The Hindrances to Green Roof Adoption in a Semi-Arid Climate Condition

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Abstract: Green roofs (GRs) offer several environmental, social, and economic benefits while numerous barriers are limiting their adoption. This study covers two gaps in the literature: first, the lack of indicating separate hindrances to different types of GRs; second, the dearth of research related to the hindrances on GR adoption in any climate of Iran. This research aims to identify and analyze the importance of hindrances to GR adoption by considering the two major types of GRs using the Fuzzy Delphi Method (FDM) and Fuzzy Analytic Network Process (FANP), respectively. The results indicated that eight out of twenty-five identified hindrances to GR adoption were rejected using FDM. Moreover, it was found that although financial hindrances are significant for both types of GRs, public awareness is the most important hindrance to extensive GR adoption. As the first research of its kind in a semi-arid climate of Iran, the findings of this research provide an insight for the researchers and policymakers regarding the hindrances to GR adoption for further research and action.

Keywords: green roof; sustainability; multi-criteria decision making; environment

1. Introduction

The construction industry is responsible for several adverse impacts on the environment such as CO₂ and greenhouse gas emissions, and sustainable approaches in the construction industry are being adopted as a practice to deal with these issues [1]. A green roof (GR), as an environmentally friendly alternative to conventional roofs [2], is adopted in many developed and developing countries due to its potential to offer several short- and long-term benefits such as energy-saving [3], stormwater management [4], and mitigation of flood risk [5], urban heat island and air pollution when installed in large-scale capacities [6]. GRs are vegetated roofs and are generally categorized into intensive GR (IGR) and extensive GR (EGR) [7]. Each of the above has its pros and cons, therefore, the most suitable type should be selected for a building based on the requirements and the specifications of the project.

IGR, colloquially known as roof garden, accommodates a wide range of plants and trees. Although it is the most expensive type of GR and requires a considerable amount of maintenance, it is a suitable option for public use, especially in places where there is limited land for creating recreational space for the public. On the other hand, as the increase in the dead load of the buildings is an important barrier in retrofitting, EGR, which requires no additional structural support and a minimum amount of budget is the optimal alternative for building retrofitting [8]. It is notable to mention that EGR has a low depth of soil, hence, it is limited in terms of type and quantity of plantations. In addition to these two major types, semi-IGR has been considered as the third type of GR in some studies [9], which has characteristics from both major types. In other words, it accommodates more species of plants than extensive type, while its required initial costs, maintenance, and depth of soil are less than intensive type [10].
GRs offer several environmental [11], social [12], and financial [13] benefits to the owners, developers, and dwellers living nearby. These benefits are considered in the design stage of the GR to ensure they offset the additional costs of GR installation [14]. A number of studies have been conducted in different climates of Iran to assess the performance and applicability of GR installation. For instance, a study conducted in Tehran, the capital of Iran, showed the positive effects of GRs in terms of air temperature, humidity, and CO₂ content [15]. Other studies have also been carried out in many other cities of Iran (due to the varying climate across the country) and the results showed that GRs contribute to energy saving for both heating and cooling [16–18]. Riahi Zamani et al. [19] found that GR is capable of reducing around 7.9 percent of energy consumption. Additionally, in the hot and dry part of Iran, GRs have a high potential in reducing the daily energy loss [20]. In the semi-arid climate of Iran, Vahdati et al. [21] assessed the performance of different types of plants and showed that despite the difficulties in selecting suitable plants in that climate, GRs perform well more than half of the year, if suitable plants are selected. Moreover, in the same climatic settings, Mirzababaie and Karrabi [22] indicated that GR installation results in a reduction in energy consumption and environmental damage costs during the hot seasons.

On the other hand, there are some hindrances to GR installation. For instance, the additional costs and efforts needed for the installation and maintenance of GR have been mentioned as the barriers that inhibit the GR adoption [23]. Furthermore, the inadequate/limited incentive policies and standards provided by the governments are considered as demotivation for the clients and developers to adopt GR as an alternative [24,25]. Another aspect of GR installation is the climatic condition of the site, as plant selection must be considered carefully and be carried out based on their capabilities and suitability to the installation site [26]. Besides, the awareness and interest of clients are of utmost importance for the adoption of such an environmentally responsible application, and a lack of considerable motivation results in lower adoption of green practices [27].

Despite offering numerous environmental, social, and long-term economic benefits to the owners in different climates, a limited number of installed GRs are found in Iran and GR adoption is still in its infancy. The lack of research focusing on the barriers of GR adoption in Iran, coupled with the need to increase the use of this environmentally friendly application, calls for an investigation of the hindrances to adoption of GRs in Iran. Although some research is carried out around the world to identify the barriers to adopt GR (e.g., Chen et al. [24] in China, Mahdiyar et al. [28] and Sanmargaraja et al. [29] in Malaysia, Zhang et al. [30] in Hong Kong, Williams et al. [31] in Australia), their findings are not applicable for other regions in account of several differences in climate, technical capabilities, public attitude in accepting new technologies, and economic circumstances. Moreover, the existing relationships among the hindrances to GR installation have been ignored in the previous analyses conducted in the literature. As a result, the focus of this research is to answer two research questions: (1) what are the hindrances to GR adoption in the semi-arid climate of Iran, with respect to EGR and IGR?; (2) How significant are these hindrances to each type of GR considering the existing relationships among the hindrances?

To address the aforementioned research questions, the aim of this paper is to identify and analyze the importance of these hindrances. To achieve the former, a Fuzzy Delphi Method (FDM) questionnaire is designed and distributed among experts to refine the hindrances identified in the literature based on the local scenario, while Fuzzy Analytic Network Process (FANP) method is employed to identify the most significant ones considering their relationships as the latter objective. It is notable to mention that Iran has different climatic conditions, and in this research, the investigations are limited to the semi-arid climate of Shiraz (a city in south-central), to which GR can contribute positively, especially in terms of environmental aspects. Shiraz is in the center of Fars Province and has been chosen for this research as it lacks vegetation and green areas, especially in central business districts. The limited number of existing GRs, and the high potential for successful implementation of GR, are among aspects considered for the selection of this city as a case for investigating the hindrances to GR installation.
The next section presents the methods that have been employed for the analyses together with the list of GR hindrances gathered from the literature. In Section 3, the results of the analyses are presented, and the research results are discussed. The last section concludes the research.

2. Materials and Methods

This research is conducted in three stages: (1) literature review; (2) identifying and refining the hindrances to adoption of GR using FDM; (3) prioritizing the selected hindrances to the adoption of IGR and EGR separately using FANP. The steps taken to achieve the aim of the research are shown in Figure 1 and discussed as follows.

Figure 1. Research flowchart.

2.1. Literature Review

In this research, an extensive body of literature is reviewed regarding the reported hindrances to GR installation in the studies conducted in different climates and regions, either in developed or developing
countries. In this research, these hindrances are identified and categorized into several groups. It is notable to mention that the categories are chosen based on the studies that focused on the barriers to—and root causes of the deficiency of GR installation around the world (e.g., Williams et al. [31], Zhang et al. [30], and Chen et al. [24], Mahdiyar et al. [28]), while the individual hindrances are gathered from various types of research on GRs. These hindrances are used as the input for FDM, which is explained in the next section.

2.2. Fuzzy Delphi Method

FDM has been widely adopted in different types of research in construction field in order to refine the influential factors [32,33]. In this research, a structured questionnaire is designed based on all hindrances to GR adoption gathered through an extensive review of literature, as shown in Table 1. Participants including architects, engineers, landscape designers, and researchers were asked to rank the importance of each hindrance using a 5-point Likert scale questionnaire: (1) least important, (2) less important, (3) neutral, (4) important, and (5) very important. The responses are then analyzed using SPSS 21 to check the reliability of the results. It is suggested that if the Cronbach’s coefficient alpha is higher than 0.7, the results are reliable [34]. Once the reliability of the results is confirmed, the 80/20 rule [32] is applied to refine the negligible hindrances to the adoption of GRs. In this research, geometric mean (GM) (Equation (1)) is used rather than a mean index to minimize the effect of extreme values in the responses.

\[ M_A = \sqrt[n]{\prod_{i=1}^{n} X_{Ai}} \]  

where \( X_{Ai} \) indicates the appraisal value of the \( i \)th expert for hindrance \( A \), and \( i \) denotes the \( i \)th expert; \( i = 1, 2, \ldots, n \). Once the GMs of all hindrances are calculated, the cumulative percentage of hindrances is determined in descending order. Those hindrances not contributing to 80% of the importance are rejected and not considered as a significant hindrance in GR adoption and are omitted from further analysis.

2.3. Fuzzy Analytic Network Process

ANP is a powerful method that is capable of prioritizing, especially when there are combinations of measurable and non-measurable factors/variables. Moreover, pair-wise comparison (the concept of weighting in ANP) is considered as an acceptable choice, when there are no available data regarding the factors that are being ranked. ANP considers the relationships among the factors as opposed to the analytic hierarchy process method. Consequently, due to the nature of the hindrances involved in this research, ANP is selected as the weighting approach for prioritizing the hindrances to GR adoption in Iran. According to the structure of ANP, weighting should be carried out in four steps: (1) indicating the importance of each category with respect to the aim of the research; (2) indicating the importance of each hindrance with respect to the corresponding category; (3) indicating the importance of each category with respect to other categories; (4) indicating the importance of each hindrance with respect to other hindrances in the same category.

There are some issues reported as the weaknesses of ANP such as a large number of required pairwise comparison and vague judgment of the experts which is due to the usage of crisp values when expressing opinions. Recent studies have found ways to reduce the number of required pairwise comparisons (e.g., Abastante et al. [35], Leal [36]). In addition, to cope with the imprecise judgment of the experts, fuzzy logic is added to ANP numbers [33]. In this research, the number of hindrances in each category is limited; as a result, there is no need to adopt a new approach to reduce the required number of pairwise comparisons. However, the fuzzy set theory is used due to the aforementioned benefits, and the steps of using FANP in this research are explained as follows.

Step 1: Develop a network that consists of three levels: goal, categories, and hindrances.

Step 2: Design the questionnaires. In this paper, the respondents are asked to compare all the categories and hindrances in different tables (pairwise comparisons) using a five-point scale “1”, “3”,...
“5”, “7”, and “9” representing “equal importance”, “moderate importance”, “strong importance”, “very strong importance”, and “extreme importance”, respectively. It is worth mentioning that as it is believed that the priority of the hindrances to GR adoption varies among its type, two sets of questionnaires were distributed to the participants for each of the two major types of GRs, i.e., IGR and EGR.

Step 3: Distribute the questionnaire to the panel of experts. According to Saaty [37], twelve experts were selected and asked to participate in this research.

Step 4: Checking the consistency of the responses. When it comes to consistency of the responses in ANP, as a significant issue in pair-wise comparison [38], the consistency of the responses has to be monitored for each pair-wise comparison. In case the responses are inconsistent, the pairwise comparison should be repeated. According to Saaty [39], the consistency measurement is developed by means of two characteristics: first, the pairwise comparison matrix gets greater consistency as \( \lambda_{\text{max}} \) becomes closer to \( n \). Second, \( \lambda_{\text{max}} \) values are constantly bigger than or equal to \( n \), as demonstrated in Equations (2) and (3).

\[
\text{Consistence index (CI)} = \frac{\lambda_{\text{max}} - n}{n - 1} \quad (2)
\]

\[
\text{Consistency Ratio (CR)} = \frac{\text{CI}}{\text{Random Index (RI)}} \quad (3)
\]

where \( \lambda_{\text{max}} \) is the maximal eigenvalue, and the size of \( n \) determines the RI. If the judgment is absolutely consistent, \( \lambda_{\text{max}} \) equals to “\( n \)”, therefore, CI is 0 and CR is 0. In contrast, when the consistency is decreased, \( \lambda_{\text{max}} \) becomes greater than \( n \) and the CI and CR are both more than 0. It is notable to mention that the responses are consistent when CR is equal to or smaller than 0.05, 0.08, and 0.1 for \( 3 \times 3, 4 \times 4, \) and larger matrices, respectively [40].

Step 5: Fuzzify the responses. This research adopts triangular distribution as a membership function as it is widely adopted in similar studies (e.g., Mahdiyar et al. [9], Valipour et al. [41]). Once it is confirmed that the responses are consistent, the comparison matrix \( R = [r_{ij}]_{n \times n} \) is constructed, where \( r_{ij} \) is the element of comparison matrix (crisp value); “\( i \)” and “\( j \)” represent the row and column factors, respectively, and \( n \) is the number of hindrances. Then, the crisp values in the developed matrices of pair-wise comparison are replaced by triangular fuzzy numbers (TFNs) for the analysis. Table 1 indicates the FANP scale that is used in this research. As a result, the fuzzy comparison matrix, \( R_{T} = [r'_{ij}]_{n \times n'} \) is constructed, where \( r'_{ij} \) are fuzzy numbers. Each \( r'_{ij} \) is a TFN defined as: \( r'_{ij} = (l_{ij}, m_{ij}, u_{ij}) \), where \( l_{ij}, m_{ij}, u_{ij} \) are the lower bound, modal, and upper bound values for \( r_{ij} \), respectively.

Table 1. Fuzzy Analytic Network Process (FANP) scale used to evaluate the importance of criteria [42].

| Intensity of Importance | Fuzzy | Reciprocal Fuzzy |
|-------------------------|-------|------------------|
| 1                       | \((\frac{1}{2}, 1, 3)\) | \((\frac{1}{2}, 1, 3)\) |
| 3                       | \((1, 3, 5)\) | \((\frac{1}{2}, \frac{1}{3}, 1)\) |
| 5                       | \((3, 5, 7)\) | \((\frac{1}{2}, \frac{1}{3}, \frac{1}{2})\) |
| 7                       | \((5, 7, 9)\) | \((\frac{1}{3}, \frac{1}{3}, \frac{1}{2})\) |
| 9                       | \((7, 9, 9)\) | \((\frac{1}{3}, \frac{1}{3}, \frac{1}{2})\) |

Step 6: Construct the sum of the rows and sum of the columns’ matrices as follows:

\[
S_{Tr} = \begin{bmatrix} s_{Tr_{ij}} \end{bmatrix}_{n \times 1} = \begin{bmatrix} l_{Tr_{ij}}, m_{Tr_{ij}}, u_{Tr_{ij}} \end{bmatrix}_{n \times 1} = \sum_{i=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij} \quad (4)
\]

\[
S_{Tc} = \begin{bmatrix} s_{Tc_{ij}} \end{bmatrix}_{n \times 1} = \begin{bmatrix} l_{Tc_{ij}}, m_{Tc_{ij}}, u_{Tc_{ij}} \end{bmatrix}_{n \times 1} = \sum_{i=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij} \quad (5)
\]
Then, construct the sum of the columns’ sum matrix as follows:

$$G'_{c} = \left[ \sum_{i=1}^{n} l_{g'cij}, \sum_{i=1}^{n} m_{g'cij}, \sum_{i=1}^{n} u_{g'cij} \right]_{1 \times 1}$$

(6)

Step 7: Calculate the value of fuzzy synthetic for each of the factors using Equation (7).

$$Y_{rij} = \left[ l_{yrij}, m_{yrij}, u_{yrij} \right]_{n \times 1} = \left[ \frac{l_{srij}}{l_{g'cij}}, \frac{m_{srij}}{m_{g'cij}}, \frac{u_{srij}}{u_{g'cij}} \right]_{n \times 1}$$

(7)

In order to calculate the weight of each factor, all these TFNs in matrix $Y_{rij}$ should be defuzzified to crisp values. To compare two hindrances presented by TFNs, for instance $A = (l_a, m_a, U_a)$ and $B = (l_b, m_b, U_b)$ pair wisely, Equations (8) and (9) should be used.

$$V(\text{A over B}) = \begin{cases} 1, & \text{if } m_a \geq m_b \\ \frac{l_a - U_b}{(m_b - U_b) - (m_a - l_a)}, & \text{if } l_a \leq U_b \\ 0, & \text{else} \end{cases}$$

(9)

Following the above mentioned for all factors, $V = (v_{ij})_{n \times n}$ is constructed. Then, the final weight of each category/hindrance is calculated as follows:

$$LW_i = \frac{\min v_{ij}}{\sum_{j=1}^{n} \min v_{ij}}, \quad j = 1, 2, \ldots, n$$

(10)

where $LW_i$ denotes the local weight of categories.

Step 8: Calculate the local and global weights of all hindrances using TFNs. In order to calculate the local weights of hindrances, the previous step is repeated where categories are replaced by hindrances in each category. Then, the global weights of hindrances are calculated using Equation (11).

$$GW_h = LW_i \times LW_h$$

(11)

where $GW_h$ and $LW_h$ denote global and local weights of hindrances, respectively.

2.4. Expert Selection

In this study, judgment sampling has been employed as a non-probability random sampling technique in account of knowledge acquisition from the experts. As explained, FDM and FANP were adopted to refine and prioritize the hindrances to GR installation. As shown in Table 2, in the former method, forty-six questionnaires were administered to the experts, while thirty-six experts (twenty-four architects, five civil engineers, three urban designers, two urban planners, and two researchers) contributed. Since architects are usually responsible for the adoption of GRs, more contribution from them compared to others is acceptable. For the latter method, according to Saaty and Ozdemir [37], the sample size of experts involved in an ANP study is around seven. In this research, as there is a need to consider the opinions of the experts with different perspectives, twelve participants (four architects, and two from each of the rest) from the previous round were contacted to participate further in prioritizing the hindrances to GR adoption. It is notable to mention that all contributed experts met the criteria that have been proposed by Hallowell and Gambatse [43].
Table 2. The information of the experts contributed to Fuzzy Delphi Method (FDM) and FANP.

| Background       | FDM  | FANP |
|------------------|------|------|
|                  | Number | Academia | Industry | Number | Academia | Industry |
| Architect        | 24    | ✓       | ✓        | 4      | ✓        | ✓        |
| Civil engineer   | 5     | ✓       |          | 2      | ✓        |          |
| Urban designer   | 3     | ✓       | ✓        | 2      | ✓        | ✓        |
| Urban planner    | 2     | ✓       | ✓        | 2      | ✓        | ✓        |
| Researcher       | 2     | ✓       |          | 2      | ✓        |          |

3. Results and Discussion

3.1. Identifying and Refining the Hindrances

The results of the research showed that of twenty-five identified hindrances through the literature, seventeen hindrances are perceived to be effective in Shiraz, which are considered for further analysis (refer to Table 3). Figure 2 illustrates how they have been analyzed using the GM and 80/20 rule. In Figure 2, the hindrances are sorted based on the highest GM value from left to right. Then, according to 80/20 rule, those hindrances with the highest GM value that have contributed to 80% of total cumulated GM values are selected as significant ones, and the rest are rejected from further analysis. In terms of financial category, rejection of F2 shows that although construction and maintenance costs of GR installation are considered as important hindrances (F1 and F3), the additional cost of designing is not perceived as one. In the study conducted by Chen et al. [24], design and construction costs are determined as an important root cause hindering the adoption of GR, while the findings of current research provide a clearer insight into the costs of GRs as a hindrance to GR adoption considering the local context.

Table 3. The list of hindrances to the adoption of green roofs (GRs).

| Category | Hindrance | Result of the Literature Review | Reference | Result of FDM |
|----------|-----------|----------------------------------|-----------|---------------|
|          | Increases in required initial construction cost | F1 Each type of GR, based on their specifications, requires a different initial cost for construction. | [13,44] | Select |
| Financial| Increases in required initial design cost | F2 If the roof is supposed to be used for different purposes, an additional charge may be required for the design and considerations of the functions. | [24,28] | Reject |
|          | Maintenance cost | F3 All types of GRs require regular maintenance throughout their lifespan; however, it varies among different types. | [16,45] | Select |
Table 3. Cont.

| Category                        | Hindrance                                                                 | ID  | Definition                                                                                                                                                                                                 | Reference  | Result of FDM |
|---------------------------------|---------------------------------------------------------------------------|-----|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|---------------|
| Legal and policy                | Lack of policy and standard for manufacturing the GR components          | L1  | Since GRs have several layers, standards are needed for the manufacturing of suitable components for each layer of different types of GRs.                                                                 | [31]       | Select        |
|                                 | Lack of policy and guideline for the design of GR                         | L2  | There are many codes and guidelines available for GR designers in many countries.                                                                                                                        | [24,31,46] | Reject        |
|                                 | Lack of decision-making approach for GR type selection                    | L3  | Each type of GR offers different levels of costs and benefits, and it is necessary to select the most appropriate type for any building.                                                                  | [9]        | Select        |
|                                 | Lack of provided incentive for the owners                                 | L4  | Some governments around the world provide financial incentives to those who install any type of GR, based on some requirements.                                                                               | [25,47]    |               |
|                                 | Lack of provided incentive for the developers                             | L5  |                                                                                                                                                                                                           |            |               |
|                                 | No/limited inclusion in the green star rating scheme                       | L6  | GR installation is considered as a part of the green star rating in many countries.                                                                                                                       | [48,49]    | Reject        |
| Technical and management        | Lack of technical experience in the installation                          | T1  | Since GRs have different layers compared to the conventional ones, technical expertise is required for the installation                                                                                  | [46,50,51] | Select        |
|                                 | Lack of technical experience in maintenance                               | T2  | Each type of GR should be maintained regularly (depending on the type of GR, depth of soil, and used plants).                                                                                              |            | Select        |
|                                 | Inadequate structural capability                                          | T3  | Adding additional dead/live loads on the roof requires additional structural supports.                                                                                                                     | [1,50]     | Reject        |
|                                 | Probability of roof leakage                                              | T4  | In case of any leakage in the roof, technical expertise is required to fix the leaking.                                                                                                                   | [12,25]    | Select        |
|                                 | Weak under wind load                                                     | T5  | Trees on the roof, especially skyscrapers, should resist heavy winds.                                                                                                                                     | [28,30]    | Reject        |
|                                 | Lack of collaboration among stakeholders                                  | T6  | Since GR installation involves many construction stakeholders, i.e., designer, engineer, technician, client, good collaboration is needed among them to ensure the project is successful. | [12,25]    | Select        |
|                                 | Lack of supplier                                                          | T7  | Different components such as drainage, filtering, and waterproofing layers, should be supplied for any GR type, which plays an important role in its performance.                                              | [24]       | Reject        |
When it comes to legal and policy hindrances, since guidelines for GR installation (L2) are available for architects, it is not perceived to be an important hindrance to GR adoption. Moreover, due to the inclusion of GRs as a sustainable practice in a construction project in the local green rating scheme, L6 is also rejected. These findings reveal that although L2 and L6 have been reported as a hindrance in other locations, it is not applicable at the moment in Shiraz. In terms of legal and policy category, T3, T5, and T7 are considered as the rejected hindrances, which indicates that there are no restrictions for the adoption of GRs regarding the additional dead, live, and lateral loads.

Regarding the climatic category, C1 is rejected, which is in line with the study conducted by Sanmargaraja et al. [29] where this hindrance is ranked among the least important ones. The rejection of C2 indicates its insignificance in the climate of Shiraz; however, it might be an effective hindrance to other climates of Iran. On the other hand, in account of the semi-arid climate of Shiraz, lack of rainfall (C3) can be considered as a hindrance to the adoption of GRs. As expected, this finding is inconsistent with the findings in other locations (e.g., in Malaysia with a tropical climate [49]). It is worth mentioning that these kinds of differences among hindrances’ categories—in different regions or
even different locations in the same region—show the necessity of conducting these kinds of research in different climates and locations.

3.2. Prioritizing the Hindrances for IGR and EGR

Once the hindrances to GR adoption are refined, they are prioritized based on their importance and relationships using FANP. As per Figure 3, the hindrances are categorized into five groups, financial, legal and policy, technical and management, climatic, and public awareness. During the analysis, the relationships among categories, and hindrances belonging to each category are considered, while the climatic category consists of only one hindrance, in which no relationship exists. Based on the responses gathered from all experts, the results of prioritizing the hindrances are provided in Tables 4 and 5 for IGR and EGR, respectively. It is worth mentioning that the CIs of all responses are checked and ensured their consistency so that the findings of the research are reliable. In the aforementioned tables, the local weight of each category includes its importance with respect to the goal and other categories. When it comes to hindrances, local weight refers to the importance of each hindrance considering its importance with respect to its category, and its importance with respect to other hindrances in the same category. The global weight of hindrances shows the weight among all other hindrances. As can be seen in Tables 4 and 5, the more the global weight, the higher the rank of the hindrance.
Table 4. The hindrances’ local and global weights, and ranks of intensive green roof (IGR) adoption.

| Category | Weight | Category Rank | Hindrance Code | Local Weight | Global Weight | Hindrance Rank |
|----------|--------|---------------|----------------|--------------|---------------|----------------|
| Financial | 0.294  | 1             | F1             | 0.388        | 0.114         | 2              |
|          |        |               | F3             | 0.612        | 0.179         | 1              |
| Legal and policy | 0.118  | 5             | L1             | 0.080        | 0.009         | 12             |
|          |        |               | L3             | 0.088        | 0.010         | 11             |
|          |        |               | L4             | 0.497        | 0.058         | 5              |
|          |        |               | L5             | 0.335        | 0.039         | 8              |
| Technical and management | 0.197  | 3             | T1             | 0.138        | 0.027         | 10             |
|          |        |               | T2             | 0.352        | 0.069         | 4              |
|          |        |               | T4             | 0.276        | 0.054         | 6              |
|          |        |               | T6             | 0.234        | 0.046         | 7              |
| Climatic | 0.142  | 4             | C3             | -            | -             | -              |
| Public awareness | 0.249  | 2             | P1             | 0.151        | 0.038         | 8              |
|          |        |               | P2             | 0.138        | 0.034         | 9              |
|          |        |               | P3             | 0.339        | 0.084         | 3              |
|          |        |               | P4             | 0.016        | 0.004         | 13             |
|          |        |               | P5             | 0.339        | 0.084         | 3              |
|          |        |               | P6             | 0.016        | 0.004         | 13             |

1 As there is only one hindrance in this category, no pairwise comparison exists, and the importance of this hindrance is discussed based on its category.

As per Tables 4 and 5, the financial category is the most important hindrance to IGR adoption followed by public awareness. These two categories are in the reverse order for the case of EGR. In the hindrances to adoption of EGR, financial and legal and policy hindrances share the second important category. Another difference between the importance of IGR and EGR adoption hindrances is the rank of the climatic category. Since, in this analysis, climatic category refers to lack of rainfall, it is perceived to be more important for IGR adoption compared to EGR. When it comes to the legal and policy hindrances, it is ranked as the second and fifth (least) important hindrance to EGR and...
IGR, respectively, while the importance of technical hindrances is quite similar for two types of GRs. These are clear pieces of evidence that the hindrances to GRs cannot be mentioned in general, which is a bias in the literature of GR barriers and this research has tried to address it.

With regards to IGR, F3 (maintenance cost) has gained the highest rank followed by F1 (increases in required initial construction cost). This indicates the significance of financial hindrance, as the first-ranked category. On the other hand, despite an increase in installation and maintenance cost of EGR compared to conventional roofs, F1 and F3 are ranked as the second and fifth most important hindrances when it comes to EGR. Many studies have reported general barriers to GR adoption and it is difficult to check the consistency of our findings with literature backup; however, the importance of financial barriers is not a surprising finding for any sustainable application, especially in developing countries with the lack of/ or limitation of financial incentives. As a result, the findings are consistent with similar studies conducted around the globe such as the one carried out by Chen et al. [24] in China.

In terms of public awareness hindrances, as the first- and second-ranked hindrance to EGR and IGR, respectively, P3 (lack of knowledge regarding the benefits of GR among the clients) and P5 (lack of information for the lifecycle cost) have the highest importance. These hindrances are followed by P2 (lack of local research). These three top-ranked hindrances in this category, not only show the importance of researching cost and benefits associated with any type of GRs, but also indicate the importance of sharing the findings of local research with the public. Moreover, in account of the difference between the importance of P3 and P4, it can be realized that the architects and engineers have adequate knowledge of the benefits of GRs, while it is lacked among the clients. The results of this part are consistent with the findings of Sanmargaraja et al. [29], however, not in line with the findings of Mahdiyar et al. [28]. The captured inconsistency might be due to the lack of consideration for a comprehensive list of barriers compared to the current research.

Shiraz has some seasons with limited rainfall [57], and C3 (lack of rainfall) is a hindrance to the adoption of GRs, especially IGR, which may cause some issues for the maintenance of the roof. In addition to the need for irrigation, IGR, such as a roof garden, needs regular maintenance such as fertilizing and pest management [58]. As a result, T2 (lack of technical experience in maintenance) is considered as a more important hindrance to IGR than EGR. The capability of GRs in containing water for a longer time is considered as a benefit in terms of water management; however, it may cause some technical issues such as leakage in the roof (T4). Since GRs have multiple layers, fixing these issues might be a difficult task. Regarding legal and policy hindrances, as can be seen in Tables 4 and 5, L4 and L5 are the most important hindrances to both EGR and IGR. As a result, taking the importance of incentives into account, the experts believed that these incentives are much more effective for EGR than IGR. It might be due to the perception that the potential incentive will neither cover the whole required initial cost of IGR nor its maintenance cost, while, due to the very low cost of installation and maintenance for EGR, the incentives can play a role in its adoption.

Executive agencies and policymakers can reduce the costs of GR for clients/developers by providing monetary incentives such as reductions or abatements in the building permit fees or granting additional net area permits. Moreover, it was found that although there has been established policies for GR installation in Shiraz, the lack of awareness and legal policies are still perceived as the major barriers to GR installation. Consequently, policymakers may establish a green roof implementation consulting unit at the office of the technical deputy of the municipality and the organization of the engineering system in Shiraz to provide manuals to the design and supervising engineers, as well as to the clients/developers. The findings of this research with regard to the investigation of the importance of existing barriers to GR installation, and considering their relationships, would be a guideline for policymakers to strategize and prioritize their plans to overcome these barriers.

4. Conclusions

Considering the different levels of costs and benefits offered by each type of GR, there is a myriad of hindrances to their adoption. In this research, the hindrances to IGR and EGR adoption have
been identified and analyzed separately using FDM and FANP in Shiraz, located in the south of Iran. Compared to the similar studies conducted in various locations around the globe, based on the findings of this research, the following conclusions are drawn:

- Although the hindrances to adoption of IGR and EGR are almost the same, the importance of each hindrance varies among each type.
- Financial and public awareness are the most significant hindrances to the adoption of IGR in order, while the mentioned scenario for the case of EGR is in the reverse order.
- The knowledge of construction stakeholders regarding the various types of benefits and life-cycle cost of GR installation can play a more effective role than financial incentives for further adoption of GRs.

To the best of the authors’ knowledge, this research is the first study of its kind in Iran. As a result, it provides academic implications for further research in this area as well as managerial implications as a guideline for the policymakers. It is notable to mention that, as a common limitation of non-probability sampling techniques, there is a limitation in generalizing the results; however, it is believed that the results are applicable in Shiraz in account of using very knowledgeable respondents and accurate methods for analysis. In terms of future study, according to the findings of this research, two types of research are recommended; first, as Iran has various climates and this study focused on the semi-arid climate of Shiraz, further study can focus on other climates; second, due to the dearth of cost–benefit analysis of GR installation in Iran, conducting a comprehensive research to show the financial feasibility of GRs could contribute to increasing the knowledge of construction stakeholders and the adoption of GRs.

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