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# Customizing well-known sustainability assessment tools for Iranian residential buildings using Fuzzy Analytic Hierarchy Process

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A R T I C L E I N F O

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A B S T R A C T

The aim of this research is to customize the categories and criteria points of well-known sustainability assessment tools regarding the priorities in sustainability concerns of Iran in order to develop an Iranian sustainability assessment tool suitable for residential buildings. Therefore, common sustainability indicators of LEED, BREEAM, CASBEE and SBTool will be used as benchmarks for the evaluation process by Iranian professional experts to revise the points allocated in Iranian assessment tool. For the revision of the points in accordance with Iranian sustainability needs, FAHP method (Fuzzy Analytical Hierarchy Process) will be conducted. Afterwards, Iranian sustainability assessment tool, consisting of six levels of certification with categories and criteria points, has been designed to promote sustainability in the residential buildings. The reliability of the assessment tool has been confirmed by comparing performance sensitivity with the existing assessment tools in terms of the points given to each category. This will encourage Iranian construction practitioners to be more aware of worldwide sustainability assessment tools and of the way to implement sustainability in their residential building projects. Results can be a basis for further investigations on other indicators which are crucial for sustainability concerns of Iran and would provide a platform for inspiration of further sustainability solutions. Introduction of the priority weights of sustainability fundamentals will be a reference for further developing a more holistic assessment tool, considering more dimensions such as economic and social sustainability issues regarding Iranian residential buildings.

## 1. Introduction

Nowadays sustainability concept has gained worldwide recognition in the building industry by considering sustainability issues in construction [1–3]. The reason behind this fact lies in its major impact on natural environment [4]. For instance, building industry generates one third of $CO_2$ emission [5]. Moreover, United Nations has reported that this sector is responsible for nearly 33% and 25% of green house gas (GHG) emission and waste production, respectively.

In Iran, the large segment of building industry, which is formed by residential buildings, accounts for 40% of used energy [6]. Therefore, sustainable building concept considered a recent response to address environmental issues for the reduction of building impacts on natural environment [7,8]. In Iranian contemporary buildings, very small amounts of renewable energy sources have been used. However, sustainability of buildings necessitates cleaner energy sources for countries, especially developing ones [9]. Therefore, in order to practically consider sustainability in the buildings of developing countries [10], sustainability indicators should be incorporated in construction process [7,11], exactly like the developed countries. Accordingly, for the creation of information concerning the environmental impacts of buildings [12], systematic and practical approaches must be implemented [13]. In such approaches, sustainability indicators act as a profitable guidance for planning or policy system. This guidance can also act as a tool providing information to ease decision making processes for better results. This helps to judge the sustainability of buildings and reduce the chance of arbitrary decisions in building construction [14]. The movements of developed countries toward the establishment of sustainability indicator list, which is called assessment tools, leads to different indicators and weighting scores suited for that country [15]. These assessment tools became references for building practitioners to promote sustainability of buildings by quantifying environmental performance [12,16] as well as collecting information for decision making in different phases of construction [13]. This helps to attain sustainable buildings which have situated crucial sustainability issues in the output. Sustainability assessment tools are not only beneficial for buildings, but also lead to healthier occupants. Since occupants spend nearly 90% of their time indoors [17], the air quality of

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indoors can influence the overall health of occupants [18]. These tools create healthier buildings for occupants by considering the quality of indoor environments, lowering building costs for energy and water use throughout the lifecycle of buildings (economical benefit), and attracting residents. Moreover, these tools consider physical health of occupants by encouraging materials and products with low volatile organic compounds. These materials will have minimal to no off-gassing and occupants can breathe easier and feel healthier [19]. Therefore, a building can improve the air and increase the overall long-term health of occupants. For occupant attraction, the sustainable aspect of buildings in the world are becoming a selling point for many costumers. In other words, sustainability assessment tools show tenants the commitment that a developer has to the environment, is in line with their ideals [19].

The tools, which gained a rapid worldwide recognition, are LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), SBTool (Sustainable Building Tool), and CASBEE (Comprehensive Assessment System for Built Environment Efficiency) [20]. Despite the fact that these tools have originated from developed countries, they are used or adapted for use in several other countries [21–26]. For instance, LEED assessment tool is used in more than 164 countries [27]. However, it should be noted that these tools are based on the local priorities of sustainability issues [12] and have been developed by local construction experts and stakeholders. Since the consideration of sustainability objective has become a priority in developing countries nowadays [28], these countries have started to use the common indicators of the well-known assessment tools as a starting point and a contribution to redevelop and revise assessment tools in accordance with regional sustainability requirements [12]. For instance, Ferreira et al., [16] developed Portuguese sustainable building assessment tool benchmarked with BREEAM and LEED, or Lee & Burnett [23] customized SBTool for Hong Kong. Vyas and Jha [29], evaluated widely used green building assessment tools such as BREEAM, LEED, SBTool, CASBEE, etc. to develop a suitable assessment tool for India. Ali and Al Nsairat [28] designed an assessment tool suitable for Jordanian context through interviews with local experts, with a focus on LEED, BREEAM and SBTool, to determine assessment indicators respecting the local conditions. Therefore, by adapting international assessment tools to local contexts, it became possible to implement sustainable building programs as references for construction in such countries [24]. There are a few researches regarding sustainability assessment tools in Iran. For instance, Namini et al. [30] introduced a new criteria-based sustainability assessment tool for residential buildings in Iran by considering the 'project management body of knowledge' as a reference for developing categories and a guideline to define a framework for evaluating different phases of construction. Moreover, Nemati et al. [25] endeavored to develop a theoretical model to describe views of sustainable architecture in Iran. Although these researches tried to introduce sustainability assessment tools, there is a lack of research study regarding the customization of "international sustainability assessment tools" according to sustainability concerns of Iran [31] in terms of well-known categories of such tools for residential buildings.

Just as other developing countries, as a starting point, Iran needs to employ international assessment tools for buildings, especially in residential sector, to prioritize sustainability issues adapted to sustainability requirements of Iran. As a result, a revision of common indicators of well-known assessment tools should be conducted by professional experts of Iran. Therefore, the aim of this research is to develop residential sustainability assessment tool suitable for Iranian context with a focus on common sustainability indicators of LEED, BREEAM, CASBEE and SBTool, to determine new assessment indicators respecting the local conditions.

Although, sustainability of a building can include many issues, the development of Iranian sustainability assessment tool will be based on common categories of international assessment tools. Considering the fact that sustainability is a new subject in Iran and since only a few researches regarding the development of sustainability assessment tool for Iranian residential buildings exist, the proposed tool is aimed to be developed on the basis of categories which are considered as global concerns of the sustainability. It should be noted that the newness of sustainability subject in Iran has led to less awareness about the aforementioned subject among the building practitioners. Accordingly, awareness raising for all the practitioners requires the development of a tool as a starting point for the assessment of sustainability in residential buildings in Iran. With the help of common categories, the information on complex issues for Iranian building practitioners, can be revealed in simplified and comprehensible formats. This action will not only raise public awareness of the key categories of worldwide sustainability issues among building practitioners of Iran, but also will be a solid basis on which Iranian assessment tool will be further modified in the future. It should be noted that according to the most of studies, which have compared widely used international assessment tools with each other, all of these tools have been developed on the basis of the common categories [32–35]. For instance, the comparison of BREEAM, LEED, CASBEE, SBTool etc. has showed that common categories are situated in these tools and such categories are found to be the basis for most of international assessment tools [36].

Moreover, the research compared and benchmarked the new assessment tools with the aforementioned assessment tools in terms of their indicator rankings and priorities.

Since the evaluation of indicators is a multi-criteria decision problem and decision-making is often a much more fuzzy process [37–39], the multi-criteria decision-making (MCDM) method of Fuzzy-AHP has been employed to weight the indicators based on sustainability concerns of Iran. It should be noted that multi-criteria decision-making method is considered an excellent choice for sustainability assessment problems [40]. This method is currently amongst the mostly used methods in sustainability assessment e.g. Refs. [41–43].

The objectives of this research are as follows:

1 Investigating the common indicators of well-known sustainability assessment tools to develop a minimum sustainability requirement for residential buildings of Iran.
2 Pairwise comparison and evaluation of common indicators based on Iranian sustainability concerns, using Fuzzy-AHP method.
3 Comparing the new assessment tool with LEED, BREEAM, CASBEE and SBTool as well as investigating the performance sensitivity of international assessment tools in terms of the newly developed Iranian assessment tool.

This will encourage Iranian construction practitioners to be more aware of worldwide sustainability assessment tools and of the way to implement sustainability in their residential building projects. Moreover, this action will lead to further investigations for other indicators crucial for Iranian sustainability concerns and will provide a platform for inspiration of further sustainability solutions. Introduction of the priority weights of sustainability fundamentals will be a reference for further development of a more holistic assessment tool considering more dimensions (such as economic and social sustainability issues regarding Iranian residential buildings).

## 2. Literature review

### 2.1. Sustainability residential buildings specific to the context of Iran

In the developing countries, environmental problems continue to escalate in a way that necessitates advanced measures for sustainability promotions [31]. For instance, the conventional buildings in Iran consume a large quantity of natural resources [44]. Despite the unsustainability of modern buildings, traditional houses are of the prominent examples of sustainability specific to the context of Iran, which display a positive correlation between the environment and buildings [3,45]. Therefore, reviewing existing literature about these sustainable buildings will enrich the proposed localized features of the sustainability assessment tool, which will be defined in the next sections.

Several studies investigated the sustainability of Iranian traditional houses in different aspects [3,45–52]. These studies believed that investigating the factors these houses had considered, can guide future practitioners to realize crucial factors for building sustainability of Iran. For instance, in traditional buildings, the form of central courtyard was implemented as a passive cooling strategy for indoor thermal comfort improvements as well as a daylight source in hot regions of Iran [45]. This approach not only reduced energy consumption in such houses, but also improved indoor environmental quality by its seasonal rooms, its landscaping and a pool [3,53]. The use of wind catchers was another solution for reducing energy used for cooling as well as providing a pleasant indoor environment for occupants. Moreover, Persian Blinds and special sealing tapes for reducing infiltration were applied in traditional houses in order to save heating energy demands [54].

Another important consideration which led to sustainability outcomes was to make use of the limited amounts of water in arid regions by developing channels of underground water called ‘qanats’ which helped the water harvesting to act as a sustainable system [50]. Therefore, efficiency can be seen in the use of the limited amounts of water in the history of Iran.

On the other hand, one of the crucial characteristics of traditional houses in Iran was that they used available local and natural materials such as clay brick, stone, lime, and plaster, which reduced energy expenditure during the occupation, as well as reducing the initial embodied energy and cost [55]. Other crucial feature of such houses was to take advantage of the passivity potentials, e.g. wind and solar energy of their site through their orientations. Therefore, the main principles in traditional houses, which provided comfort in most of the time as well as minimizing the fossil energy, were the suitable pattern of sustainable concepts in their buildings. According to a study conducted [45], amongst the prominent principles and features of Iranian traditional buildings which made them sustainable, Energy conservation (minimizing the need for fossil fuels), Minimizing new resource (recycling of materials), Working with climate (site, water, sun, etc.), and Respect for users (human comfort) can be mentioned.

In summary, material selection, the efficiency of water and energy, embodied energy, and occupants' comfort were the most important and successful concepts in achieving sustainability which were the part of traditional sustainable buildings in Iran.

### 2.2. International sustainability assessment tools and their development

Building assessment tools are not new to the global audience [56]. However, sustainability assessment tool is new on the part of Iranian policy makers and building practitioners. Due to the lack of a fundamental basis of residential sustainability assessment tool in Iran, a customized sample based on successful assessment tools, can solidify the basis of the evaluation system for further modifications. As a result, benchmarking the processes through which international assessment tools have been devised, will be helpful and will inform the researchers of the development of Iranian building sustainability assessment tool. Therefore, the well-known sustainability assessment tools will be discussed in this section.

In general, sustainability assessment tools aim to contribute and integrate sustainability indicators into building design and construction [57,58]. According to [35], there are two types of country benefiting from building sustainability assessment tool, (1) countries with their own green building councils [59], in which sustainability assessment tools were developed, (2) countries which use the most common and established assessment tools in order to reach sustainability objectives. The former type is mostly associated with developed countries, while the latter type is associated with developing ones. According to [60], four selection criteria should be considered when selecting well-known assessment tools. Based on these criteria, LEED, BREEAM, CASBEE, and SBtool, are found to be globally adopted by almost all of the developing countries [60], which will be discussed in this research for consideration in Iranian building sustainability assessment tool. Since these well-known assessment tools are being used by worldwide design and construction industries, the aforementioned tools as references will make contractors and engineers better understand the process as well as their contribution towards a successful project in achieving sustainability criteria through these assessment tools [61].

One of the examples is the LEED assessment tool which is globally accepted by building practitioners and is adopted in sustainable building practices and performance criteria [62]. Therefore, United States continues to consider LEED as a mostly used tool [60]. LEED began to develop in 1993, directed by “Natural Resources Defense Council”. The early LEED committee members included US Green Building Council (USGBC), architects, builders and engineers. In 1996, many engineers formed LEED technical committee [63]. Until 1998, USGBC, which is a nongovernmental organization including representatives from industry, academia, and government, continued to develop [63]. Since the time of the development, LEED has been revised, integrated, and nationally customized. Founding chairman of the LEED Steering Committee, directed a broad-based meetings until 2007, bringing together non-profit organizations, government agencies, architects, engineers, developers, builder, and other industry leaders [64]. Therefore, LEED is a sustainability assessment tool which is developed and continuously modified by workers in the green building industry in the United States [65]. LEED weighs the environmental impacts of buildings by giving more credits in certain categories. Its existing weighting scheme was proposed by the “National Institute of Standards and Technology”. However, in future LEED revisions, the USGBC expects to have its own weighting system, but at the present time LEED credits are proposed to be weighted based on the specific categories, which are in order of weighted importance [62]. LEED certification is a third-party verification to ensure that a building project has reached the highest level of sustainability by measuring according to the level of certification attained [61]. The General Services Administration, municipalities, and government departments, as well as private investors and owners, have established policies postulating LEED certification for their new construction projects [62]. It should be noted that different schemes exist for assessing newly constructed and existing residential, commercial, and institutional buildings. Despite the fact that each scheme has similar list of performance requirements set out in five categories, the number of credits, and available points differ considerably according to the building type [60]. For instance, the points of indoor water use reduction criteria of Water efficiency category or lighting criteria vary in commercial and residential buildings in LEED v4 assessment tool [66] or acoustic comfort criteria is not an issue in retail buildings compared to residential buildings. Another example is SBTool, in which the weighting factors are different for various building types, such as residential buildings, commercial buildings, new-builds and existing constructions, or a mix of the two [60].

Another successful assessment tool which is internationally developed is Building Research Establishment Environmental Assessment Method (BREEAM) from United Kingdom [56]. The first development of BREEAM began at the Building Research Establishment (BRE) of UK in 1988 and 1990 [23,28]. It was the first sustainable assessment tool for buildings which is implemented in UK building design, construction and use [67]. Since then, BRE administration, consisting of a group of researchers, engineers, technicians, and scientists started to globally create a variety of building performance assessment tools [68]. In 1998, BREEAM underwent a major revision, and the establishment occurred in the layout of scheme, by considering weighting for different sustainability categories [67]. In 2011, through major updates, BREEAM New Construction was developed to assess and certify all new UK buildings. This revision, which was provided by an expert team, included the reclassification and consolidation of categories and criteria to further streamline the BREEAM process. The latest update of BREEAM UK New Construction was developed in 2014, after the extensive consultation executed for the scheme [67]. This tool is now an international standard, implemented by a network of international operators, assessors and industry professionals and is locally adapted and operated [67]. Through its implementation, BREEAM facilitates measuring and reducing the environmental impacts of buildings for clients, which will create higher value and will lower risk assets [69]. BREEAM gives credits according to performance within each category, which are then summed up to reach a single score represented by a star rating of 1–5 stars [67]. BREEAM includes categories and related criteria. Each category includes a number of environmental criteria that may have a potential impact on the environment [70]. It is worth noting that BREEAM certification is independent confirmation by an expert which ensures that a building meets, and continues to meet, specific standards [67].

Comprehensive Assessment System for Built Environment Efficiency (CASBEE) is an assessing method according to the environmental performance of buildings in Japan. CASBEE was developed by a research committee established in 2001. This committee consisted of industry, academia, and national and local governments, in which the Japan Sustainable Building Consortium (JSBC) was established with the support of the housing Bureau of the “Ministry of Land, Infrastructure, Transport and Tourism” [71]. Since the time the first assessment tool of CASBEE developed (in 2002), many revisions were applied to it. The latest revisions of CASBEE (New Construction), which is widely used for planning, design, and construction of buildings, help the sustainability promotion of buildings [72]. The CASBEE system consists of four assessment tools corresponding to the life cycle of buildings [62]. After it was launched on the international market in 2005, it was presented in several Japanese municipalities across the country in 2014 [71]. CASBEE does not allocate points to each credit criteria [72]. It consists of categories in which the weights are calculated and showed on a radar chart and each credit point is evaluated based on a scale ranging from 1 to 5.

The SBTool is the Green Building Challenge assessment tool for assessing the sustainable performance of buildings. It was established by International Initiative for a Sustainable Built Environment (iiSBE), a non-profit organization formerly known as GBTool before 2002. In 1996, iiSBE aimed to establish energy and environmental performance standards to be useful for international and national contexts [73]. To be used internationally, this tool was developed by the work of representatives from 20 countries, which led to ‘SBMethod’ to offer a common international standard. This method is continually updated by a technical committee managed by the iiSBE [74]. The SBTool includes a framework which evaluates the sustainability of buildings against specific categories and criteria and assigns scores to a number of areas [74]. The weighting factors are different in SBTool for different building types, such as single buildings, residential buildings, commercial buildings, etc. This weighting can be partly modified by authorized third parties [74].

It can be concluded that building experts such as government agencies, municipalities, architects, engineers, and academia were involved in the development process of all mentioned assessment tools. The reason behind this is that they realized that experts' participation in specifying the benchmarks for the scoring of categories and criteria will facilitate the process [75]. Cole (2005) [24] defines assessment tool as a scheme with ‘frameworks which classify environmental performance criteria in a structured manner with assigned points or weightings which ‘are managed by and operate within known organizational contexts’. Moreover, many studies emphasize on the contribution of experts in the development process of assessment tools. For instance, Haappio & Viitnaniemi (2008) [76] reported that a consideration of the experiences of different tool users namely, architects, engineers, and contractors is important in developing assessment tools [76]. Du Plessisa and Cole [77] and Yang and Zou's study [78] encouraged internal stakeholders' cooperation (contractor, consultants, etc.) in motivating further improvements in sustainable buildings which can be reached through the development of sustainability assessment tools. Other studies indicating the crucial role of experts are [79–83]. In other words, if the problem needs a deeper professional insight, the expert approach will be more appropriate [84].

Therefore, the development of the aforementioned tools indirectly confirms that the appropriate experts are included in these processes [85], which can be implemented in the development of a new assessment tool for developing countries. Since a few number of sustainable building experts are available in Iran, the research has endeavored to contact almost all experts working in this field or achieving sustainability scholarship.

### 2.3. Comparative analysis among the world sustainability assessment tools

Since a large number of assessment tools for assessing the sustainability of buildings exists, comparative analysis of international assessment tools will give insights into this research subject. Many recent studies have compared the international sustainability assessment tools and indicated the similarities and differences [29,32,56,60,86,87]. In order to extract key categories from well-known sustainability assessment tools, sustainability categories and criteria of these tools should be investigated and compared, because each assessment tool has variations and similarities when compared with each other. Fig. 1 indicates the categories and certification levels in different international assessment tools. In all of the assessment tools, categories are the top level of the framework and define the scope of sustainability assessment in which specific sustainability criteria are developed. In all of these rating tools, credit points are given to each of these criteria and the scores are summed up to reach a single score to attain specific certification of a building [76,88–90]. However, in these assessment tools, based on the local conditions of a particular country, the weights assigned to each criteria differ in order to present the importance of each criterion for that country.

According to Fig. 1, BREEAM consists of 10 categories. It uses checklist measuring and allocates credits in each category according to the performance. The total number of credits awarded in each category is multiplied by an environmental weighting factor which defines the importance of the category and the overall score is produced by adding all the credits given to the sustainability performance of a building [91]. On the other hand, LEED has checklist and benchmark comparison measurement with the total points of 100. This tool which has 9 categories, measures the performance of a building through credits, allocating points when the requirements are achieved in these categories [92]. While CASBEE with 6 categories, has a benchmark assessment tool which scores criteria for each assessment category, SBTool with 8 categories, has indicator-weighting approach, which takes into account weighting factors fixed at the national level and the score is obtained from the comparison of the building and the national reference [13].

Each assessment tool has common and different sustainability categories. Table 1 reflects differences and common categories of LEED, BREEAM, CASBEE, and SBTool. It should be noted that the terms used to describe the same entity might be different, or the terms used for different entities might be similar in these tools [32]. Therefore, duplicate categories were presented as one category in this table. However, there are differences in the categories of these assessment tools. For instance, management is considered as a category in BREEAM, whereas LEED, CASBEE, and SBtool distribute all the criteria of management across other categories [93]. Service quality is also considered in SBtool, given less attention in BREEAM, LEED and CASBEE. In SBTool, social and economic, as well as cultural and perceptual aspects are considered as categories but LEED, BREEAM, and CASBEE do not

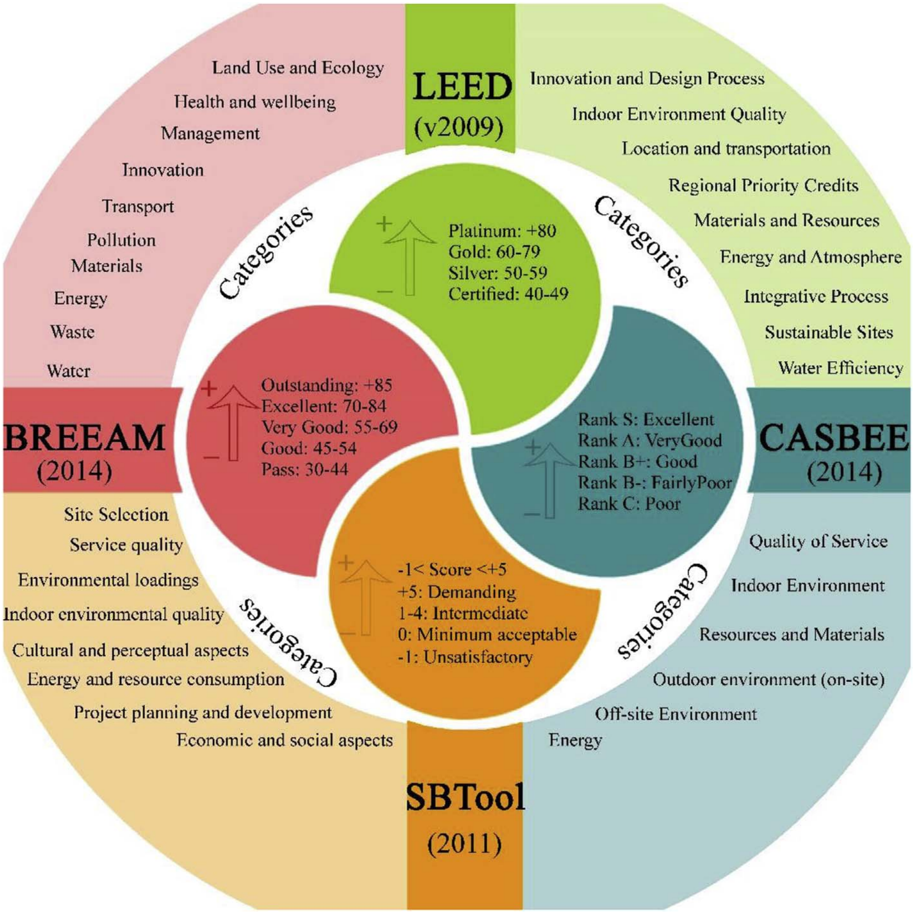


**Fig. 1.** Categories and certification levels of international assessment tools (LEED, BREEAM, CASBEE, and SBTool).

have such categories in their scheme. On the other hand, transport is included in BREEAM and LEED but not in SBTool and CASBEE. Moreover, there are similarities and differences in the points given to each category by the assessment tools, which will be further discussed in section 5.

Despite all the differences mentioned above, there are some key categories which are included in all of the assessment tools. It should be noted that one can reach a basic scheme from common categories of international assessment tool which can further provide the basis for the other standards to develop [94]. The reason behind the emphasis on the common categories of such assessment tools is to define appropriate scope for the development of a new assessment tool, because scope should be determined on the initial phase of assessment tool development [95]. This scoping should be based on the identification and categorization of related issues in order to expand the scoping later [96]. Scope of assessment tool should first be identified with common values of global society [97,98] in order to serve as a clear starting point for developing customized assessment tools [99]. The difficulties in scoping can be solved, through the adaptation of international standards by customizing the criteria used to assess building sustainability in particular context [100]. This adaptation makes the assessment system sustain focus on issues of global importance while letting the implementation of strategies be customized to the specific context of a country [95]. Many developing countries also started to use these assessment tools as a guidance for sustainability consideration to the extent that it became a major step for sustainability promotion for their country (for instance, Lee, et al. [23], Alwaer et al. [75], Mao et al. [101], Haapio et al. [76], Reed et al. [102], Banani et al. [103], Alyami & Rezgui [34], Ferreira et al. [16], and Gou et al. [91]). However, each country allocated different scores for the same categories in terms of sustainability issues which was considered to be more important from their local experts' point of view.

According to Table 1, there are a number of categories comprehensively included in the scheme of BREEAM, LEED, SBTool, and CASBEE assessment tools. The research extracted these key categories, which are amongst the list of priorities, to be customized according to the context of Iran. It should be noted that in other researches such as Lee [36]; Bernardi et al. [60]; Illankoon et al., [35]; Amasuomo et al. [56]; Alyami & Rezgui [34]; Mao et al. [101]; Chandratilake and Dias [104]; Rosa & Haddad [105], these categories are mentioned to be amongst the most important and key categories in all of the worldwide sustainability assessment tools, which represent the interaction between buildings and their environment [106].

## 3. Research methodology

### 3.1. Research design & data collection method

The research design of the paper includes several steps. The first step includes identifying categories and criteria from literature review of well-known assessment tools, which were specified in previous sections. Therefore, the main categories of energy efficiency, water efficiency, indoor environmental quality, materials and resources, and sustainable site were deemed to be the basic and initial sustainability concerns for evaluation by Iranian experts for residential buildings of Iran. The second step was to choose residential building experts based on their experience towards sustainability issues. In the third step, questionnaires were designed to allocate weights to each criterion and category for the determination of the relative importance in sustainability assessment of residential buildings. The Fourth step was to employ FAHP method for the development of a comprehensive assessment tool based on prioritization of categories and criteria applicable to

**Table 1**
Comparison of well-known sustainability assessment tools [34,36,60].

| | | LEED v2009 | BREEAM 2014 | SBtool 2011 | CASBEE 2014 |
|---|---|---|---|---|---|
| Country | | USA (1998) | UK (1990) | Canada (1998) | Japan (2001) |
| Scope | | New build,<br>Refurbishment,<br>Existing building | New build,<br>Refurbishment,<br>Existing building | New build,<br>Refurbishment,<br>Existing building | New build,<br>Refurbishment,<br>Existing building |
| Sustainable Categories | -Sustainable Site | ✓* | ✓ | ✓ | ✓ |
| | -Location and transportation | ✓ | ✓ | –* | – |
| | -Water Efficiency | ✓ | ✓ | ✓ | ✓ |
| | -Energy Efficiency | ✓ | ✓ | ✓ | ✓ |
| | -Materials | ✓ | ✓ | ✓ | ✓ |
| | -Indoor Environment Quality | ✓ | ✓ | ✓ | ✓ |
| | -Innovation and Design Process | ✓ | ✓ | – | – |
| | -Regional Priority | ✓ | ✓ | ✓ | – |
| | -Integrative Process | ✓ | – | – | – |
| | -Management | – | ✓ | ✓ | – |
| | -Land Use and Ecology | ✓ | ✓ | – | – |
| | -Waste | ✓ | ✓ | ✓ | ✓ |
| | -Cultural and perceptual aspects | ✓ | – | – | – |
| | -Project planning and development | ✓ | – | ✓ | ✓ |
| | -Service quality | ✓ | – | – | – |
| | -Economic and social aspects | – | – | ✓ | – |
| Building type | | Residential buildings<br>Commercial buildings<br>Office buildings<br>Educational buildings<br>Other type of buildings<br>Urban planning | Residential buildings<br>Commercial buildings<br>Office buildings<br>Educational buildings<br>Other type of buildings<br>Urban planning<br>Industrial buildings | Residential buildings<br>Commercial buildings<br>Office buildings<br>Educational buildings | Residential buildings<br>Commercial buildings<br>Office buildings<br>Educational buildings<br>Other type of buildings<br>Urban planning<br>Industrial buildings |
| Assessed life cycle phase | | Construction<br>Post-construction<br>Use/Maintenance | Predesign and Design<br>Construction<br>Post-construction<br>Use/Maintenance | Predesign and Design<br>Construction<br>Post-construction | Predesign and Design<br>Construction<br>Post-construction<br>Use/Maintenance |

*Note: The symbol ✓ indicates that the tool includes the categories, whereas – indicates that it does not.

Iranian residential buildings. Therefore, in this paper, quantitative approach was used in a way that it represented the qualitative judgment of the decision maker as quantitative data [107]. Fuzzy-based techniques can be viewed as a generalized form of interval analysis to handle uncertain information. Moreover, it is evident that fuzzy-set theoretic approaches provide more flexibility to deal with variations among decision makers' judgments. The involvement of fuzzy theory allows an effective synthesis of group evaluations and derives meaningful and reliable priorities from heterogeneous groups [107]. The final step is to compare Iranian assessment tool with the existing ones in order to investigate the performance sensitivity of international assessment tools in terms of Iranian assessment tool. The aforementioned steps are briefly shown in Fig. 2 below.

Overall, to revise well-known sustainability categories and criteria points regarding the priorities in sustainability concerns of Iran, a methodology was needed. In this methodology, experts analyze, investigate, and compare sustainability categories and criteria to find optimization goals and actions to achieve Iranian sustainability assessment tool under certain conditions [108]. After reviewing the categories and criteria of the well-known sustainability assessment tools (qualitative analysis), priorities were set among the categories and criteria through the allocation of points. This could be possible by representing the qualitative judgments of the experts (decision makers) as quantitative data [109]. Therefore, various approaches such as ranking or point could be used to transform qualitative variables into quantitative units which could be reached through MCDM [110]. As a result, it was not possible for this research to reach accurate points without conducting quantitative decision analysis (MCDM technique). Most of the MCDM models are basically mathematical and ignore qualitative and often subjective considerations [111]. However, FAHP could make better decisions by taking into account qualitative and quantitative aspects of experts' decisions [112], since this method combines qualitative and quantitative system analysis to set the order allocation in realistic situations [111,113,114]. After the quantitative analysis, detailed information regarding sustainability issues was reached through qualitative analysis, in order to provide details regarding sustainability category impacts on environment of Iran and to reach solutions which experts recommended to address sustainability categories and criteria in Iranian residential buildings. Therefore, in this research, the technique of statistical analysis, which combines "qualitative-quantitative-qualitative" analysis, was employed to achieve a combination of quantitative and qualitative analysis [108].

### 3.2. Expert selection and sampling procedure

For the selection of experts, efforts were made in order to ensure clarity of the assessment according to the state of the art in sustainability field. Therefore, the experts were selected based on their experience towards residential buildings and sustainability construction from local universities, construction industry, and municipal organizations. The highly informed experts were carefully selected from the academicians and authorities, designers and building industry professionals, considering the following criteria:

- In possession of a formal professional title. For instance, decision-maker, manager, or practitioner in the field of sustainable construction and green building.
- Educated from or academic specialist of sustainability field such as professors and their role and influence on sustainable development practices.


**Fig. 2.** Research design.

- Had experience in positions such as policy making or governmental management in sustainability field and had influence in adoption of resulting methodology.
- Willingness to participate (these surveys are usually lengthy).

The detailed background of the selected experts with various professions can be seen through Table 2.

Since the stakeholders of residential buildings in Iran consist of Ministries such as housing and urban design, Iran Construction engineering organization, Supreme council of architecture and urban development, and municipalities, it was endeavored to select experts which had experience in the fields of policy making or governmental management. Therefore, the sample also benefits from academics with management experience in the Ministry of housing and urban design, environment and Supreme council of architecture and urban development. Moreover, all these experts are the members of Iran Construction engineering organization, which makes policy, standards & general rules for Iranian building construction. Therefore, the respondents are somehow the leaders in the field of green construction in Iran and this is why their opinions and judgments are of great importance, which can reflect practitioners' preferences of Iran.

For the sample size, many decision-making techniques e.g. Delphi, AHP (Analytical hierarchy process), FAHP, TOPSIS and etc., recommends rational sample size which is large enough to allow the patterns of responses to be clearly seen, without being so large to become complicated [115,116]. Since sustainability decision making process is very complex and multi-dimensional, research should not put statistical emphasis on the size of a sample, because this issue is not important to such techniques [117]. Instead, selecting experts with the capability, professional qualifications, considerable experiences, and knowledge should be the main goal in the field under investigation [118]. For instance, according to [115,116], various number of experts (from 10 to 50 members) can be used in a Delphi panel, which is said to be sufficient without any further complexity. Moreover, previous researches in the field of sustainability decision making process included specified sample size ranging from 30 to 103 [23,28,29,34,105,119,120]. Therefore, in this research, a total of 72 valid responses from experts and stakeholders, were received for analysis among 145 distributed questionnaires and involved in this revision of assessment tool suitable for Iran.

Since purposive sampling techniques were employed in accordance with the aforementioned expert selection criteria, the selection of experts resulted in 47% from construction organizations, 40% from municipality, and 13% from academia.

It is worth noting that few experts who have experience between 4 and 10 years of sustainable construction, have PhD education in the field of sustainability as well as being professional researchers of sustainable construction, contributing in state of art researches of sustainability. Therefore, most of the experts are PHD holders and can be represented as researchers as well.

### 3.3. *FAHP process*

Since 1970s, multi criteria decision making (MCDM) has been considered a prominent method to resolve decision-making problems related to multiple criteria [121], and has been used extensively for sustainability evaluation [40].

A considerable number of decision models based on the MCDM theory has been developed such as ANP (analytic network process) [122], DCA (discrete choice analysis) [123], TCO (total cost ownership) [124], DEA (data envelopment analysis) [125], TOPSIS (technique for order preference by similarity to ideal solution) [126], PROMETHEE

**Table 2**
Background information of stakeholders.

| Organization | Percentage | Role | Participant number | Experience in building sustainability | Qualification |
|---|---|---|---|---|---|
| Construction organizations | 47 | Contractor | 5 | +30 years | PHD-Master |
| | | | 2 | +20 years | PHD-Master |
| | | | 1 | 7 years | PHD |
| | | Consultant | 6 | +25 years | PHD-Master |
| | | | 3 | +15 years | PHD-Master |
| | | Environmentalist | 5 | +30 years | PHD-Master |
| | | | 1 | 25 years | Master |
| | | | 1 | 17 years | PHD |
| | | | 1 | 10 years | PHD |
| | | Project manager | 6 | +30 years | PHD-Master |
| | | | 3 | +20 years | PHD-Master |
| Municipal organizations | 40 | Supervisor | 7 | +30 years | PHD-Master |
| | | | 2 | +25 years | Master |
| | | Engineer | 6 | +30 years | PHD-Master |
| | | | 2 | +20 years | PHD-Master |
| | | | 1 | 10 years | PHD |
| | | | 1 | 5 years | PHD |
| | | Architect | 1 | 31 years | Master |
| | | | 5 | +20 years | PHD-Master |
| | | | 2 | +10 years | PHD-Master |
| | | | 1 | 8 years | PHD |
| | | | 1 | 4 years | PHD |
| Academia | 13 | Professors[a] | 7 | +25 years | PHD-Master |
| | | | 2 | +15 years | PHD-Master |
| Total | 100 | | 72 | | |

[a] These professors selected in a manner that had significant management and policy making experiences in the field of sustainability.

(preference ranking organization method) [127], ELECTRE (elimination et choice translating reality) [128], and AHP. However, according to Saaty [129] and Hochbaum & Levin [130], AHP method is considered a prominent method to solve decision-making problems and is the leading approach used for MCDM [131]. According to researches conducting comparative analysis between various MCDM models, AHP is realized to be more preferable in this study when compared to other models. For instance, according to a comparative study conducted by Velasquez & Hester [132], TOPSIS model is difficult to weight and keep consistency of judgments, or PROMETHEE does not provide a clear method by which the weights can be assigned. While, AHP is easy to use, scalable, and the hierarchy structure can easily be adjusted to fit many sized problems.

AHP method uses pairwise comparisons on the judgments of experts by employing linguistic variables assigned with numerical values from 1 to 9 [131,133]. However, AHP alone is not adequate to deal with the fuzziness of human subjective judgments [43,134,135]. Moreover, it has difficulty with interval judgments to implement in real-life problems [132]. In order to resolve ambiguities, Fuzzy-AHP (FAHP) method is used in this study, since, in such cases, application of fuzzy logic integrated with classic AHP method is appreciated in most of the studies [136,137]. Moreover, fuzzy revised AHP is the best fuzzy MCDM method amongst the well-known fuzzy MCDM methods investigated by Ref. [138].

Buckley (1985) incorporated a fuzzy matrix into the AHP method, so that vagueness in the response of people involved in decision-making can become integrated, getting closer to human reality and providing decision-making analysis with more validity [49]. FAHP method is amongst the mostly used methods for sustainability assessment (e.g. Govindan et al., [41,42]; Chen and Fan, [43]) [135]. However, the most important criticism of this method concerns the impossibility of including value judgments not on a continuous scale but rather on a discrete one which can be solved by fuzzy logic. This problem was resolved by using the fuzzy logic extension of the AHP method proposed by Chang [139]. This is because, among FAHP methods (e.g. Chang [139], Csutora and Buckley [140]), Chang's method deemed to be the most widely accepted one for research studies [133,139,141–143]. Therefore, for the comparison, matrices are formed with the aid of questionnaire for experts to compare categories based on linguistic variables. When the organization of fuzzy pairwise comparison matrices are done by experts, linguistic judgments will be converted into triangular fuzzy numbers [144,145], for the reason of their popularity among researchers [146,147] to obtain weights of each sustainability category.

The research methodology to obtain final scores of sustainability assessment tool of Iranian residential building for new construction will be illustrated in detail in the sections below.

In this research, scores from experts were first obtained through FAHP questionnaires. The questionnaires were devised based on the common variables of international assessment tools introduced previously in section 2. In these questionnaires, pairwise comparison questions were asked to compare entities in pairs to judge which of each entity (category and criteria) is preferred, or has a greater amount of some quantitative priority. Judgments by linguistic variables were converted to triangular fuzzy numbers (TFNs) using membership functions (Fig. 4). The questionnaire survey was developed in two types of paired comparisons of categories and criteria in which experts compared each category with another category and each criterion with another criterion. The hierarchy structure of questionnaires included three levels of main goal, categories and criteria to be prioritized by experts (Fig. 3). The main goal indicates the objective of the research and the second and third levels are those variables which should be compared with another variable of their level for prioritization of the variables regarding the defined goal.

After the scores were obtained from experts, the FAHP steps were implemented based on Chang's extend method [147] as follows:

According to Chang's extend method [147], if $X = [1 \times n]$ is an object set and $U = \{u_1, u_2, ..., u_n\}$ is a goal set, each object is taken as extensive analysis against each goal ($g_i$). Therefore, extend values for object is $M_{g_i}^1, M_{g_i}^2, ..., M_{g_i}^m (i = 1,2,...,n)$ , which are TFNs ($l_{ij}$, $m_{ij}$, $u_{ij}$).

In the first step, for fuzzy synthetic extend value, pairwise comparison of questionnaire determined relative importance of each pair of

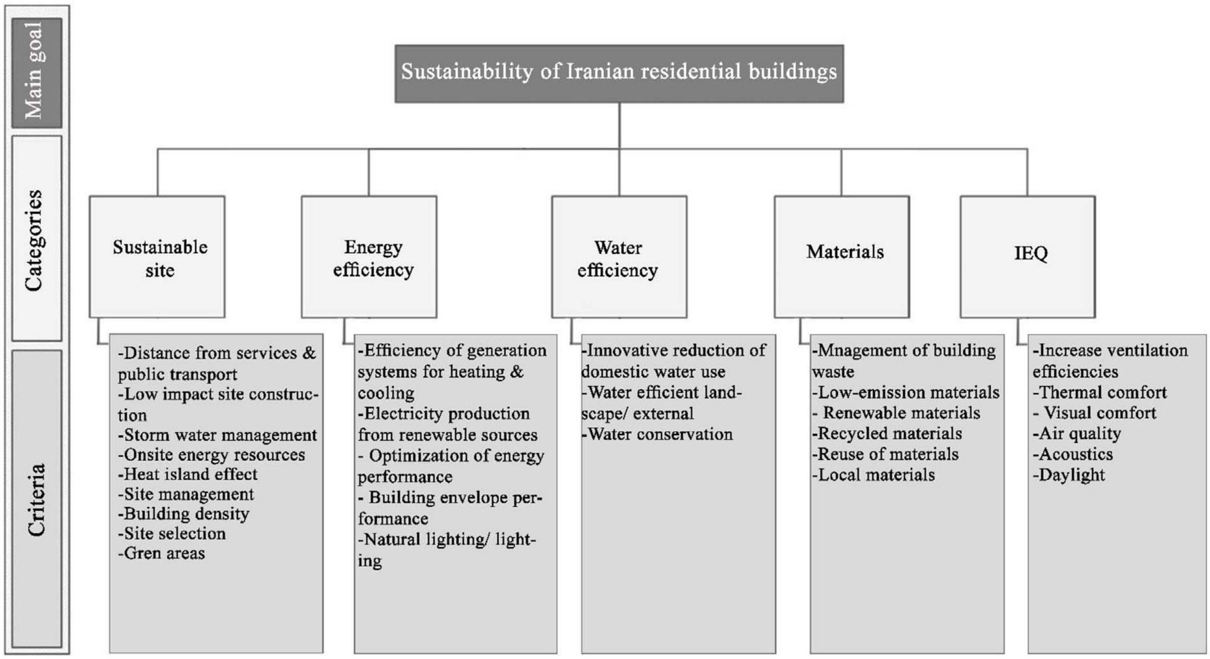


**Fig. 3.** Proposed hierarchy structure developed in three levels.

**Table 3**
FAHP linguistic scale.

| Linguistic scale | Triangular fuzzy scale | Triangular fuzzy reciprocal scale |
|---|---|---|
| Equally important | (1,1,1) | (1,1,1) |
| Weakly important | (1,3,5) | (1/5,1/3,1) |
| Strongly important | (3,5,7) | (1/7,1/5,1/3) |
| Very strongly important | (5,7,9) | (1/9,1/7,1/5) |
| Absolutely important | (7,9,9) | (1/9,1/9,1/7) |

categories from a set of triangular fuzzy scale illustrated in Table 3.

Then fuzzy synthetic extend value of the rows of the pairwise comparison, $S_i$, will be calculated from the following equation:

$$Si = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \quad (1)$$

where $i$ is the row of matrices and $j$ represents the column number.

In order to facilitate the understanding of triangular fuzzy scale, membership functions of five levels of FAHP linguistic scale is shown in Fig. 4.

The values of $\sum_{j=1}^{m} M_{gi}^{j}$, and $\left(\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right)^{-1}$ could be determined through Eqs. (2) And (3), respectively.

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_{ij}, \sum_{j=1}^{m} m_{ij}, \sum_{j=1}^{m} u_{ij}\right) = (l_l', m_l', u_l') \quad (2)$$

$$\left(\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right)^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_l'}, \frac{1}{\sum_{i=1}^{n} m_l'}, \frac{1}{\sum_{i=1}^{n} l_l'}\right) \quad (3)$$

In the second step, the calculation of possibility degree between two TFNs will be conducted that is shown in Fig. 5. For fuzzy numbers of $S_1 = (l_1, m_1, u_1)$ and $S_2 = (l_2, m_2, u_2)$, possibility degree, $V\,(S_1 \geq S_2)$, is calculated in Eq. (4):

$$V\,(S_1 \geq S_2) = Highest\,(S_1 \cap S_2) = \mu_{S_1}(d)$$

$$\mu_{S_1}(d) = \begin{cases} 1 & if\,(m_1 \geq m_2) \\ 0 & if\,(l_2 \geq u_1) \\ \frac{l_2 - u_1}{(m_1 - u_1) - (m_2 - l_2)} & otherwise \end{cases} \quad (4)$$

where $d$ is the ordinate of the highest intersecting point between $\mu_{s1}$ and $\mu_{s2}$.

In the third step, degree of possibility for convex fuzzy number greater than $k$ convex fuzzy numbers $S_i$; $i = 1,2, \ldots, k$ could be obtained from the following equation:

$$V\,(S \geq S_1, S_2, \ldots, S_k) = V\,((S \geq S_1), (S \geq S_2), \ldots (S \geq S_k))= Min\,(V\,(S \geq S_1), V\,(S \geq S_2), \ldots, V\,(S \geq S_k)) = Min\,(V\,(S \geq S_i)) \quad (5)$$

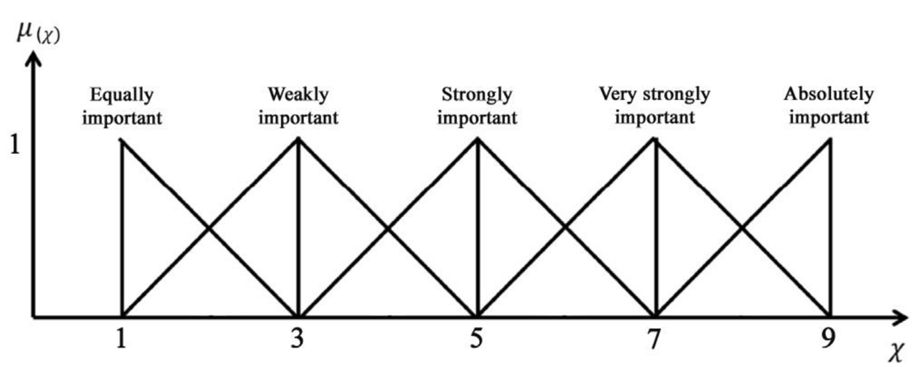


**Fig. 4.** Membership functions of the linguistic variables for criteria comparisons.

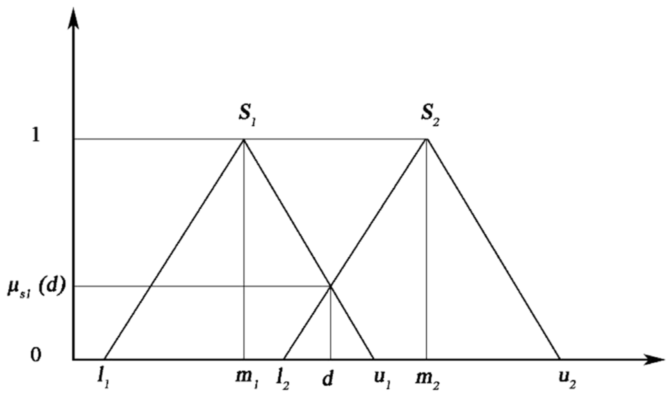


**Fig. 5.** Possibility degree between fuzzy numbers $S_1$ and $S_2$.

If $k = 1,2, \ldots, n\ (k \neq i)$, $d'(A_i) = \min(V(S_i \geq S_k))$, measurement of the weight vectors of the categories and criteria are as follows:

$$W' = (d'(A),\ d'(A_2)\ldots,d'(A_n))^T; \quad A_i(i = 1,2,\ldots,n) \tag{6}$$

In the Fourth step, normalized final weight vectors of individual category will be calculated through following equation.

$$W = (d(A),\ d(A_2),\ldots,\ d(A_n))^T \tag{7}$$

where $W$ is a non-fuzzy number and a local priority weight that is comparable with all other normalized weights calculated for categories and criteria.

In order to obtain the final rankings of criteria of each category, the global priority weights are needed. For the derivation of mathematical index for calculating global priority weights of criteria, local weights categories and criteria are needed. Therefore, after the calculation of the local priority weights of the categories and criteria, global priority weights can be calculated through the following equation:

$$W_G = W_{C1} \times W_{C2} \tag{8}$$

where $W_G$ is a global priority weight, $W_{C1}$ *and* $W_{C2}$ are category and criterion local weights, respectively.

### 3.3.1. Validation of results

It should be noted that the results based on the decision makers' judgments, might be affected by the lack of knowledge. However, the inconsistency associated with judging the importance of categories in these methods could be resolved by measuring the degree of consistency in the decision makers' judgments [148]. The consistency ratio equation could be found in the research employed by Saaty [149]. Moreover, to obtain consistency ratio (*CR*), the random consistency index should be calculated based on Kahramn's research [107]. If $CR < 0.1$, the compatibility of the matrix is accepted, otherwise, the inconsistent elements in the comparison matrix should be revised.

## 4. Calculation of FAHP model

FAHP procedure explained in Section 3.2.1 was applied to determine the categories and criteria weights. By using the fuzzy scale shown in Table 3, 72 experts were asked to make pairwise comparison of the relative importance of categories and criteria. Firstly, the experts compared categories with respect to sustainability index through questionnaires. Then, they compared the criteria with respect to the categories. As shown in Table 4, the judgments from the experts were combined using operational laws for two TFNs, using Eq. (4). After that, through Eq. (7), the fuzzy numbers were converted into normalized final weights. Owing to space constraints, the summary of normalized vector weights of categories and criteria were presented in Table 5, which were calculated based on Chang's FAHP steps.

For the verification and consistency of the experts' judgments regarding weight determination, maximum eigenvalue was calculated in a way that the priority vector weights from Table 4 were multiplied by the judgments' values of Table 4. The maximum eigenvalue was $\lambda_{max} = 5.2761$. The consistency index (*CI*) was then calculated 0.0690. According to Kahraman [107], for the matrix size of $n = 5$, *RI* is equal to 1.12. As a result, the *CR* developed at the final step equals 0.0616, which is consistent. After the consistency test, Chang's FAHP was applied to obtain the normalized weight vector (W) of each dimension and criteria.

It should be noted that to conduct Eq. (8), which is used to set scores for Iranian building assessment tool, the weights of the criteria were calculated. Therefore, in addition to local weights, the global priority weights of criteria needed to be calculated to quantify environmental performance through the final score of residential buildings in terms of sustainability, which is shown in Table 6. The local and global weights can also be seen through Figs. 6–10 in section 5.

The same steps were implemented for prioritization of related criteria. However, due to space constraint for the criteria matrices, final weights will only be shown in the next section.

## 5. Results and discussion

As described previously, major categories of mostly used existing assessment tools were selected and evaluated by professional local experts. The FAHP results for these categories are illustrated in detail in this section. Each category was compared with another category to obtain the degree of their importance in the field of Iranian residential new construction.

After the local priority weight calculations above, the global priority weights of criteria suggested by experts, as well as the overall results could be obtained through Eq. (8). These results will be used to set scores for assessment tool to be adapted as a guideline by building practitioners to evaluate Iranian residential building's sustainability performance. The results are shown in Table 6.

The priority arrangement of categories from the most important to the least is energy efficiency, water efficiency, sustainable site, materials and resources, and indoor environment quality which are shown in Table 6. Moreover, the priority weights of related criteria suggested by experts were obtained through FAHP process. Local experts stated that all the suggested criteria are important to be considered in the assessment tool for Iranian residential buildings, which will be further discussed in the next sections.

### 5.1. Iranian sustainability assessment tool for residential buildings

As a starting point, including main categories and criteria of the well-known international assessment tools for the evaluation of sustainability building performance could contribute to the better establishment of Iranian assessment tool. For this purpose, common categories and criteria were prioritized based on the local experts' viewpoints towards sustainability issues concerned new residential buildings in Iran. This tool is proposed in order to be utilized as an assessment system for Iranian residential buildings as well as promoting sustainability performance of such buildings. In this system, based on the LEED, BREEAM, CASBEE and SBTool, local experts suggested the assessment scale which is presented in Table 7. Despite the fact that the scale of 39 is the minimum acceptable score for the sustainability of Iranian residential buildings, no award will be considered for these buildings ranging from 39 to 44, and such buildings will be only certified for achieving minimum requirements of sustainability. Although buildings which attain the scores ranging from 39 to 80 will be considered as certified sustainable buildings, the experts recommended a scale ranging 45 to 100 (Good to Outstanding) to be satisfactory score for Iranian residential buildings and from their point of view, awards should be recommended for such buildings (Fig. 11). These certification levels could be obtained through the scores summation of categories

**Table 4**
Iranian sustainability assessment categories' final pairwise comparison matrix.

| Assessment categories | Energy efficiency | Water efficiency | Sustainable site | Materials and resources | Indoor environmental quality |
|---|---|---|---|---|---|
| Energy efficiency | (1,1,1) | (1,3,5) | (3,5,7) | (5,7,9) | (7,9,9) |
| Water efficiency | (1/5,1/3,1) | (1,1,1) | (3,5,7) | (3,5,7) | (7,9,9) |
| Sustainable site | (1/7,1/5,1/3) | (1/7,1/5,1/3) | (1,1,1) | (1,3,5) | (3,5,7) |
| Materials and resources | (1/9,1/7,1/5) | (1/5,1/3,1) | (1/5,1/3,1) | (1,1,1) | (3,5,7) |
| Indoor environmental quality | (1/9,1/9,1/7) | (1/9,1/9,1/7) | (1/7,1/5,1/3) | (1/7,1/5,3) | (1,1,1) |

and criteria from Table 6. The main categories and their weights are shown as percentage scores in Fig. 12. Overall, sustainability performance of Iranian residential buildings could be calculated through Eq. (9). As can be seen through the aforementioned equation, score range is from 0 to 100.

**Residential sustainability performance score** = 0.175*(site selection score) + 0.301*(energy efficiency score) + 0.281*(water efficiency) + 0.150*(materials and resources) + 0.093*(Indoor environment quality) (9)

### *5.2. Comparison of Iranian assessment tool with the existing assessment tools*

The comparison of ISAT and international sustainability assessment tools were shown in Table 8 below. Since each of the existing assessment tools is developed in accordance with local context, the scores allocated for the common categories vary in different countries. Therefore, in this section, comparative analysis of the allocated points will be conducted and in the next section, investigation of the reasons behind the differences and similarities of Iranian category points and international category points will be situated by further investigating reasons of locality.

Table 8 shows the average difference of scores of international assessment tools with Iranian sustainability assessment tool (ISAT). In order to better realize the similarities and differences, the performance sensitivity of existing tools in terms of ISAT categories has been shown through Fig. 13. Besides, the sensitivity of the average score in terms of ISAT categories could be seen through Fig. 14. It is worth noting through these figures that energy efficiency category sensitively affect the sustainability of residential buildings worldwide. Other tools emphasize on indoor environment quality more sensitively. While, in ISAT, water efficiency plays much more crucial role compared to other assessment tools. Therefore, major differences could be seen in the category namely water efficiency of existing tools and Iranian assessment tool. In Iranian tool, water efficiency is 23 points more than the average point of other tools. Unlike the highlighted difference, similarities exist for some categories. For instance, ISAT gave approximately the same score as LEED, by giving 30.1 points to energy efficiency category. Nevertheless, all assessment tools consider energy efficiency category as the most important issue by giving more scores to the category. Overall, the two categories of energy efficiency and water efficiency were considered to be the most important categories for Iranian experts for residential buildings' sustainability, accounting for the half of the total score (58.2%). The scores of two categories of sustainable site and materials and resources in ISAT, were almost the same as the existing tools with only the average differences of 3.4 and 2 points, respectively. Indoor environment quality category, with the score of 9.3 was the least important category in ISAT compared to other assessment tools. However, it should be noted that all these category scores were above 9 points, which ascertains the experts' emphasis on all the categories to be considered in sustainability assessment of Iranian residential buildings. Justification of the mentioned results will be given in the next section.

Overall, it could be concluded from the results that development of an assessment tool adapted to specific country is a necessity with respect to local context and the country's sustainability issues.

Results are in line with previous researches which investigated sustainability benchmarks and features of traditional houses of Iran. Previous research works enrich the proposed localized features of the sustainability assessment tool in Iran. For instance, the utilization of renewable energy as well as the consideration of the passivity potentials were situated in most of these Iranian international houses [3,45,46,52,150,151]. This major attention was given through utilization of renewable solar and wind energies for passive heating and cooling, energy efficient insulation and etc. [3,152]. This can explain the priority given to Energy efficiency for contemporary residential buildings of Iran. Since, most of the Iranian sustainable traditional houses were energy efficient in the first place. According to principles extracted by Ref. [45], most important sustainability issues which have made these houses sustainable are in line with the proposed localized features of the sustainability assessment tool in Iran. The first and foremost principle was concluded to be 'energy conservation'. This issue can be related to Energy Efficiency category of the proposed Iranian sustainability assessment tool, since, the goal of the aforementioned principle was to minimize the need for fossil fuels in Iranian traditional houses [45]. The second principle of Iranian sustainable traditional houses was 'working with climate' in which traditional buildings conserved water as well as benefiting from sustainable site [50,153]. This issue can be related to Water Efficiency and Sustainable site in the proposed Iranian sustainability assessment tool, since, the goal of the aforementioned principle was to conserve water and to benefit from sustainability of the site such as sun, vegetation, orientation, etc. [45,154,155]. The third principle was 'Minimizing new resource' in which traditional houses utilized recycled and local material throughout their construction [156]. This issue has been addressed in the category of "Materials and resources" in Iranian sustainability assessment tool. The last principle which was considered in the environmental sustainability feature of traditional houses was 'respect for users' in which human comfort (visual & thermal) and ventilation were situated [45]. This issue can be related to 'Indoor environment quality', which is proposed in the assessment process of sustainability performance of Iranian residential buildings. Therefore, the mentioned categories can be regarded as important sustainability issues for the sustainable residential building of Iran.

**Table 5**
Normalized local weights of the assessment categories.

| Sustainability categories | Energy efficiency | Water efficiency | Sustainable site | Materials and resources | Indoor environmental quality | Total |
|---|---|---|---|---|---|---|
| Weights | 0.301 | 0.281 | 0.175 | 0.150 | 0.093 | 1.00 |
| Percentage (%) | 30 | 28.1 | 17.5 | 15 | 9.3 | 100 |

**Table 6**
Final weights of sustainability categories and criteria for Iranian residential building assessment tool.

| Sustainability categories | Local priority weight ($W_{C1}$) | Category scores (%) | Sustainability criteria | Local priority weight ($W_{C2}$) | Global priority weight ($W_G$) | Criteria scores |
|---|---|---|---|---|---|---|
| Sustainable site | 0.175 | 17.5 | On site energy resources | 0.185 | 0.032 | 3.2 |
| | | | Building density | 0.171 | 0.030 | 3 |
| | | | Low impact site construction | 0.162 | 0.028 | 2.8 |
| | | | Heat island effect | 0.143 | 0.025 | 2.5 |
| | | | Distance from services & public transport | 0.123 | 0.022 | 2.2 |
| | | | Storm water management | 0.102 | 0.018 | 1.8 |
| | | | Site management | 0.093 | 0.016 | 1.6 |
| | | | Site selection | 0.021 | 0.004 | 0.4 |
| Energy efficiency | 0.301 | 30.1 | Electricity production from renewable sources | 0.251 | 0.076 | 7.6 |
| | | | Building envelop performance | 0.204 | 0.061 | 6.1 |
| | | | Efficiency of generation systems for heating & cooling | 0.196 | 0.059 | 5.9 |
| | | | Optimization of energy performance | 0.183 | 0.055 | 5.5 |
| | | | Natural lighting/lighting | 0.166 | 0.050 | 5 |
| Water efficiency | 0.281 | 28.1 | Innovative reduction of domestic water use | 0.370 | 0.104 | 10.4 |
| | | | Water efficient landscape/external | 0.332 | 0.093 | 9.3 |
| | | | Water conservation | 0.298 | 0.084 | 8.4 |
| Materials and resources | 0.150 | 15 | Low emission materials | 0.234 | 0.035 | 3.5 |
| | | | Renewable materials | 0.221 | 0.033 | 3.3 |
| | | | Recycled materials | 0.199 | 0.030 | 3 |
| | | | Reuse of materials | 0.157 | 0.024 | 2.4 |
| | | | Local materials | 0.120 | 0.018 | 1.8 |
| | | | Management of building waste | 0.069 | 0.010 | 1 |
| Indoor environment quality | 0.093 | 9.3 | Air quality | 0.277 | 0.026 | 2.6 |
| | | | Daylight | 0.248 | 0.023 | 2.3 |
| | | | Thermal comfort | 0.195 | 0.018 | 1.8 |
| | | | Acoustics | 0.141 | 0.013 | 1.3 |
| | | | Visual comfort | 0.139 | 0.013 | 1.3 |
| Σ | 1.000 | 100 | | | 1.000 | 100 |

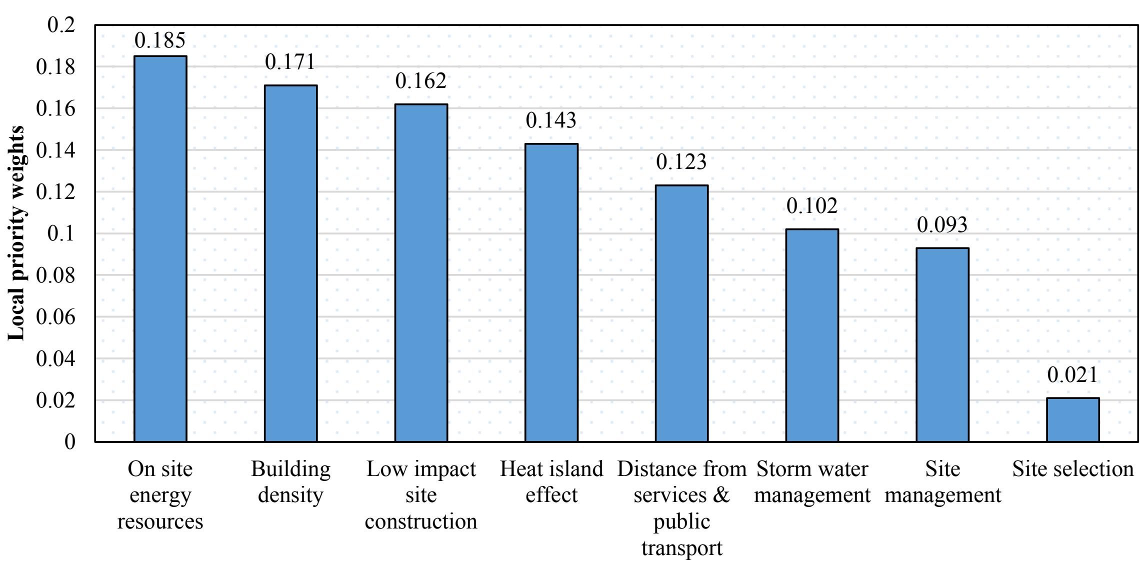


**Fig. 6.** Local weights of the assessment criteria of sustainable site.

### 5.3. Evident effects of the categories on the environment in Iran

As stated previously, for developing countries such as Iran, the awareness should be increased by developing a sustainability building assessment tool suitable for Iranian local context. Weights of the categories can be better defined with their evident effect on the environment. Since the effect on the environment varies according to the climatic conditions from a location zone to the other, this section will compare the effect of the climatic and other specificities to the case of Iran with other international tools. In this section, categories and three most important criteria of each category, which were emphasized by the experts, will be more discussed. As shown in Table 8, the similarities and differences exist among category points of ISAT and other international tools, which will be discussed in order to reach the reasons behind this fact.

#### 5.3.1. Energy efficiency

Energy Efficiency was weighted as most important category in all of the assessment tools including Iranian sustainability assessment tool. Evident effect of energy use on the environment has been pointed out by many international organizations. For instance, in 2009, United Nations Environment Programme [157] asserted that residential

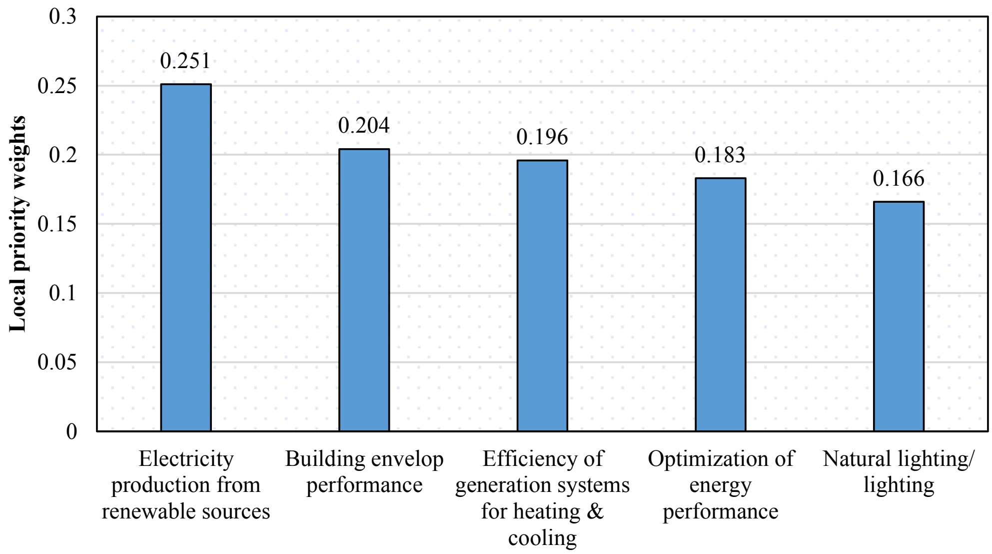


**Fig. 7.** Local weights of the assessment criteria of energy efficiency.

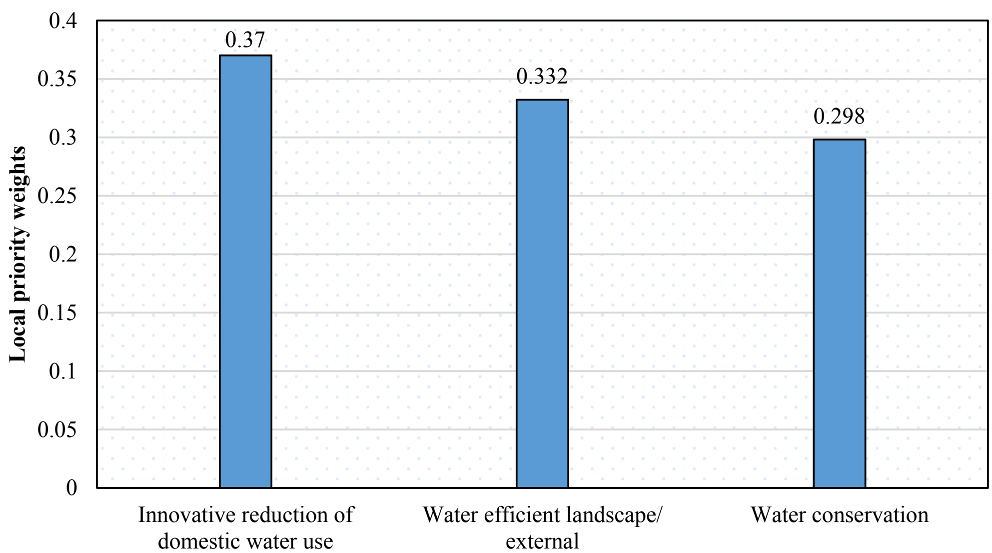


**Fig. 8.** Local weights of the assessment criteria of water efficiency.

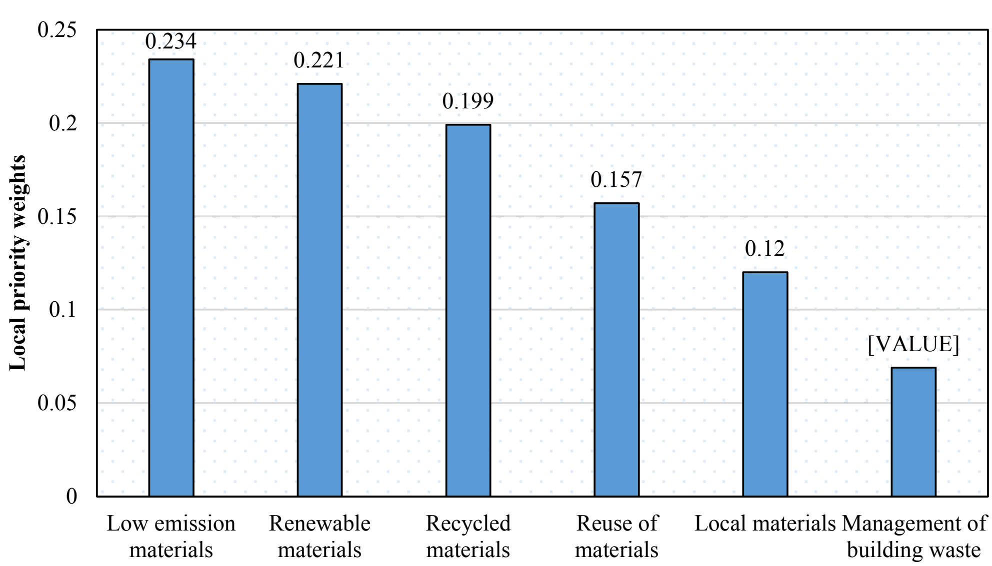


**Fig. 9.** Local weights of the assessment criteria of materials and resources.

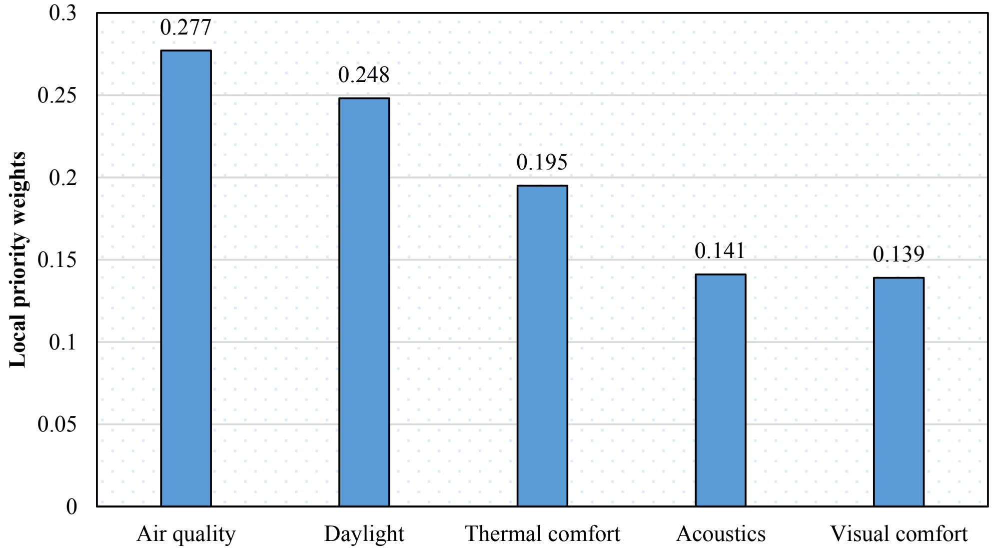


**Fig. 10.** Local weights of the assessment criteria of Indoor environment quality.

**Table 7**
Iranian residential sustainability performance ratings.

| Level of certification | Scores |
|---|---|
| unsatisfactory | < 39 |
| Minimum acceptable | ≥39 |
| Good | ≥45 |
| Very good | ≥55 |
| Excellent | ≥65 |
| Outstanding | ≥80 |

buildings use 40% of the global energy which is considered to be critical situation to be addressed in the future sustainable buildings. Moreover, Global Climate Legislation Study in 2015 stated that energy sector is responsible for about 77% of overall GHG emission [44]. This rising energy consumption has caused environmental damages as well as the deterioration of health condition [158]. Despite the major endevoures to better address energy efficiency of sustainable buildings in developed countries, priority is still given to this category by all of the well-known assessment tools, since international institutions and agencies stated that many regions in the world do not have sufficient access to energy [159]. Another reason is the reports of a study stating that energy savings will lead to a 45% reduction in $CO_2$ equivalent emission by 2030, comparing to the business as usual (BAU) trend [158]. On the other hand, Iran as the fourth largest producer of gas and oil, consumes 1% of renewable resources for the energy production [160]. Finding suitable alternative sources is crucial for reducing fossil fuels which globally have an immense contribution in the energy use [161]. Therefore, energy efficiency is one of the solutions which Iranian governors try to reach by increasing renewable resources [158]. It can be concluded from this evidence that one of the sustainability concerns of Iranian policymakers is to optimize energy use of buildings, especially in the residential sector, by increasing sustainable renewable energy use [161]. However, due to renewable energy potentials in Iran, e.g. wind, solar, geothermal and biomass, residential buildings can benefit from these opportunities [162]. Under the efficiency scenario, Iran will be able to reduce its energy consumption and energy intensity by approximately 40 and 60 (lower than the world average) percent by 2030, respectively [158]. Therefore, priority is also given to Iranian assessment tool's energy efficiency category to make building practitioners aware of this issue.

In addition to the calculation of category weights, related criteria of each category were obtained in this research. For energy efficiency category, the three most crucial issues for residential sustainability, which all the practitioners should be aware of, were believed to be electricity production from renewable sources, envelop performance, and efficiency of heating & cooling systems.

The average household electricity use at the end of the year 2014 increased by 93% compared to 2013, indicating a higher consumption of energy in domestic sectors [163]. According to Ministry of Energy in Iran, while the average household electricity use in the world is 900 kW, the amounts of electricity use in Iran is three times more than the global standards [164]. Electricity production from renewable energy was recommended by experts to lower the dependency of residential sector on fossil fuel consumption for energy generation in Iran. Therefore, additional attention should be given to renewable energies of the country for electricity production, since many studies have indicated the high potential of Iran regarding the renewable energy supply [153,155,165–169].

A variety of natural resources in different regions of Iran can be considered as the main sources of renewable energy as well as the supplementary energy in the Iranian energy mix policies [165,170].

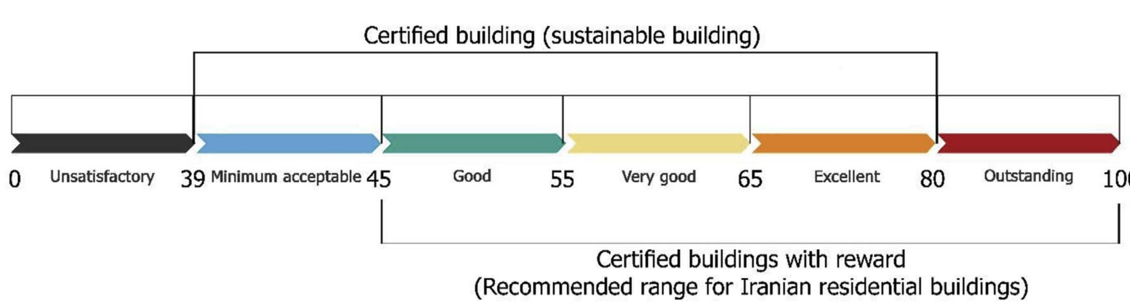


**Fig. 11.** ISAT certification range.

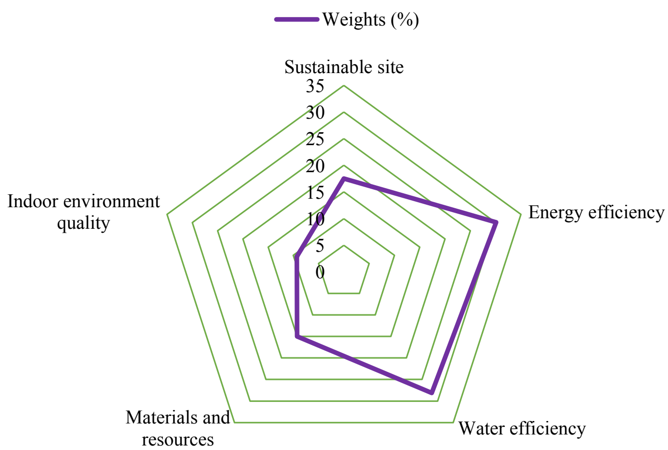


**Fig. 12.** Category weights of Iranian residential sustainability assessment tool.

Many of these renewable potentials stem from regional conditions of Iran. For instance, the diversity of climate and terrain in Iran are the fundamentals for the cultivation of various energy crops for biodiesel production and around 7% of Iran has been covered with forest which can be great sources for biofuel products [170]. The geographical conditions of Iran show the strong air flow in different months of winter and summer due to its low air pressures compared to the high air pressures in the north and northwest parts of the country [171]. Despite the high capacity of wind energy in Iran, wind power plants have not been developed with respect to expectations in this country [172], which is too insignificant compared to developed countries such as USA, China, and Germany with the capacity of more than 27,000 MW [153]. A study conducted in Iran, showed that 26 locations of the country have the potential to construct wind power generators which could have about 6500 MW energy [173,174]. Solar energy is another clean energy resource which could be consumed in Iran through various technologies including solar heating, thermal electricity and photovoltaic [175]. Iran enjoys 2800 sunny hours per year with the solar insulation average rate of 2000 kWh/m2 year, since it is located on the world's Sun Belt [176]. For instance the south, northwest and southeast regions of Iran receive around 300 days of sun per year, suited for solar energy [177]. In this regard, the country's Sixth Development Plan provided for the installation of 500 MW of new solar capacity by 2018 [178]. Studies showed that central parts of Iran have immense capability to utilize solar and wind energy due to the hot and dry climate [179]. Another way for electricity production suggested by experts was electricity generation by geothermal with a low-cost opportunities. For instance, Sabalan, Sahand, Damavand, Maku-Khoy and Sareyn regions have potentials for electrical generation through geothermal [171]. According to experts, geothermal potential is situated by various studies for Iran in northern provinces with several hot water springs, which their temperature reach 85°C. According to a study, development of geothermal energy in Iran could be reached in 14 separate geographies, including nearly the entire country [180]. Out of these renewable energy sources indicated, experts suggested that wind and

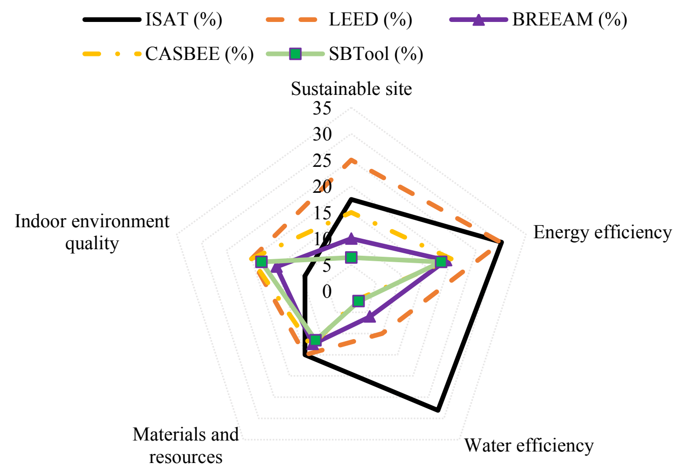


**Fig. 13.** The performance sensitivity of LEED, BREEAM, CASBEE, and SBTool interms of ISAT categories.

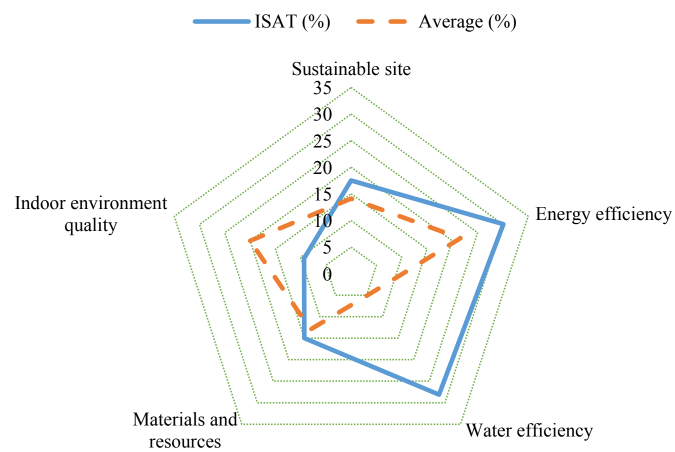


**Fig. 14.** Sensitivity of the average score in terms of ISAT categories.

solar energy technology, has great potentials in terms of electricity generation for Iranian residential buildings.

Another two crucial criteria are Building envelop performance and Efficiency of heating & cooling systems. Experts believe that due to the lack of insulation of the building envelope, a significant amount of energy loss is encountered by residential buildings in Iran. Statistics show that the approximate average of 35% of energy loss from the sidewalls, 25% from ceiling, 10% from floors and 25% from windows and doors is occurred in Iran, which play a crucial role in saving energy in residential sector [181]. On the other hand, Iran lacks efficiency of systems in a way that after ten years of implementation of the standard requirements and energy labeling heaters, the country's major heater products still have F or G classifications or even no energy label. Therefore, high efficiency systems (HVAC system-lighting- hot water) considered to be another important subject for residential buildings in

**Table 8**
ISAT comparison with international assessment tools.

| Sustainability assessment tool | Energy efficiency | Water efficiency | Sustainable site | Materials and resources | Indoor environment quality |
|---|---|---|---|---|---|
| ISAT (%) | 30.1 | 28.1 | 17.5 | 15 | 9.3 |
| LEED (%) | 30 | 10 | 25 | 15 | 20 |
| BREEAM (%) | 19 | 6 | 10 | 12.5 | 15 |
| CASBEE (%) | 20 | 2 | 15 | 13 | 20 |
| SBTool (%) | 18 | 2.4 | 6.4 | 11.6 | 18 |
| Average score of assessment tools' category | 21.6 | 5.1 | 14.1 | 13.0 | 18.3 |
| ISAT difference from average | +8.5 | +23 | +3.4 | +2 | −9 |

this country.

#### 5.3.2. Water efficiency

Another important category regarding local context of Iran which has a difference of 1.3 points when compared to Energy Efficiency category, is Water Efficiency. According to the World Health Organization, great number of those affected by water scarcity and sanitation issues in the world, live in developing countries [182]. In other words, issues surrounding water usage are significant in most of the developing countries [183] such as Iran. For instance, unlike the developed countries, one-fourth of the country comprises deserts [184]. On the other hand, this category is amongst the least important category in the international sustainability assessment tools. This difference lies on the climatic reasons. The government blames the present crisis on the changing climate and frequent droughts in Iran [184]. Moreover, the seasonal characteristic of rainfall in Iran has led to a rainy season between October and March, leaving the land parched for the rest of the year [185]. Unequal distribution of water in Iran has resulted in water shortages in this country. Iran is located in West Asia, bordering the Caspian Sea in the north and near this sea, rainfall averages 1280 mm per year, but this rainfall rarely exceeds 100 mm in the Central Plateau and the lowlands to the south [186]. Moreover, the annual renewable water per capita of Iran is decreased from 7000 $m^3$ in 1956 to currently less than 1700 $m^3$ [184], whereas in European countries, the annual renewable water per capita is higher than the aforementioned amount [187]. It should be noted that in 2004, 92% of water was used for agricultural purposes, 6% for domestic use and 2% for industrial use [188]. Although this is equal to nearly half of the percentage of actual available renewable water resources, annual abstraction from aquifers (53 BCM in 2004) is currently more than the expected safe yield which is 46 BCM [188]. Also, Potable water consumption for domestic use in the country is 70% over the global average [187]. Therefore, according to statistics, Iran suffers from water scarcity. Experts relate this problem to the inadequate natural water resources to supply a region's demand which is called physical (absolute) water scarcity [183]. Therefore, incorporating the efficient use of water into building design and securing water supply are essential [183] to reach sustainable buildings in Iran.

Experts recognize the need for wastewater consumption and alternative source water criterion for water efficiency and innovative reduction of domestic water use in residential buildings in Iran. For instance, using gray water, rainwater and storm water for non-potable water needs, e.g. toilet flushing or garden use, were among the expert's recommendations. Moreover, there are guidelines for non-potable and alternate water sources for residential on-site water reuse, which can be referred to [189]. Experts also recognize the efficiency of water use for landscape as another crucial consideration for residential buildings. One of the efficient solutions suggested was to create rain gardens in the residential external landscape. Therefore, by collecting and using rainwater that would otherwise run off the landscape, rain gardens receive runoff water from roofs of the residential buildings [190]. This approach will not only lead to a water conservation, but also will create attractive vista for residential buildings.

#### 5.3.3. Sustainable site

Experts believed that sustainable site and location are of the primary considerations in construction proceedings, since, sustainable construction begins with appropriate location choice. Thery believe that through an appropriate location of residential buildings, one can reach sustainable solutions. For instance, a study was conducted by Ref. [191] encouraged effective passive cooling design strategies in one of the hot and arid cities of Iran through flexibility in design (e.g. adjustable shading), so that the strategies for the cooling season do not have negative effects in the heating season.

Among the most crucial criteria for sustainable site category, site energy resources and building density were considered by local experts. As statde previously, potential of on-site energy resources to be used for electricity generation is high in Iran. Accordingly, wind and solar energy technologies are deemed to be amongst the useful solutions in Iran, due to the reasons of locality. According to experts' point of view, building density is another issue which should be considered in residential construction in Iran. Due to the high-density construction permission in Iran, sustainability of the site have negatively been affected, which should be noted by Iranian construction experts [192]. Unfortunately, there are policies and decisions of the municipality in selling densities which will increase the demolition of the existing buildings [193]. As a result, constructors can buy density to destroy low-density buildings, which will harm natural environment. Therefore, experts believed that constructors should be aware of the harm imposed on environment by these kinds of policies on sustainability of residential buildings in Iran, especially Tehran.

Another issue to be considered is that the majority of residential buildings in Iran are constructed using traditional onsite methods of construction. High waste and low quality as well as deforestation and extreme soil extraction, are deemed to be the major environmental damage of these methods of construction in Iran [194]. Therefore, experts focused on ‘Low impact site construction’ category in order to be addressed in Iranian residential building construction. Offsite construction can be regarded as a potential solution to this issue in Iran [195]. Therefore, according to experts, advanced methods of construction should be considered as potential answers to the issue. Heat island was another criterion emphasized by experts compared to other criteria. They believed that the demand of residential construction in one side and the lack of natural covers of residential buildings such as water bodies and green spaces on the other, have increased heat island effect in Iran. For instance, in Tehran, mean temperature changes annually from 15 to 18 °C and for the reason of the height differences in the city, different regions have an average of 3 °C difference in temperature [196]. A study conducted by Ref. [197] suggested three effective strategies for heat island mitigation, especially in residential areas in the megacity of Tehran on a hot summer day. These effective strategies were more green roofs and vegetation spaces in residential buildings and spaces, respectively.

It should be noted that the category of sustainable site in LEED is the second important sustainable issue (after Energy Efficiency) considered by their experts to avoid harming habitat, open space, and water bodies. A United Nations study indicates that about 60% of the assessed ecosystem services, are being used unsustainably [198]. Between 1982 and 2001 in the U.S., about 34 million acres of open space was lost to development—approximately 6000 acres a day [199]. Moreover, ‘Washington State Department of Ecology study’ noted that rainwater runoff from roads, parking lots, and other hardscapes carries approximately 200,000 barrels of petroleum into the Puget Sound every year. Therefore, the US experts recognized this category as an important category giving the second place of priority [200].

#### 5.3.4. Materials

Materials category has the same amount of importance by equal point allocation in LEED and ISAT (Table 8). According to local experts, the most crucial criteria were ‘Low emission materials’, ‘Renewable materials’ and ‘Recycled material’. They believed that these criteria are vibrant for residential buildings to minimize environmental impact of material use and waste problem of the country. The reason is a lack of consideration regarding recyclability of materials and adaptability of the building in construction procedures [201]. Therefore, experts suggested building waste management to be considered in sustainability construction of Iranian residential buildings. Generally, construction and demolition waste generation in Iran is much higher than other countries, especially developed countries [202]. For example the average construction and demolition waste generation in the United States is 0.77 kg per capita per day [203], while this proportion is 4.64 kg per capita per day in Tehran, based on reports from ‘Tehran

Municipality Waste Management' [204].

Low emission materials which are environmental friendly materials, can minimize the life cycle cost and $CO_2$ emissions of the residential buildings [201]. A study conducted by Ref. [202] recommended design for deconstruction with the consideration of Iranian vernacular architecture potentials and the establishment of a National secondary material administrative system as solutions which could address renewable and recycled material criteria in Iran. Results of a study by Ref. [205] showed that construction and demolition waste were produced with an average of approximately 82,000,000 $m^3$ during the years 2011–2016 which only about 26% of them have been recycled in the capital city of Iran. They also concluded that soil (11%), broken bricks (18%), sand and cement mix (30%), and concrete (19%) have the highest amounts of the construction and demolition wastes in Tehran. Utilizing appropriate materials and innovative solutions, e.g. self-compacting lightweight concrete which is regarded as an innovative generation of concrete, can decrease environmental impacts of material and improve the sustainability of residential construction [206–208].

In other words, recycling and reusing materials which are used on site, minimizing massive fragment and wastes at the construction site, and recycling wastes that are not reusable on site should be considered in Iran [205].

In spite of the fact that the amount of construction and demolition waste generation is less than Iran, the amount indicated previously is still more than the total waste stream in the European Union. Therefore, LEED considered this category as important as the material category in ISAT. Approximately, 25% of the total solid waste stream in the European Union and 40% of the total solid waste stream in the United States is due to the construction and demolition process [209].

#### 5.3.5. Indoor environment quality

Indoor environment quality, which addresses air quality, comfort, and health of residents, is given less priority in ISAT, when compared to international assessment tools. For instance, in BREEAM, this category is the next important issue after the Energy Efficiency category. Moreover, in CASBEE and SBTool, the same amount of point in Energy Efficiency is given to Indoor environment quality point (Table 8). The reason is that the improvement of the air-conditioning appliances caused health problems [210]. Although, the wide use of air conditioning led to the improvement of thermal comfort, health problems associated with poor 'Indoor air quality' started to appear more frequently [211]. For instance, there were complaints about the health of the inhabitants of Japan, because pollutants in indoor air have increased as a result of the increased airtightness of the newly constructed residential buildings and the frequent use of chemical products in their new method of construction [212]. Moreover, experts believed that developed countries have already addressed many sustainability issues through innovative approaches in residential construction such as developing green materials, renewable energy resources, water efficiency and etc. However, Iran has not addressed these categories in buildings yet. For instance, although Iran has high potentials of renewable energies or local materials, Iranian practitioners have not considered these categories in their buildings. Moreover, Iran suffers from poor available technologies in the category of Indoor environment quality [161]. Therefore, experts believed that focusing on the categories that Iran has the potentials, are required in the first step regarding sustainability promotion in residential buildings. As a result of this problem, ISAT has placed more emphasis on the aforementioned sustainability issues than Indoor air quality category in the first place, in order to make it possible for practitioners to reach sustainable certification by attaining specific points. They believe that after addressing these categories, focusing on indoor environment quality will be more demanding in order to reach the outstanding level of sustainability and as a result, technologies will start to be available over time. According to experts, giving less priority to this category compared to other categories does not mean that this category is not important in sustainability concerns related to residential buildings. In fact, they believed that addressing previous categories could lead to a better indoor environment quality to some extent. For instance, it is believed that emission-based approach (Low emission materials), not only will address "materials and resources" category, but also will enhance residents' health. Moreover, the use of renewable energy resources such as solar and wind, will decrease the use of fossil fuels, which cause air pollution and consequently, contamination of indoor environments through the air pollution penetrating from outdoor environment [213], since, air pollution is a mixture of gases and particles affecting the air quality [214]. Another criterion which indirectly addresses indoor environment quality is building envelop performance in Energy Efficiency category, which addresses thermal comfort criterion for residents in most of the hot and arid regions of Iran through an effective insulation [152].

As stated previously, for the reason that this category point is above 9 points, experts recommended that considering this category will lead to better outcomes in sustainability of residential buildings in Iran. Some regions of Iran have suffered from dust storms in recent years [215]. The most crucial criterion of this category recognized to be air quality. Since Iran is located on the arid belt and more than half of the land area of the country is arid and semiarid climate [216], regional issues such as drought phenomenon has been occurred, which had negative environmental effects in Iran. In recent years, these severe climatic changes occurred with urbanization and industrialization in this country (drought and air pollution) [216]. Moreover, factors such as: lower relative humidity environments, persistent drought, and reduced rainfall exacerbated the dust [217], which is an important part of air pollution resources occurred in large areas of Iran, especially southern regions, in recent years. According to experts, various solutions could be given which may address indoor environment quality issues in Iran. For dust problems, experts suggested mandatory issues for residential construction regulations to consider airtightness testing in building code for regions with dust problem in Iran. Moreover, experts suggested implementing strategies such as installing $CO_2$ sensors for constant monitoring of air quality or mitigation of air pollution through volatile organic compound products, which was discussed in Ref. [218].

Another crucial criterion compared to other criteria was daylight. Unfortunately, most of the Iranian residential spaces suffer from dark areas, not adhering to the minimum daylight factor required for particular areas [3]. This criterion could be addressed by considering appropriate location to benefit from adequate level of daylighting in day time, which is discussed in studies by Refs. [219,220]. This will not only reduce artificial lighting for buildings, but also will save energy in cooling and heating as well as maximizing the criterion of visual comfort. The third most important criterion among other criteria was thermal comfort. As stated above, this criterion is addressed to some extend in the energy efficiency category. However, in addition to insulation solutions, intelligent use of natural ventilation, most likely employing night-time ventilation, could further improve thermal comfort in Iran [191].

In conclusion, as discussed in this section, the similarities and differences among category points of ISAT and other tools can be better realized. These differences and similarities can be attributed to two reasons. The similarities stem from worldwide concerns and critical conditions of a particular issue, which various organizations such as worldwide health organizations, United Nations and etc. have addressed that issue for further considerations by nations. The differences occur when it comes to climatic and regional conditions of a particular country, which will affect the points obtained by some categories.

Despite the evident effect of these issues on the environment, a practical approach was needed to manage environmental impacts of residential buildings in which sustainability indicators act as tools providing information to ease decision making in construction. This will help building practitioners to judge building sustainability and to reduce the chance of arbitrary decisions in building construction. In other words, the integration of expert opinions along with bringing evident effects can make building practitioners to better manage the building construction through this framework. Therefore, the awareness cannot be achieved without a development of comprehensive framework of sustainability priorities of residential buildings, which can be achieved by experts' opinion through decision making process. It should be noted that despite the evident effects, the need for experts' opinion regarding the priorities should be a starting point for the awareness of practitioners regarding sustainability issues in order to show evidences and solutions for sustainability promotion of buildings. In other words, in spite of these evident effects, little awareness exists among building practitioners and little researches show these issues interactively to be grouped as a comprehensive framework showing crucial sustainability concerns of Iranian residential building. In general, this framework will guide these practitioners to take actions more appropriately for sustainability construction regarding these priorities.

### *5.4. A proposal for implementation of ISAT in Iran*

Although sustainability issue is a new subject in Iran and that some of the categories mentioned in ISAT have been referred to by national regulations of Iranian engineering organization, the implementation of ISAT as a contributory tool for the improvement of sustainability in the residential building sector is crucial in Iran. ISAT is proposed to be a starting point for further consideration and implementation in Iranian building regulations of the future. This implementation of the evaluation system in Iranian building regulations can be proposed in 5 steps over time, which is shown through Fig. 15.

In the first step, the awareness should be enhanced in Iran by introducing ISAT to different organizations such as municipal and engineering and also purchaser, using TV and radio advertisements. Therefore, in the first step, ISAT should be a voluntary based program.

In the second step, after the enhancement of the awareness among organizations, in order to incentivize building practitioners to consider ISAT in their building project, incentives such as lowering taxes or discounted bills can be considered for buildings which utilize this tool to promote sustainability.

In the third step, regulations can be considered over time regarding the utilization of ISAT. For example, some of the criteria, which have higher priority compared to other criteria in each category, should be mandatory by municipalities and engineering organizations, so that all the residential buildings attain the least acceptable certification degree, e.g. minimum acceptable level ($\geq 39$).

In the next step, for the reason that compliance with these criteria might be expensive, special incentives and bonuses for buildings, which achieve a minimum acceptable certification level through the mandatory categories and criteria, can be considered.

The final step can be the step of idealization of Iranian residential buildings in the field of sustainability in a way that all the categories of ISAT are compelled, in order to reach the best level of sustainability. In fact, in this step it is hoped to make Iranian residential buildings reach a maximum level of certification in sustainability.

## 6. Summary and conclusions

This paper endeavored to customize international sustainability assessment tools to develop an Iranian sustainability assessment tool for residential buildings with respect to Iranian sustainability issues, priorities, and practices with one of the reliable decision-making method of FAHP. Therefore, just as other adaptive assessment tools in developing countries, the common categories of well-known international assessment tools such as LEED, BREEAM, CASBEE, and SBTool were investigated to be included in Iranian assessment tool.

In order to confirm the reliability, ISAT was validated in accordance with the existing assessment tools and the performance sensitivity of ISAT was compared to other tools. It has been concluded by evident effects as well as the local experts that similarities and differences exist in the categories of ISAT, when compared to international sustainability assessment tools. These results can be considered logical and reasonable when it was further explained and supported by evident effects specific to a region as well as worldwide concerns. For instance, the category such as energy efficiency, is among the categories that does not have major differences in all the five assessment tools for the reason of worldwide concerns on this subject. However, water efficiency in ISAT is more sensitively focused by Iranian experts for the reasons of regional and sustainability issues of the country. Therefore, it has been recommended by local experts that this assessment tool could be a profitable and adaptive tool for Iranian context, since it is based on technical knowledge and the experiences of professional residential construction experts. In the proposed assessment tool, five mostly addressed categories of international assessment tools, namely, energy efficiency, water efficiency, sustainable site, materials and resources, and indoor environment quality were evaluated and given particular points. Moreover, each criterion of a category was weighted according to FAHP process with respect to the priority of the local sustainability situations which are included in the assessment scores of ISAT.

In this research, by introducing the priority weights of sustainability fundamentals, the development of ISAT aimed to be a starting point for further investigation of a more holistic assessment tool, considering more dimensions such as economic and social sustainability issues regarding Iranian residential buildings. This is because, these assessment tools should be evolved constantly to address their various limitations. Therefore, as an information platform, ISAT could be a reliable tool to be a guidance for policy makers and construction experts to implement sustainability with respect to Iranian unsustainability issues of residential buildings.

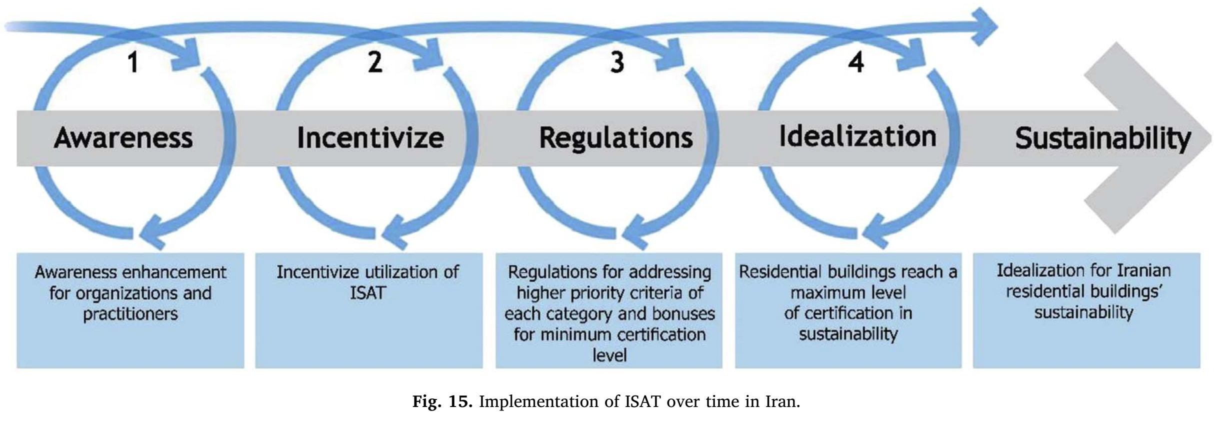


Fig. 15. Implementation of ISAT over time in Iran.

## Conflicts of interest

The authors declare no conflict of interest.

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