoor air quality (IAQ)" are "very high" and "medium low", respectively. Upon selecting the mentioned values (as shown in Fig. A12b), the entered information is stored within a Python Numpy list titled "swv", which represents the subjective weights (of the criteria) in verbal format. Therefore:

swv = [['vh', 'ml']]

Step 3: The next step is selecting the desired passive energy consumption optimisation strategies within the third tab. For this example, assume that the desired passive strategies are "utilising naturally ventilated envelope" and "utilising sun shading devices" (as shown in Fig. A12c). This information is stored within a Python Numpy list titled "selected_alternatives", thus:

selected_alternatives = [['Utilising naturally ventilated envelope', 'Utilising sun shading devices']]

Step 4: In this step, the decision-maker needs to specify the potential of the selected passive strategies with respect to the selected criteria. For this example, assume that the decision-maker's preference is based on the information in Table 11.

Upon selecting the presented potentials within the fourth tab of the PSAT (as shown in Fig. A12d), the information is stored within a Python Numpy array titled "dmv"", which represents the decision matrix in verbal format. Considering that two criteria and two passive strategies were selected, dmv is a 2x2 array as follows:

dmv = [['vh', 'm'], ['l', 'vh']]

By clicking the "Submit" button, the MCDM analysis is automatically executed. It is crucial to highlight that the different commands, functions, and procedures executable by the proposed PSAT culminate into over 1000 lines of programming codes within Python. It would therefore be too laborious to explain every single aspect of the execution here. Therefore, only the most vital steps were highlighted to enhance clarity and appreciation of the PSAT platform. Finally, the results are stored in a Python dictionary titled "final_results" as follows:

final_results = { 'Utilising naturally ventilated envelope': 0.9169, 'Utilising sun shading devices': 0.0831 }

The obtained results are finally shown to the decision-maker, as illustrated in Fig. A12e. It is crucial that the obtained results are saved; therefore, it is possible to do so by clicking on the "Export to PDF" button. The output PDF document is then generated and saved within the same directory where the PSAT exists. A complete report guide is written for the users of the PSAT, as shown in Fig. A13, which is also available within the PSAT package. The report generated for this hypothetical example is shown in Fig. A14.

6. Validation

As explained in Section 2.3, experts with both industrial and academic backgrounds were meticulously selected to validate the PSAT against pre-defined validation criteria, i.e., user-friendliness (VC1), structural layout (VC2), processing speed (VC3), ease of integration with other platforms (VC4), and representativeness and relevance of captured information (VC5).

According to the guidelines presented within previous relevant studies (e.g., [41;39]), at least four experts are required to validate any developed decision support tool. However, this study recruited 24 experts (which is significantly more than those applied in previous studies) with a wide range of expertise including in architecture, civil engineering, mechanical engineering, construction engineering and

Fig. A12. Procedure of the application of the PSAT for solving the hypothetical example.

management, and building services engineering, to validate the PSAT against the mentioned validation criteria. The background of recruited experts including job/position, years of experience, educational qualification, and area of professional expertise is presented in Table 12.

Analysis of the gathered validation data presented an efficiency score of 4.76 for the PSAT, which can confirm its validity according to [39]. Table 13 highlights the obtained scores for the PSAT with respect to the validation criteria. Also, further information regarding the validation scores of the PSAT is presented in Table A1 within the Appendix Section, whereby the recruited experts are denoted by EX1-EX24..

Additionally, the free text comments provided by the experts were also analysed as qualitative data, using thematic analysis which in turn complemented the quantitative data shown in Table 12. The free text comments led to the identification of three themes for future development of the PSAT including flexibility, interoperability, and comprehensiveness. More specifically, several constructive suggestions were provided by the experts, which formed the five codes of the thematic network (denoted by C1-C5). Further information regarding the identified themes/codes is provided in Table 14. Also, thematic network of the validation comments is shown in Fig. 5.

Most of the suggestions made by the validating experts were minor and did not entail extensive modifications. Hence, they were immediately implemented. For instance, according to the comments regarding Code 5 (embedded operational guidance), a new sub-menu titled “Architecture” was added within “Help” menu and the proposed architecture of the PSAT was inserted therein, as can be seen in Fig. 6. This upgrade makes it easier for users to gain a more comprehensive understanding of how PSAT works in a step-by-step manner. Moreover, the link of this study will be added to this section once it is published. However, suggestions that required substantial changes to the existing architectural framework (e.g., flexibility through compatibility with different operating systems such as Windows or Mac (C1) or regular update cycle (C4)) were earmarked for future development, particularly during real-life commissioning of the PSAT.

Apart from the suggestions regarding the future development of the PSAT, it is noteworthy to mention that there were many positive comments. The most prominent comments of the experts are shown in Table 15. Overall, the obtained efficiency score and the comments illustrated the potential of the PSAT for facilitating the selection of passive energy consumption optimisation strategies for buildings by practitioners.

Passive Strategy Assessment Tool (PSAT) for Buildings

Report Guide

This document provides information regarding the report generated by PSAT. The first section of the report shows the selected criteria, followed by the importance of each criterion in section 2. Please consider that the order of items within section 2 matches with the order of criteria shown in section 1. Also, please consider the following verbal terms:

Table 1. Linguistic terms used within the report

Linguistic term	Code
Very Low	VL
Low	L
Medium low	ML
Medium	M
Medium high	MH
High	H
Very high	VH

The selected alternatives are shown in the third section, which is followed by the potential of each strategy with respect to the selected criteria in section 4. In this section, each row illustrates the potential of strategies and the order of rows match with the order of passive strategies shown in section 3. Also, the columns represent the selected criteria, and the order is the same as section 2. Finally, the final weights of the selected passive strategies are illustrated in section 5. Please find below an example for better understanding.

Example:

Assume that you have selected "**compatibility with climate**" and "**capital investment cost**" as the selection criteria, and the importance for them is "vey high" and "low" respectively. In this case, section 2 will be as follows: **['vh', 'l']**.

Also, assume that you have selected "**utilising sun shading devices**" and "**optimising the orientation of building**" as passive strategies and the potential of the selected passive strategies with respect to the selected criteria are as follows:

1

Table 2. Example of the importance of passive strategies with respect to the selection criteria

	Compatibility with climate	Capital investment cost
Utilising sun shading devices	Very high	High
optimising the orientation of building	Medium	Very low

In this case, section 4 will be as follows:

- ['vh', 'h']
- ['m', 'vl']

Therefore, the final report will be as follows:

1. **Selection of Criteria**:
   - Compatibility with climate
   - Capital investment cost
2. **Importance of Selection Criteria**:
   - ['vh', 'l']
3. **Selection of Passive Strategies**:
   - Utilising sun shading devices
   - Optimising the orientation of building
4. **Potential of Passive Strategies**:
   - ['vh', 'h']
   - ['m', 'vl']
5. **Results**:
   - Utilising sun shading devices: 0.76
   - Optimising the orientation of building: 0.58

2

Fig. A13. PSAT report guide.

PASSIVE-STRATEGY-ASSESSMENT-TOOL-FOR-BUILDINGS

1.Selection of Criteria :
- Compatibility with climate
- Improvement of indoor air quality (IAQ)

2.Importans of Selection Criteria :
- ['vh', 'ml']

3.Selection of Passive Strategies :
- Utilising naturally ventilated envelope
- Utilising sun shading devices

4.Potential of Passive Strategie :
- ['vh', 'm']
- ['l', 'vh']

5.Result :
- Utilising naturally ventilated envelope : 0.9169
- Utilising sun shading devices : 0.0831

Fig. A14. PSAT report for the hypothetical example.

Table A1
Complete validation scores of the PSAT against the pre-defined criteria.

Expert ID	VC1	VC2	VC3	VC4	VC5
EX1	5	4	5	5	5
EX2	5	5	5	4	5
EX3	5	5	5	5	5
EX4	5	5	5	5	5
EX5	5	5	5	5	5
EX6	5	5	5	4	5
EX7	4	5	5	4	5
EX8	5	5	5	5	5
EX9	5	5	5	5	5
EX10	4	4	5	5	5
EX11	5	5	5	5	5
EX12	5	5	5	5	5
EX13	4	4	5	4	4
EX14	5	5	5	5	5
EX15	5	5	5	5	4
EX16	4	4	4	4	4
EX17	5	5	5	5	5
EX18	4	5	5	4	5
EX19	5	5	5	5	5
EX20	5	5	5	4	5
EX21	5	5	5	4	4
EX22	4	5	4	5	5
EX23	5	5	5	5	5
EX24	4	4	4	4	4
Average	4.71	4.79	4.88	4.63	4.79
Efficiency score (ES)	**4.76**				

7. Conclusion

This study developed a KB-DST titled PSAT to facilitate quick, consistent, and repeatable multiple criteria selection of passive energy consumption optimisation strategies for buildings. Further explanation of the novel contributions of this study are as follows:

- The criteria involved in the selection of passive energy consumption optimisation strategies for UK buildings, especially within social, technical, and economic contexts were identified. This would be beneficial for future research in this area.
- The existing passive energy consumption optimisation strategies for buildings were identified, which will be valuable for future research.
- Drivers and barriers to the adoption of passive energy consumption optimisation strategies for UK buildings were identified, which is necessary to further promote the use of passive strategies within the UK building sector. Furthermore, the user-friendliness of the developed KB-DST especially its incorporation of information regarding the drivers and barriers to the adoption of passive energy consumption optimisation strategies for UK buildings, the selection criteria involved in this selection, and passive strategies themselves, makes the platform very valuable for making quick, guided, and succinct decisions with reduced subjectivity and uncertainty.
- A novel algorithm to facilitate automatic selection of passive strategies for UK buildings was generated using Python, by hybridising a fuzzy extensions CRITIC and EDAS approaches. The methodology and hybridisation applied here can be used to solve similar or other MCDM problems in the future, irrespective of the discipline.

Validation of the PSAT was conducted against five pre-defined validation criteria including user-friendliness (VC1), structural layout (VC2), processing speed (VC3), ease of integration with other platforms (VC4), and representativeness and relevance of captured information (VC5) through questionnaire survey. The gathered data confirmed the validity of the PSAT by obtaining an efficiency score of 4.76. Also, the free text comments from experts which formed complementary qualitative data underwent thematic analysis and generated five codes (i.e., cross-operating systems (OS) compatibility, web-based accessibility, integration with BIM tools, regular update cycle, and embedded operational guidance) within three themes (i.e., flexibility, interoperability, and comprehensiveness). Some of the comments were addressed immediately and the others which required substantial efforts can be considered as suggested pathways for future studies. These include the development of a specific version of the PSAT for MAC OS, generating the web-based version of the PSAT, and the integration of the PSAT with other building management platforms such as building energy management systems (BEMs) or building information modelling (BIM) to facilitate a robust through-life management system. Also, considering that sensitivity analysis was not conducted for the PSAT in this study due to its dynamic and user-driven nature, it is suggested that future studies focus on specific projects and analyse the outcome of the PSAT using sensitivity analysis. This approach would allow for an in-depth exploration of weight variations in controlled decision-making scenarios while maintaining the flexibility and adaptability of the PSAT.

CRediT authorship contribution statement

Amirhossein Balali: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **Akilu Yunusa-Kaltungo:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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NA.

Appendix

Data availability

Data will be made available on request.

References

[1] B. Considine, Y. Liu, A. McNabola, Energy savings potential and life cycle costs of deep energy retrofits in buildings with and without habitable style loft attic conversions: A case study of Irelands residential sector, Energy Policy 185 (2024) 113980, https://doi.org/10.1016/j.enpol.2023.113980.
[2] N. Ranjbar, A. Balali, A. Valipour, G. Pignatta, S. Wei, Identification and Prioritization of Energy Consumption Optimization Strategies in the Building Industru Using the Hybrid SWARA-BIM Model, J Green Build 18 (2023) 37–69, https://doi.org/10.3992/jgb.18.1.37.
[3] A. Balali, A. Yunusa-kaltungo, R. Edwards, A systematic review of passive energy consumption optimisation strategy selection for buildings through multiple criteria decision-making techniques, Renew. Sustain. Energy Rev. 171 (2023) 113013, https://doi.org/10.1016/j.rser.2022.113013.
[4] D.R. Liyanage, K. Hewage, S.A. Hussain, F. Razi, R. Sadiq, Climate adaptation of existing buildings: A critical review on planning energy retrofit strategies for future climate, Renew. Sustain. Energy Rev. 199 (2024) 114476, https://doi.org/10.1016/j.rser.2024.114476.
[5] N. Ranjbar, A. Balali, A. Valipour, A. Yunusa-Kaltungo, R. Edwards, G. Pignatta, et al., Investigating the environmental impact of reinforced-concrete and structural-steel frames on sustainability criteria in green buildings, J Build Eng 43 (2021) 103184, https://doi.org/10.1016/j.jobe.2021.103184.
[6] A. Balali, A. Valipour, Prioritization of passive measures for energy optimization designing of sustainable hospitals and health centres, J Build Eng 35 (2021) 101992, https://doi.org/10.1016/j.jobe.2020.101992.
[7] A. Balali, A. Valipour, Identification and selection of building façade's smart materials according to sustainable development goals, Sustain. Mater. Technol. 26 (2020) e00213, https://doi.org/10.1016/j.susmat.2020.e00213.

[8] Y. Mehrpour, A. Balali, A. Valipour, A. Yunusa-kaltungo, Envelope design optimisation for residential net zero energy buildings within cold and semi-arid climate : A case study of Shiraz, Energy Sustain Dev 78 (2024) 101352, https://doi.org/10.1016/j.esd.2023.101352.
[9] European Commission. Towards an inclusive energy transition in the European Union: Confronting energy poverty amidst a global crisis. 2020.
[10] N. Frilingou, K. Koasidis, N.A. Spyridaki, A. Nikas, V. Marinakis, H. Doukas, Is it feasible to implement minimum energy performance standards (MEPS) for existing buildings in Greece? A Cost-Benefit Evaluation. Energy Policy 188 (2024) 114112 https://doi.org/10.1016/j.enpol.2024.114112.
[11] United Nations. Sustainable Development Goals 2024. https://www.un.org/sustainabledevelopment/sustainable-development-goals/ (accessed August 8, 2024).
[12] B. Wen, S.N. Musa, C.C. Onn, S. Ramesh, L. Liang, W. Wang, et al., The role and contribution of green buildings on sustainable development goals, Build. Environ. 185 (2020) 107091, https://doi.org/10.1016/j.buildenv.2020.107091.
[13] R. Alawneh, F.E. Mohamed Ghazali, H. Ali, M. Asif, Assessing the contribution of water and energy efficiency in green buildings to achieve United Nations Sustainable Development Goals in Jordan, Build. Environ. 146 (2018) 119–132, https://doi.org/10.1016/j.buildenv.2018.09.043.
[14] S. Mirasgedis, L.F. Cabeza, D. Vérez, Contribution of buildings climate change mitigation options to sustainable development, Sustain. Cities Soc. 106 (2024), https://doi.org/10.1016/j.scs.2024.105355.
[15] C. Barbier, D. Ghailani, European Briefing: Digest, J. Eur. Soc. Policy 18 (2008) 303–315, https://doi.org/10.1177/0958928707091067.
[16] UK Government. Town and Country Planning Act 1990 1990. https://www.legislation.gov.uk/ukpga/1990/8/contents (accessed August 8, 2024).
[17] C. Panakaduwa, P. Coates, M. Munir, Identifying sustainable retrofit challenges of historical Buildings: A systematic review, Energ. Buildings 313 (2024) 114226, https://doi.org/10.1016/j.enbuild.2024.114226.
[18] UK Government. Climate Change Act. 2008.
[19] A. Balali, A. Hakimelahi, A. Valipour, Identification and prioritization of passive energy consumption optimization measures in the building industry: An Iranian case study, J Build Eng 30 (2020), https://doi.org/10.1016/j.jobe.2020.101239.
[20] F. Amiri Fard, F. Nasiri, Integrated Assessment-Optimization Approach for Building Refurbishment Projects: Case Study of Passive Energy Measures, J. Comput. Civ. Eng. 32 (2018) 05018003, https://doi.org/10.1061/(asce)cp.1943-5487.0000785.
[21] M. Sheikholeslami, Z. Khalili, Enhancing photovoltaic solar panel performance with integration of PCM-based spectral filter and self-cleaning coating, J Build Eng 94 (2024) 110019, https://doi.org/10.1016/j.jobe.2024.110019.
[22] G. Lo Basso, B. Nastasi, F. Salata, I. Golasi, Energy retrofitting of residential buildings—How to couple Combined Heat and Power (CHP) and Heat Pump (HP) for thermal management and off-design operation, Energ. Buildings 151 (2017) 293–305, https://doi.org/10.1016/j.enbuild.2017.06.060.
[23] Y. Chen, H. Lee, A. Ozaki, Y. Choi, Y. Arima, Experimental and numerical investigation of integrating energy recovery ventilation into a thermodynamic-potential-based passive dehumidification system using renewable energy, Energy 289 (2024) 129888, https://doi.org/10.1016/j.energy.2023.129888.
[24] S. Motamedpooya, M. Ashour, A. Mahdiyar, E. Jamei, Diagnosing the cause-effect relationship among deterrents to intensive green roof adoption: A hybrid EFDM-FDEMATEL approach, Sustain. Cities Soc. 99 (2023) 104972, https://doi.org/10.1016/j.scs.2023.104972.
[25] M. Behzadi Hamooleh, A. Torabi, M. Baghoolizadeh, Multi-objective optimization of energy and thermal comfort using insulation and phase change materials in residential buildings, Build. Environ. 262 (2024) 111774, https://doi.org/10.1016/j.buildenv.2024.111774.
[26] H. Seddon, H. Zhong, An investigation into the efficacy of the pulse method of airtightness testing in new build and Passivhaus properties, Energ. Buildings 295 (2023) 113270, https://doi.org/10.1016/j.enbuild.2023.113270.
[27] G. Zhang, H. Wu, J. Liu, Y. Liu, Y. Ding, H. Huang, A review on switchable building envelopes for low-energy buildings, Renew. Sustain. Energy Rev. 202 (2024) 114716, https://doi.org/10.1016/j.rser.2024.114716.
[28] H. Yang, Z. Xu, Y. Shi, W. Tang, C. Liu, A. Yunusa-Kaltungo, et al., Multi-objective optimization designs of phase change material-enhanced building using the integration of the Stacking model and NSGA-III algorithm, J Energy Storage 68 (2023) 107807, https://doi.org/10.1016/j.est.2023.107807.
[29] M.K. Kuzman, P. Grošelj, N. Ayrilmis, M. Zbašnik-Senegačnik, Comparison of passive house construction types using analytic hierarchy process, Energ. Buildings 64 (2013) 258–263, https://doi.org/10.1016/j.enbuild.2013.05.020.
[30] C. Díaz-López, A. Serrano-Jiménez, K. Verichev, Á. Barrios-Padura, Passive cooling strategies to optimise sustainability and environmental ergonomics in Mediterranean schools based on a critical review, Build. Environ. 221 (2022) 109297, https://doi.org/10.1016/j.buildenv.2022.109297.
[31] Z. Romani, A. Draoui, F. Allard, Metamodeling and multicriteria analysis for sustainable and passive residential building refurbishment: A case study of French housing stock, Build. Simul. 15 (2022) 453–472, https://doi.org/10.1007/s12273-021-0806-7.
[32] A. Balali, A. Yunusa-Kaltungo, R. Edwards, A Systematic Literature Review of Passive Energy Consumption Optimisation Strategies in Buildings and Their Selection Criteria, ASME Int Mech Eng Congr Expo Proc 6 (2022), https://doi.org/10.1115/IMECE2022-93887.
[33] X. Cao, R. Yao, C. Ding, N. Zhou, W. Yu, J. Yao, et al., Energy-quota-based integrated solutions for heating and cooling of residential buildings in the Hot Summer and Cold Winter zone in China, Energ. Buildings 236 (2021), https://doi.org/10.1016/j.enbuild.2021.110767.
[34] H. Khalesi, A. Balali, A. Valipour, J. Antucheviciene, D. Migilinskas, V. Zigmund, Application of Hybrid SWARA–BIM in Reducing Reworks of Building Construction Projects from the Perspective of Time, Sustainability 12 (2020) 8927, https://doi.org/10.3390/su12218927.
[35] A. Balali, A. Yunusa-kaltungo, Description of the Characteristics of Different Multiple Criteria Decision-Making (MCDM) Techniques for the Selection of Passive Energy Consumption Optimisation Strategies, Key Themes Energy Manag., Springer Nature Switzerland (2024) 199–271, https://doi.org/10.1007/978-3-031-58086-4_12.
[36] A. Balali, A. Yunusa-kaltungo, Investigating the Potential of Evaluation Based on Distance from Average Solution (EDAS) Method in Crisp and Fuzzy Environments for Solving Building Energy Consumption Optimisation Multiple Attribute Decision-Making (MADM) Problems, Key Themes Energy Manag., Springer Nature Switzerland (2024) 273–296, https://doi.org/10.1007/978-3-031-58086-4_13.
[37] X. Cao, R. Yao, C. Ding, N. Zhou, W. Yu, J. Yao, et al., Energy-quota-based integrated solutions for heating and cooling of residential buildings in the Hot Summer and Cold Winter zone in China, Energ. Buildings 236 (2021) 110767, https://doi.org/10.1016/j.enbuild.2021.110767.
[38] R. Tariq, C.E. Torres-Aguilar, N.A. Sheikh, T. Ahmad, J. Xamán, A. Bassam, Data engineering for digital twining and optimization of naturally ventilated solar façade with phase changing material under global projection scenarios, Renew. Energy 187 (2022) 1184–1203, https://doi.org/10.1016/j.renene.2022.01.044.
[39] H. Sadeghi, X. Zhang, Towards safer tower crane operations: An innovative knowledge-based decision support system for automated safety risk assessment, J. Saf. Res. 90 (2024) 272–294, https://doi.org/10.1016/j.jsr.2024.05.011.
[40] X. Zhao, B.G. Hwang, S.P. Low, An enterprise risk management knowledge-based decision support system for construction firms, Eng. Constr. Archit. Manag. 23 (2016) 369–384, https://doi.org/10.1108/ECAM-03-2015-0042.
[41] B.G. Hwang, M. Shan, K.Y. Looi, Knowledge-based decision support system for prefabricated prefinished volumetric construction, Autom. Constr. 94 (2018) 168–178, https://doi.org/10.1016/j.autcon.2018.06.016.
[42] S.H. Liao, Expert system methodologies and applications-a decade review from 1995 to 2004, Expert Syst. Appl. 28 (2005) 93–103, https://doi.org/10.1016/j.eswa.2004.08.003.
[43] L.O. Iheukwumere-Esotu, A. Yunusa-Kaltungo, Development of an Interactive Web-Based Knowledge Management Platform for Major Maintenance Activities: Case Study of Cement Manufacturing System, Sustain 14 (2022), https://doi.org/10.3390/su141711041.
[44] L.O. Iheukwumere-Esotu, A. Yunusa-Kaltungo, Knowledge criticality assessment and codification framework for major maintenance activities: A case study of cement rotary kiln plant, Sustain 13 (2021), https://doi.org/10.3390/su13094619.
[45] S. Tabatabaee, A. Mahdiyar, S. Ismail, Towards the success of Building Information Modelling implementation: A fuzzy-based MCDM risk assessment tool, J Build Eng 43 (2021) 103117, https://doi.org/10.1016/j.jobe.2021.103117.
[46] O.S. Alshamrani, A. Alshibani, Automated decision support system for selecting the envelope and structural systems for educational facilities, Build Environ 181 (2020) 106993, https://doi.org/10.1016/j.buildenv.2020.106993.
[47] A. Mahdiyar, S. Tabatabaee, S. Durdyev, S. Ismail, A. Abdullah, W.M. Rani, Wnm., A prototype decision support system for green roof type selection: A cybernetic fuzzy ANP method, Sustain Cities Soc 48 (2019) 101532, https://doi.org/10.1016/j.scs.2019.101532.
[48] European Commission. Taking action on the TOTAL impact of the construction sector. 2019.
[49] UK Government, Climate Change Act (2008) 2024.
[50] X. Liang, Y. Wang, M. Royapoor, Q. Wu, T. Roskilly, Comparison of building performance between Conventional House and Passive House in the UK, Energy Procedia 142 (2017) 1823–1828, https://doi.org/10.1016/j.egypro.2017.12.570.
[51] A. Balali, R.C. Moehler, A. Valipour, Ranking cost overrun factors in the mega hospital construction projects using Delphi-SWARA method: an Iranian case study, Int. J. Constr. Manag. 22 (2022) 2577–2585, https://doi.org/10.1080/15623599.2020.1811465.
[52] A. Balali, A. Valipour, E.K. Zavadskas, Z. Turskis, Multi-criteria ranking of green materials according to the goals of sustainable development, Sustain 12 (2020), https://doi.org/10.3390/su12229482.
[53] A. Balali, A. Valipour, R. Edwards, R. Moehler, Ranking effective risks on human resources threats in natural gas supply projects using ANP-COPRAS method: Case study of Shiraz, Reliab Eng Syst Saf 208 (2021) 107442, https://doi.org/10.1016/j.ress.2021.107442.
[54] M.K. Ghorabaee, E.K. Zavadskas, M. Amiri, Z. Turskis, Extended EDAS method for fuzzy multi-criteria decision-making: An application to supplier selection, Int J Comput Commun Control 11 (2016) 358–371, https://doi.org/10.15837/ijccc.2016.3.2557.
[55] R. Rostamzadeh, M.K. Ghorabaee, K. Govindan, A. Esmaeili, H.B.K. Nobar, Evaluation of sustainable supply chain risk management using an integrated fuzzy TOPSIS- CRITIC approach, J. Clean. Prod. 175 (2018) 651–669, https://doi.org/10.1016/j.jclepro.2017.12.071.
[56] A. Menekşe, H.C. Akdağ, Medical waste disposal planning for healthcare units using spherical fuzzy CRITIC-WASPAS, Appl. Soft Comput. 144 (2023) 110480, https://doi.org/10.1016/j.asoc.2023.110480.
[57] P. Majumder, An integrated trapezoidal fuzzy FUCOM with single-valued neutrosophic fuzzy MARCOS and GMDH method to determine the alternatives weight and its applications in efficiency analysis of water treatment plant, Expert Syst. Appl. 225 (2023) 120087, https://doi.org/10.1016/j.eswa.2023.120087.
[58] Tom Schimansky. CustomTkinter : A modern and customizable python UI-library based on Tkinter n.d. https://customtkinter.tomschimansky.com/ (accessed May 10, 2024).

[59] Python Software Foundation. Auto-Py-to-Exe 2.44.1 2024.
[60] Qualtrics 2024. https://www.qualtrics.com/uk/?rid=ip&prevsite=en&newsite=uk&geo=GB&geomatch=uk (accessed May 18, 2024).
[61] J. Zheng, B. Zeng, Unleashing the influencing factors of solar energy adoption to combat climate change: A roadmap toward sustainable energy technologies, Sustain Energy Technol Assessments 57 (2023) 103303, https://doi.org/10.1016/j.seta.2023.103303.
[62] Y. Yu, W. Umer, X. Yang, M.F. Antwi-Afari, Posture-related data collection methods for construction workers: A review, Autom. Constr. 124 (2021) 103538, https://doi.org/10.1016/j.autcon.2020.103538.
[63] A. Balali, A. Yunusa-kaltungo, Selection of passive energy consumption optimisation strategies for buildings, Renew Sustain Energy Rev 210 (2025) 115222, https://doi.org/10.1016/j.rser.2024.115222.
[64] S. Hashemkhani Zolfani, M. Pourhossein, M. Yazdani, E.K. Zavadskas, Evaluating construction projects of hotels based on environmental sustainability with MCDM framework, Alexandria Eng J 57 (2018) 357–365, https://doi.org/10.1016/j.aej.2016.11.002.
[65] A. Mahdiyar, S.R. Mohandes, S. Durdyev, S. Tabatabaee, S. Ismail, Barriers to green roof installation: An integrated fuzzy-based MCDM approach, J. Clean. Prod. 269 (2020) 122365, https://doi.org/10.1016/j.jclepro.2020.122365.
[66] K. Kabirifar, M. Ashour, M. Yazdani, A. Mahdiyar, M. Malekjafarian, Cybernetic-parsimonious MCDM modeling with application to the adoption of Circular Economy in waste management, Appl. Soft Comput. 139 (2023) 110186, https://doi.org/10.1016/j.asoc.2023.110186.
[67] V. Braun, V. Clarke, Using thematic analysis in psychology, Qual. Res. Psychol. 3 (2006) 77–101, https://doi.org/10.1191/1478088706qp063oa.
[68] M. Sedighi, Application of word co-occurrence analysis method in mapping of the scientific fields (case study: the field of Informetrics), Libr. Rev. 65 (2016) 52–64, https://doi.org/10.1108/LR-07-2015-0075.
[69] NumPy Developers. NumPy 2024. https://numpy.org/doc/stable/index.html# (accessed May 12, 2024).
[70] Tom Schimansky. CustomTkinter : A modern and customizable python UI-library based on Tkinter n.d.
[71] Python Software Foundation. Tkinter 2024. https://docs.python.org/3/library/tkinter.html (accessed May 12, 2024).
[72] Jeffrey A. Clark and contributors. Pillow 2024. https://pillow.readthedocs.io/en/stable/ (accessed May 10, 2024).
[73] S. Andrew, C. Bishop, G.W. Tigwell, Light and Dark Mode: A Comparison Between Android and iOS App UI Modes and Interviews with App Designers and Developers, Proc ACM Interactive, Mobile, Wearable Ubiquitous Technol 8 (2024) 1–23, https://doi.org/10.1145/3643539.