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Sustainable Futuristic Energy Scenarios for Low-Carbon Industrial Heritage: Green Adaptive Reuse of Karaj Iron Foundry

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Abstract

Addressing climate challenges related to carbon emissions, particularly after the Industrial Revolution, is one of our current major global issues. Today, many industrial heritage sites have become abandoned and are known as wastelands. The adaptive reuse of these sites has been recognized as a potential and effective solution to prevent environmental damage while preserving their unique characteristics. Moreover, the conservation of industrial heritage sites requires meticulous planning with a futuristic vision, particularly at the early phases of decision-making. Therefore, this study aimed to examine futuristic sustainable scenarios for industrial heritage sites to reduce their carbon footprint by 2050, with a specific focus on enhancing the energy performance of an industrial heritage site in Iran, the Karaj Iron Foundry. In this study, future scenario-making has been employed as a significant methodology to analyze and investigate future possibilities in energy efficiency and the sustainable reuse of the case study. Three scenarios are presented through the future design and discipline of anticipation frameworks (the FD-DoA method). Each scenario shows alternatives that the site can pursue to mitigate carbon emissions and improve energy efficiency by 2050, which have impacts on the urban scale. The scenarios provide a framework for low-carbon policy development for such valuable industrial heritage sites.

Keywords

carbon footprint; carbon neutrality; designerly decision support system; energy efficiency; futuristic visioning; green adaptive reuse; industrial heritage; low-carbon heritage

1. Introduction

The construction sector is one of the largest energy consumers and a major source of global warming due to greenhouse gases and carbon dioxide production (Abd Elgawad et al., 2025). Adaptive reuse of built environments/buildings reduces carbon dioxide emissions and leads to achieving a low-carbon future (Blagojević & Tufegdžić, 2016). In addition to preserving latent energy (Huang et al., 2025), this approach can also reduce energy costs and control negative environmental impacts through the implementation of energy efficiency ideas and low-carbon strategies (Angrisano et al., 2024; Barone et al., 2024; Gustafsson et al., 2017). Adaptive reuse of industrial heritage (ARIH) sites can play a positive role in improving the urban environment due to their unique features, such as large spaces, strong structures, and location often within the urban context (The International Committee for the Conservation of Industrial Heritage, 2003). However, the problem is that many of these sites are considered urban voids and wastelands due to their semi-abandoned or dilapidated condition. In the adaptive reuse process, due to its impact on urban spaces, it is necessary to coordinate with other urban elements to integrate into the urban context and fulfill the needs of citizens (Trusiani & D'Onofrio, 2024). Furthermore, considering interdisciplinary issues such as climate conditions, urban factors, and the preservation of historical features in the adaptive reuse process is necessary (Abd Elgawad et al., 2025; Blagojević & Tufegdžić, 2016). This makes the decision-making process more complex (Huang et al., 2025; Yung & Chan, 2012). Moreover, given rapid urbanization, adaptive reuse must be carried out with long-term futuristic visioning to ensure sustainability (Boostani & Sadeghiha, 2022; Ouf, 2024), taking into account the opinions and needs of future generations, to improve the urban environment in line with sustainable development (Holtorf & Bolin, 2022).

Recent studies have addressed the energy assessment in the ARIH process. Yang et al. (2025) analyzed the energy consumption of an industrial heritage site before and after reuse in the energy analysis in DesignBuilder software and obtained two scenarios of "enhancements" and "reductions." Huang et al. (2025) emphasized the full life cycle in ARIH for the assessment of embodied carbon and proposed energy efficiency solutions considering the heritage characteristics. This is because compensating carbon emissions is different for a factory that has never been in operation than for a factory that has been active at the time. Wang et al. (2023) have presented strategies for energy efficiency and carbon reduction that include urban-scale considerations such as the number of floors, road network density, building density, and green space ratio. The results of the study by Guidetti and Ferrara (2023) showed that the latent energy in urban heritage and land use is important in prioritizing interventions for the preservation and reuse of existing buildings in the urban context. Sinou et al. (2023) highlighted strategies in green–blue infrastructure and landscape elements, including ecological corridors or connections between urban elements, which can play an effective role in sustainable ARIH. Pavlović et al. (2022), by examining energy efficiency improvement for an industrial heritage site, emphasized new strategies such as thermal insulation for facades.

Existing research highlights various strategies in ARIH that are often focused on energy efficiency and carbon reduction aspects, and emphasize the connection between the urban environment landscape and people. However, it is necessary to have a comprehensive perspective for a sustainable ARIH. Cultural heritage, as an integral part of the built environment, is significantly linked to identity (Dezfuli et al., 2024) and encompasses valuable human-made features (Goodarzi et al., 2023; Ranjazmay Azari et al., 2023; Shaeri et al., 2022). However, a critical research gap persists; most of these strategies neglect heritage features with a long-term futuristic perspective and lack interdisciplinary integration with futures studies.

In addition, striking a balance between preserving heritage values and applying energy efficiency principles is essential in ARIH. Since heritage belongs to future generations, the perspective of future generations must be taken into account in the decision-making process for ARIH. However, given the lack of future generations' existence, it is necessary to adopt a new approach in which there are some representatives from the current generation, such as Imaginary Future Generations (IFGs).

Therefore, to address these gaps, this study aims to provide energy-efficient solutions for ARIH in Iran, focusing on the Karaj Iron Foundry (KIF), while preserving its historical values and making decisions based on the future generations' needs through the interdisciplinary knowledge of futures studies. This study employs a futuristic visioning approach through expert surveys as IFGs and scenario analysis to balance heritage preservation and energy efficiency. In this study, first, the indicators related to ARIH were identified with a comprehensive perspective. Then, the importance of the indicators for ARIH in Iran was assessed through a questionnaire completed by experts in the form of IFGs. Next, experts presented energy efficiency solutions based on the priorities of the indicators, and in sustainability dimensions, with a futuristic perspective in what we called a "future design" workshop. The case study, KIF, needs reconstruction and revitalization due to its current unfavorable condition and serious threats of destruction. Also, due to the rapid urban development and population growth of Karaj city in recent years, this area will face challenges in the future. Finally, the differences, similarities, and impacts of the solutions were examined through a tree diagram analysis (TDA) by analyzing the scenarios. This study provides practical strategies for policymakers, decision-makers, and government institutions for adaptive reuse of the KIF, considering future conditions of Iran and preserving heritage values. The future design and discipline of anticipation frameworks (the FD-DoA method) provides a useful path for decision-making for other industrial heritage sites.

2. Energy Efficiency in Iran

Iran is one of the top ten carbon dioxide-producing countries in the world, and its energy consumption is three times the global average (Hosseini et al., 2019; Iran Renewable Energy Association, 2022). Buildings, as the largest energy consumers in Iran, play a significant role in this condition, and most of the country's energy is supplied by fossil fuels. Although the trend of oil production and consumption has fluctuated in recent years (International Energy Agency, 2025; World Bank, 2025), due to Iran's complex energy relations and the oil trade restrictions, dependence on these sources must be reduced and alternatives found (Shikh Mohammadi & Hashemi, 2024). The importance of this issue is so great that a major part of Iran is covered by warm and arid climate zones, and this amount is expected to reach more than 90% by 2050 (Kiani & Kamangar, 2022). Also, increasing carbon dioxide emissions by 2100 will increase the average temperature of the country by 1.5–4.5°C, which could have significant effects on energy demand (Ghazi et al., 2025). In this regard, one of the domestic measures to control this issue is the document by the Research Center of the Islamic Consultative Assembly (RCICA) in 2023. While this document presents a set of solutions (e.g., implementing energy optimization plans, diversifying the energy portfolio by developing renewable energies, creating sustainable job opportunities to address environmental problems, developing a circular economy in the country, and promoting interactions with neighboring countries to strengthen the technology transfer mechanism), they are just proposals, not requirements. Moreover, the enforcement mechanisms are weak and need careful planning to deal with the environmental crises in Iran. Although numerous abandoned industrial heritage sites exist in Iran (Gharaati et al., 2023) and represent untapped potential for reducing urban greenhouse gas emissions, such strategies remain absent from current policy proposals.

3. The Industrial Heritage of the KIF

3.1. Historical Context

During the Pahlavi era (1925–1978), an industrial revolution occurred in Iran that was accompanied by the cooperation of foreign engineers and led to the implementation of many industrial infrastructures. This experience played a significant role in Iran's self-sufficiency in the production of industrial goods. One of these major projects was the KIF, which started in 1936 with the collaboration of German experts. The 18-hectare factory was designed by the German consortium Demag-Krupp and architects Hans G. Meyer and Martin Hoffmann in the modern Iranian-Pahlavi style. It was initially intended to produce 100,000 tons of steel per year, but the construction was halted due to the World War II (Figure 1). Today, the KIF is a historical monument that reminds the aspirations of Iran's industrial society, as well as reflects the impact of World War II on the country (Ghazi Moghadam & Madahi, 2014; Lajvardi, 1985).

Figure 1. The KIF during operation. Source: Bildarchiv der Philipp Holzmann AG (1939–1940).

3.2. Current Use and Condition

Today, the Alborz Mining Industry and the Karaj Municipality are known as the owners of the KIF. It is estimated that around eight years of its useful life remain (Sotodeh & Ghobadian, 2022). The Iran Steel Trading Services Company has allocated a part of the land to the depot and scrap metal at present. Another part has been leased to the organizations for truckers' parking and a CNG fuel station. One of the most important features of this industrial heritage site is its location in the urban context and its proximity to a variety of uses (Figure 2).

No	Name	Use	Distance (m)
1	Karaj Truckers Cooperative	Transportation and parking	Next to the site
2	Kalantari Gas Station	Gas Station	200
3	Residential area	Residential	500
4	Mohammad Shahr (Mahdasht)	Metro Station	1000
5	Karaj Shahid Kalantari Terminal	Bus Terminal (Cites)	1000
6	Bus Terminal Alborz	Bus Terminal (Urban)	1000
7	Residential area	Residential	300
8	Data and Fruit Distribution Center	Comercial	800
9	Bus Station	Bus Station	300
10	University of Applied Sciences	University	600
11	Karaj-Qazvin FW	Free Way	600
12	Residential area	Residential	800
13	Industrial town	Industrial	200
14	District 2 Education Department	Official	700
15	3 Bus stations	Bus station	700
16	Alborz Province Standard Office	Official	700
17	Alborz Province Headquarters	Official – military	700
18	Shariati Sports Complex	Sport	1000

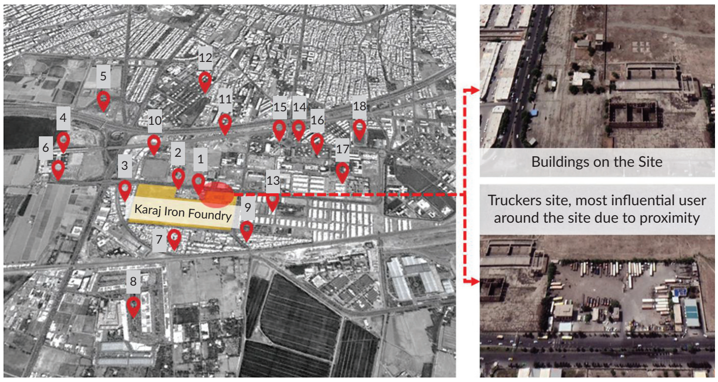

Figure 2. Around the KIF, up to an almost 1 km radius. Images collected using Google Maps.

3.3. Site Visit Observations

According to the visit conducted by the first and third authors in 2022, the overall condition of the site is very critical, and since this site has never been used, it is only familiar to a group of people. Therefore, it needs to be addressed as soon as possible. The industrial area can be divided into two parts: (a) an eastern-western area and (b) non-industrial spaces, which include houses for engineers. The structures in the industrial part are in the skeleton stage, and some of them do not have roofs. They have been designed in the modern Iranian Pahlavi style, and show a unique fusion of modern and traditional architectural elements. Although most of the buildings in this area are structurally stable, they are in a deteriorating condition and need serious attention. Furthermore, coatings, exterior layers, and interior spaces are at risk of destruction due to the lack of cover in the openings. The site's physical condition is almost stable, though material efficiency and sustainability are compromised due to decay. Moreover, it seems it is not very aesthetically pleasing to local people. In terms of urbanity, it has no relation to other surrounding areas, but it has the potential for reuse.

Based on observations during site visits, in the non-industrial space, there are several houses near the site that were designed for German engineers at the time. There is also a building near the site that was a guesthouse for other engineers, now converted into the Harmonic Centre.

In the western part of the industrial area, the constructions on site are (see Figure 3): the office brick building with two floors, built in the German architectural style, and in reasonably good structural condition—the interior space here has a flat roof covered with beams and brick frames and embossed semi-crescent arches decorate the exterior (3a); a semi-finished brick structure with no interior space (3b); semi-finished concrete structures, in which one of the buildings has exposed rebars—a concrete placer material transfer channel of about 200 meters in length and more than 2 meters in width starts from the main hall and the possible location of the kilns and extends to the back of the office building (3c); a six-story building, the use of which was for refrigeration and storage nearby (3d); an office building and a large pond on the west side (3e, 3f); structures in the initial stages and foundation (3g). In the eastern part of the industrial area, there is a concrete building about 10 meters high, built on two levels, with a railway crossing on 4 meters under the ground (Figures 3h and 3I).

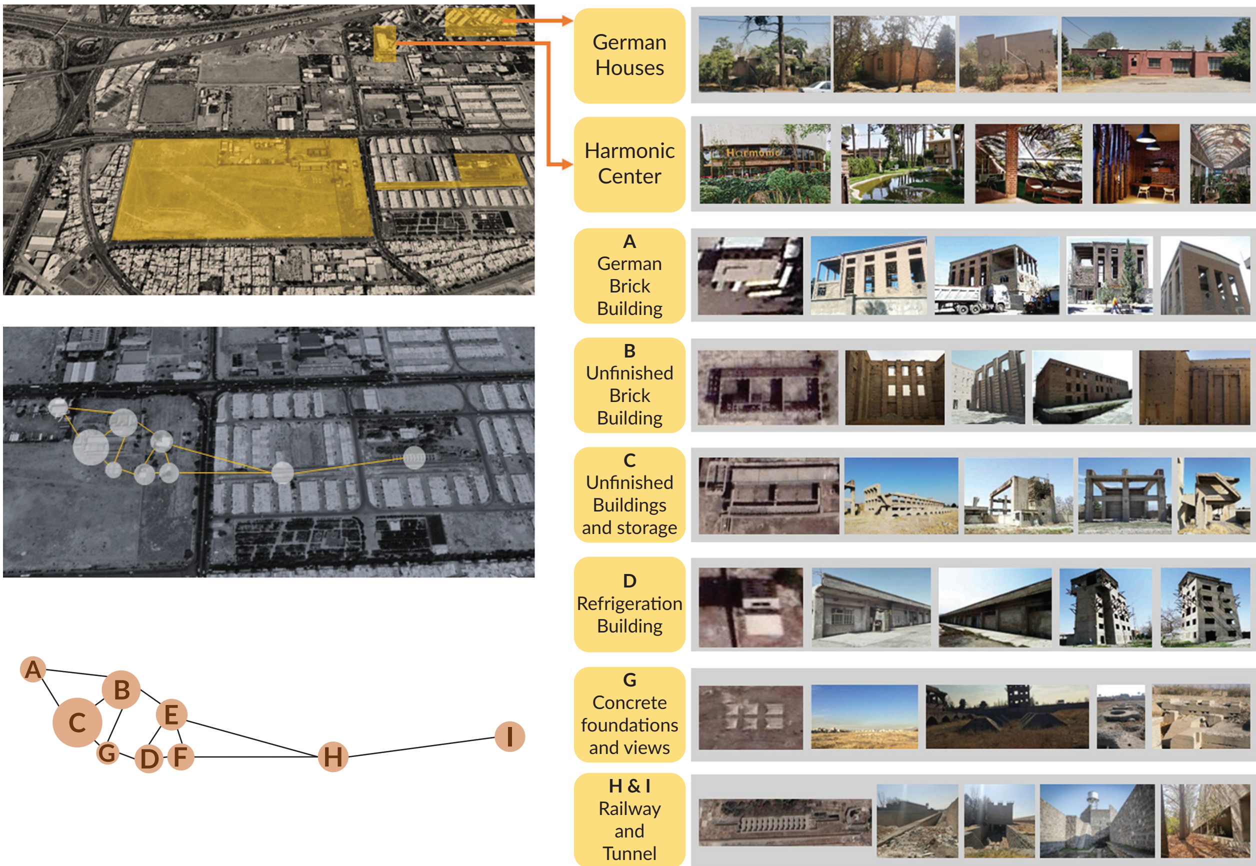

Figure 3. Current situation of the remaining buildings and structures of the KIF. Source: Location map was collected using Google Maps and photos were taken by the authors.

3.4. Heritage Significance

The architectural style is a combination of modern and traditional Iranian aesthetics, which reflects the aspirations and identity of the Pahlavi era. While a part of the land serves industrial purposes, the larger section remains abandoned. There are several threats, such as the absence of vegetation, potential vandalism by truck drivers, and the lack of protective policies. Moreover, the pure volumes of the buildings, rectangular geometry, and low-rise core are the prominent architectural features of the buildings. The consecutive windows on the walls play an effective role in lighting the space. Wooden molds on the concrete from under the roof add a touch of modern decoration. Semi-finished brick and concrete structures, along with a six-story building, portray the technical prowess of the time. The large spaces and robust structures of the KIF make it ideal for adaptive reuse. However, the future climate condition of Iran (Section 2) and the current situation of the site need innovative approaches to balance heritage preservation and carbon reduction goals. Although studies on the KIF emphasize the urgent need for its conservation (Sotodeh & Ghobadian, 2022), Iran lacks specific legal frameworks for conserving industrial heritage sites (Gharaati et al., 2023). Therefore, this study addresses these gaps through a futures' study methodology to develop future scenarios considering both historical values and energy efficiency goals.

4. The Karaj City: Current Conditions and Future Challenges

Considering the location of the KIF in Karaj city, it is essential to examine the sustainability dimensions of this region, including climate and urban conditions. Karaj (the capital of Alborz province), the fourth largest city in Iran, is located 36 kilometers from Tehran (the capital of Iran) and under the influence of the Alborz highlands, the Chalus Valley, and the Karaj River, has a cooler and wetter climate than Tehran. This city sometimes experiences heavy rainfall and flash floods during the summer. The absolute minimum and maximum temperatures are −20°C and +42°C, respectively, and the annual average temperature is 14.1°C. The prevailing wind in Karaj is northwesterly, and its average speed is 3.4 meters per second.

Air pollution and inversion are among the most important environmental challenges in Karaj, which occur due to the expansion of the city, heavy vehicle traffic, and the presence of factories and industrial estates (Boostani & Sadeghiha, 2022). Air pollution in this city is so severe that in 2021, Karaj experienced 94 days of unhealthy air due to high amount of the matter smaller than 2.5 microns (PM2.5; Shahbeik et al., 2022). Another environmental challenge is its high vulnerability to frequent earthquakes (Aslani et al., 2019).

Karaj city recorded the highest population growth rate among Iranian cities in 2023, at 4.7%. This issue was so significant that until 2010, Karaj was part of Tehran province. However, due to rapid urban growth and population increase, it was introduced as the capital of Alborz province. This population increase, which was caused by widespread migration, has become a significant issue due to its proximity to Tehran and lack of comprehensive urban planning (Shakarami et al., 2021). In the past, Karaj city was beautiful with green urban gardens due to its favorable climate and water resources. However, today, these areas have been mainly converted into residential areas and roads due to urbanization, human construction, and extensive migration. Recent studies show that there is a significant decrease in the area of gardens and vegetation in Karaj (approximately 10 million square meters, from 56.689.539 m^2 to 45.876.904 m^2, from 2001 to 2021; see Ghorbani & Sajadzadeh, 2024). Furthermore, the environmental quality of Karaj has notably decreased. The Remote Sensing Ecological Index reflected a decrease of 0.34 (from 0.59 to 0.25, from 2010 to 2022; this index typically ranges from 0 to 1, with higher values indicating better ecological quality; see Naseri et al., 2025). As pollution and climate change continue to increase, environmental conditions and quality of life in Karaj will face more challenges by 2050 (Figure 4). These urban pressures directly impact the adaptive reuse potential of the KIF. For example, controlling air pollution requires environmentally friendly and low-carbon adaptive reuse strategies. Moreover, population growth could pose a threat to KIF by increasing

Figure 4. The changing face of green spaces and urban sprawl in Karaj city, the KIF area: March 2004 (left) and March 2024 (right). Images collected using Google Earth.

demand for housing development. Therefore, the 18-hectare KIF site has the potential to address these pressures through green rehabilitation.

5. Anticipating Urban Futures

Cities are complex networks of elements and are known to be highly sensitive to various factors in sustainability dimensions (Huang et al., 2025). This complexity makes it challenging to accurately anticipate their future. However, forecasting methods can anticipate future directions, taking into account uncertainties while embracing the different dimensions of sustainability (Ouf, 2024).

Urban futures can be classified as possible, plausible, and probable futures. Possible futures are formed based on past trends, probable futures mostly rely on scientific predictions, and plausible futures are shaped based on the opinions of city leaders and people (Gall et al., 2022; Mahdavinejad et al., 2025). On the other hand, due to the nature of heritage and its transmission to future generations, "time depth" becomes important since heritage can act as a bridge to connect the past to the future (Grazuleviciute-Vileniske & Zmejauskaite, 2025). Hence, it is necessary to make decisions for the adaptive reuse of the KIF by utilizing the interdisciplinary knowledge of futures studies. The FD-DoA methods were used to advance this goal.

5.1. Future Design

The decisions of the current generations will have a significant impact on the future generations' lives. However, future generations are not present in today's decision-making process and cannot express their opinions. Therefore, there is a need to adopt a method in which the current generation acts as representatives of future generations and participates in decision-making. The "future design" method seeks to incorporate the perspectives of future generations into the current decision-making process (Saijo, 2019) while defining the term "futurability." This method was implemented in a workshop series structured around three designs: past design, present design, and future design. The purpose of the future design method is to help current generations imagine themselves as IFGs and participate in the group decision-making of current generations (Kamijo et al., 2017; Saijo, 2023). The main mechanism of the future design method is that participants travel to the future with a time machine at the same age and make decisions about issues based on the condition of that future. When they travel into the future, they no longer pay attention to short-term and superficial issues, and long-term issues attract their attention with a deeper perspective (Hara et al., 2019). Then, the person offers appropriate strategies for *their* present (Saijo, 2025). This approach raises awareness of the current generations about their responsibilities toward future generations (Hara et al., 2021; Saijo, 2024). Since adaptive reuse is a process that requires careful attention to various aspects, such as legal restrictions related to heritage preservation, the feasibility of proposed solutions, and the ability to address the challenges, holding workshops with experts is necessary (Arfa et al., 2024). Therefore, in this research project, due to the complexities of adaptive reuse, the future design workshop was held with experts. Conducting all three workshops helps to assess shifts in participants' perspectives. However, the future design workshop, as the core session of the future design method, activates the futurability. Therefore, according to the aim of this study—which is to develop future scenarios and strategies—only the future design workshop was conducted.

5.2. The Discipline of Anticipation

Engaging in anticipation studies requires a meticulous approach that begins with defining the knowledge area and selecting appropriate methodologies. To overcome the challenges in evaluating anticipations, it is useful to adopt the concept of futures literacy (FL), which is similar to acquiring a new language skill for effectively navigating the future (Holtorf, 2022; Miller, 2018). FL encompasses the understanding of "what to know," "when to know," and "why it is important to know" (Miller et al., 2013).

Anticipation aims to implement results derived from forecasting and foresight into decision-making and actions. This is evident in various temporal patterns, from micro anticipations in perception to broader forms of social anticipation spanning seconds to decades (Poli, 2017). The first phase of anticipation studies raises critical questions about participant selection, methods of invitation, and the location of the process. One of the challenges of FL is to collectively change participants' perceptions to form a shared understanding of the future, and it often requires collaborative work in small groups. The selection of participants and locations depends on factors such as the group members, the topic, the time available, and the context (Miller, 2018). The integration of the discipline of anticipation (DoA) in this research is explained in more detail in the following section.

6. Research Method

To create a balanced vision between preserving heritage values and energy efficiency in ARIH, by referring to the international charters for the conservation of cultural and industrial heritage (including Nizhny Tagil, Dublin, Taipei, and Venice; see Gharaati et al., 2023) and green building certifications (including DGNB, LEED, CASBEE, BREAM, and GREEN-star), 47 indicators were divided into seven categories (see Table 1).

Then, using the perspective of the IFGs and examining the anticipated futures for Iran as well as scientific studies on energy efficiency, an initial assessment was conducted based on the identified indicators. At this stage, 23 experts were selected with doctoral degrees in the fields of architecture (6), civil engineering (5), urban planning (5), archaeology (4), and environment (3). The number of experts was balanced to ensure a comprehensive perspective and minimize potential bias, inspired by DoA. They were selected based on previous knowledge by the authoring team to ensure a minimum of five years of experience and peer-reviewed publications in their fields, with various geographic representations across Iran. They were asked to assess the importance of the indicators from the perspective of the IFGs, considering the future of Iran's energy for ARIH, through a 7-point Likert scale questionnaire. The results of this stage and the weight of the indicators were also useful for assessing other Iranian industrial heritage at level 1 (De Santoli, 2015). The future design mechanism (Sec 5.1) was explained to the participants via a 7-minute movie.

Then, for the presentation of energy efficiency scenarios for the KIF, inspired by DoA among the 23 experts, based on their close field of study with adaptive reuse of heritage, nine of them met the criteria and were invited. The online future design workshop was held on the Zoom platform since the experts were from different geographical locations in Iran. The authors acknowledged that the virtual FD workshop might have limited the depth of creative ideas compared to in-person future design workshops, but they tried to mitigate this limitation by creating a friendly environment for discussion during the online meeting. Finally,

Table 1. The indicators and categories.

Category	Abbreviation	Indicators
History	HIST	1—Integrity, 2—Sense of place, 3—Homogenous use, 4—Reversible physical intervention, 5—Public participation, 6—Use of educational facilities, 7—Creativity
Environment	ENV	1—Building life cycle assessment, 2—Local environmental impact, 3—Sustainable resource extraction, 4—Potable water demand, 5—Land use, 6—Biodiversity
Economy	ECO	1—Life cycle cost, 2—Flexibility and adaptability, 3—Commercial viability
Social-Cultural	SCO	1—Thermal comfort, 2—Indoor air quality, 3—Acoustic comfort, 4—Visual comfort, 5—User control, 6—Quality of indoor and outdoor space, 7—Safety and security, 8—Design for all, 9—Future generation perspective
Process	PRO	1—Comprehensive project brief, 2—Sustainability aspect in tender phase, 3—Documentation for sustainable management, 4—Urban planning and design process, 5—Construction process, 6—Quality assurance of construction, 7—Systematic commissioning, 8—User communication, 9—Facility management planning, 10—National legal policies
Technology	TEC	1—Fire safety, 2—Insulation layers, 3—Quality of building envelope, 4—Use of technology, 5—Ease of cleaning, 6—Ease of recovery and recycling, 7—Immission control, 8—Mobility infrastructure
Site	SITE	1—Natural disaster and risk management, 2—Influence of district, 3—Transport access, 4—Access to amenities

five experts participated in this meeting (one heritage specialist, one civil engineer, two architects, and one urban planner). The future design workshop followed Saijo's (2025) protocol and was held as follows:

1. A week before the future design workshop session, information related to the energy efficiency of Iran, the industrial heritage of Iran, the KIF, the Karaj city's conditions, and the results of the questionnaire were sent to participants in the form of a pamphlet (see also Nishimura et al., 2020).
2. On the day of the FD workshop, before the discussion session, through the future design method, participants were given the task of imagining themselves in the future at the same age, traveling to the future in 2050 by a time machine, and present energy efficiency scenarios for the KIF (see Nakagawa et al., 2024).
3. During a two-hour discussion, three scenarios were presented.

In the final stage, the scenarios were analyzed using TDA by the authors, and their similarities and differences were analyzed. The TDA was used for its capacity for visual mapping, and provides a clear visual representation of the similarities and differences in each scenario. As a result, a general energy efficiency approach for the KIF was proposed with a futuristic perspective up to 2050. In addition to preserving heritage values, this approach incorporates time-based energy efficiency strategies aligned with future predictions (Figure 5).

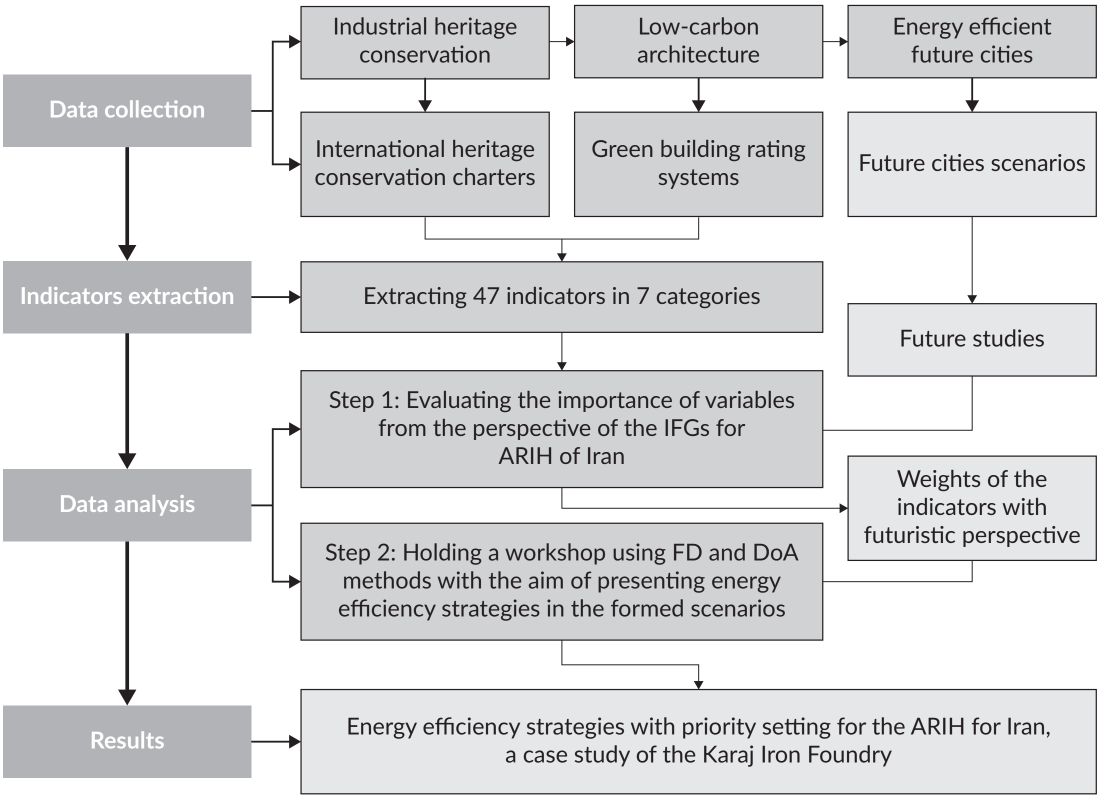

Figure 5. The structure of the research.

7. Results

7.1. 1st Step: Determining the Weight of Indicators

In this step, a fuzzy computing environment for data analysis was necessary due to the high uncertainty. The fuzzy Shannon entropy, as one of the most powerful MCDM methods, was selected for its capacity to handle this linguistic uncertainty and objectively weight indicators without requiring a priori assumptions. Therefore, the data was analyzed using the Shannon entropy method in a fuzzy environment (Monghasemi et al., 2015). Hosseinzadeh Lotfi and Fallahnejad (2010) proposed an approach based on Shannon's entropy using interval data such as the α-cut (Table 2). According to previous studies, the most commonly used alpha value is 0.5; therefore, this value was applied in the calculations.

Table 2. Linguistic values and their alpha interval values.

Linguistic value	Alpha interval value
Very low	[0.060, 0.186]
low	[0.186, 0.311]
Somewhat Low	[0.311, 0.437]
Neutral	[0.437, 0.562]
Somewhat High	[0.562, 0.686]
High	[0.686, 0.811]
Very High	[0.811, 0.935]

After the analyses, the weights of the indicators were obtained as shown in Figure 6 and Table 3. The top 10 indicators with the highest weight are respectively: PRO7 (0.0276), PRO2 (0.0255), PRO3 (0.0244), PRO4 (0.0244), ENV3 (0.0241), PRO1(0.02388), SITE1 (0.02385), ENV4 (0.02339), ENV1 (0.0232), TEC4 (0.0229). Also, the order of importance of the categories is as follows: PRO (0.224), SOC (0.187), TEC (0.162), HIST (0.146), ENV (0.132), SITE (0.082), ECO (0.064).

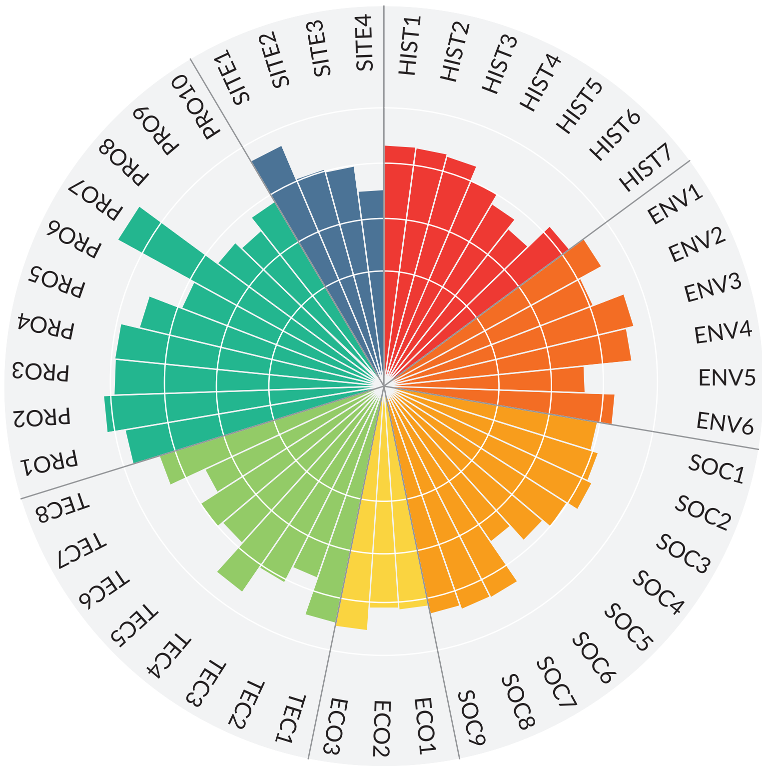

Figure 6. Prioritization of indicators with their categories.

The dominance of "process" (PRO, 22.4%) reflects experts' prioritization of adaptive reuse implementation indicators over the other categories. Furthermore, the mid-range weighting of the HIST (14.7%) shows that IFGs consider a more balanced preservation needs with adaptive reuse requirements, in contrast to approaches focused solely on preservation. The maximum weighted indicator (PRO7) shows the IFGs' prioritization in futurability, and phased planning ensures reversible interventions and the protection of heritage values by taking into account uncertainties and temporal changes. These weighted indicators shaped the future design workshop's scenario-making, as discussed in the next section.

7.2. 2nd Step: Holding the Future Design Workshop

Based on futures studies, the major category of the three scenarios for the KIF was developed by the authors: probable, possible, and plausible futures. The participants were asked to discuss the details, such as hypotheses, uncertainties, solutions, challenges, and impacts for each scenario collectively as one group. The solutions were proposed based on the weighted indicators in the previous step. In all scenarios, the final use of the KIF was envisioned as a mixed-use complex.

Table 3. Weights of the indicators and their categories based on the questionnaire analysis.

Economy (0.0641)	Environment (0.1326)	History (0.1467)	Process (0.2242)	Social-Cultural (0.1870)	Technical (0.1625)	Site (0.0825)
ECO1 0.02083	ENV1 0.02324	HIST1 0.02213	PRO1 0.02388	SOC1 0.02052	TEC1 0.02224	SITE1 0.02385
ECO2 0.0206	ENV2 0.02116	HIST2 0.02208	PRO2 0.02556	SOC2 0.02121	TEC2 0.01867	SITE2 0.02053
ECO3 0.02268	ENV3 0.02410	HIST3 0.02194	PRO3 0.02445	SOC3 0.02161	TEC3 0.02028	SITE3 0.02025
	ENV4 0.02339	HIST4 0.02062	PRO4 0.02445	SOC4 0.02076	TEC4 0.02291	SITE4 0.01789
	ENV5 0.01900	HIST5 0.01969	PRO5 0.02266	SOC5 0.01960	TEC5 0.01926	
	ENV6 0.02172	HIST6 0.01873	PRO6 0.01957	SOC6 0.01764	TEC6 0.01989	
		HIST7 0.02149	PRO7 0.02762	SOC7 0.02211	TEC7 0.01791	
			PRO8 0.01874	SOC8 0.02199	TEC8 0.02141	
			PRO9 0.01792	SOC9 0.02159		
			PRO10 0.01938			

7.2.1. Scenario 1: Sustainable Progress (Plausible Future)

In this scenario, it is assumed that by 2050, Iran has succeeded in developing sustainable energy policies, reducing its dependence on fossil fuels, and replacing them with renewable energy sources. Economically, the country has transitioned towards sustainability, and there is effective coordination between the Cultural Heritage Organization and the owner. The government has provided sufficient financial resources to invest in the rehabilitation and adaptive reuse of the KIF. On the other hand, the population of Karaj, which was a major challenge in 2025, has been managed sustainably, and the urban infrastructure has been improved for the rehabilitation of the KIF.

The uncertainties of this scenario include the quality of implementation and innovations. Public acceptance is also another uncertainty that depends on the support of local communities and officials for the ARIH and the level of public acceptance after the adaptive reuse.

Effective solutions in this scenario are based on the success of Iran's sustainable energy policies in 2050. Therefore, a step-by-step systematic implementation with phased perspectives (every ten years, until 2030, 2040, and 2050) and detailed planning for the exploitation of all buildings was proposed (PRO7). The management plan is provided up to 2030, the urban issues, connections through roadways or bicycle paths have been designed, and green spaces and open areas have been implemented up to 2040. Furthermore, the energy-efficient and smart technologies have been implemented up to 2050. Office buildings located in the truckers' area are prioritized due to their good physical conditions (TEC4). In this scenario, on-site energy generation and its use for other local users are also possible, provided that the heritage identity of the existing buildings is preserved (ENV1). In the case of implementing a double-skin brick facade, interventions should not affect the heritage values of the facade. Since the skeletal structures are roofless, the use of natural light or skylights will be useful (TEC4). Moreover, due to Iran's progress in the field of production, the use of sustainable and recyclable materials such as recycled bricks is recommended, along with compliance with health and environmental standards at all stages (ENV3). Also, in open spaces and on an urban scale, due to the coordination of decision-making bodies, to interact with other urban elements after the adaptive reuse of KIF, medicinal and indigenous plants can be used for greening the space (PRO4). In addition, due to the development of sustainable energy systems, life cycle analysis will be useful with the aim of reducing environmental impacts (ENV1). For the use of passive energy, according to the "compact cities," the use of underground spaces that lead to maximum use of urban land is suggested. In Iranian vernacular architecture, a *Shavadan* (or *Shadan*) is an underground and naturally cool space used in hot and humid climates to escape the heat. These spaces were typically constructed with stone and brick that provided thermal comfort for occupants through insulating properties and protection from direct sunlight. A similar effect for the KIF can be attained by connecting it to the adjacent Mohammad Shahr metro station through underground corridors. Commercial, cultural, and educational activities can take place in this corridor. Also, due to the government's financial support for the adaptive reuse of KIF, new and additional structures can be added to the space in a precise and planned manner. Due to the coordination of government agencies, it is also possible to plan for public participation in the adaptive reuse process through surveys and discovering their local needs (PRO1).

One of the most important challenges is the complexity of planning and implementing solutions for the adaptive reuse of the KIF. No matter how good the economic conditions in Iran are, the decision to implement energy efficiency solutions in this process still complicates the situation. The combination of new technologies and sustainable energy efficiency solutions must also be coordinated with the conservation of heritage and identity. The technical implementation of innovative ideas requires high technical knowledge and specialized teams. The location of photovoltaic cells in this scenario was discussed by experts. On a macro-scale, if photovoltaic cells are to be installed on the ground, their impact on vegetation should not be overlooked. Also, the balance in land use between vegetation and photovoltaic cells should be considered, as this affects local biodiversity. On a micro scale, photovoltaic cells can affect the color, geometry, reflection, and elevation of the ground. Furthermore, if the installation is on the roof of buildings, the proportionality of its geometry and the preservation of the historical identity should be prioritized.

As a result of this scenario, the adaptive reuse of the KIF can serve as a model for reducing and properly managing energy consumption and carbon emissions for other industrial heritage sites. Also, if the KIF could draw public attention after adaptive reuse, this project can help increase public trust in the government and cultural institutions.

7.2.2. Scenario 2: Survival and Adaptation (Possible Future)

In this scenario, it is assumed that by 2050, climate change and economic pressures have continued to affect the country, but the government has been able to provide limited financial resources for the restoration and sustainable reuse of the KIF. Karaj's urban population has continued to grow, but it has not posed a significant threat to the city or the restoration of the KIF. The Iranian government's energy efficiency policies have generally been implemented gradually, but with limited effects.

The uncertainty in this scenario is the limited resources. Besides, the extent of government policies to support the sustainable reuse of the KIF and the availability of a skilled and experienced workforce to implement these project goals are unknown. Moreover, although public transportation can play a positive role in urban energy efficiency, a precise decision cannot be made for KIF due to the limited energy efficiency policies.

In this scenario, assuming that energy efficiency policies in Iran have been generally established, solutions extend beyond energy efficiency and move towards low-carbon strategies. Systematic implementation is combined with the concept of monitoring, which occurs every five years (PRO7). Moreover, at each stage of monitoring, testing, and evaluation of progress and changes should be carried out, and planning must be readjusted based on the results (PRO1). Regarding sustainability, it is necessary to examine the past, present, and future of the KIF in sustainability dimensions. In particular, due to the inactivity of the KIF in the past, this site is considered relatively a low carbon producer and has caused less environmental damage than other industrial sites that produced lots of carbon during their operation. However, due to its inactivity in the past, it did not contribute to the growth of the economy of Iran at that time and did not employ people for iron smelting (PRO2). In addition, due to its inactivity in the past, people only remember a few stories of the past. These issues became more serious in the past dimensions of this scenario to enhance the sense of belonging (ENV1). Regarding open spaces, Iranian garden design principles are considered a solution to improve air quality and increase energy efficiency (TEC4). In the past, Karaj was covered with gardens, but urbanization has led to their disappearance. It is time to attract people to KIF through collective memory. Iranian gardens do not require much care and can improve the microclimate by creating shade, pleasant air in the open air, and natural ventilation because of the use of special geometries, precise sizes and proportions, and native plants (Afsahhosseini, 2024). In addition, due to the limited water resources in this scenario, rainwater and greywater recycling systems can be used to reduce water consumption for irrigation (ENV4). Similarly, due to limited financial resources, it is necessary to propose energy efficiency solutions through BIM for optimal management and operation of buildings (PRO3). Therefore, passive energy solutions combined with active ones are proposed (TEC4). The orientation of the buildings on the KIF is East-West and has the potential to use natural lighting. Due to the prevailing northwesterly winds from the Alborz Mountains and the orientation of each building, which has the largest influence on energy demand, the buildings have good potential for natural ventilation. Also, the use of natural light in this scenario should be without heat transfer. Due to resource limitations, it is necessary to prevent the construction waste at the site during the adaptive reuse process (ENV1).

Similar to the first scenario, the complexity of adaptive reuse, while considering the preservation of heritage values, remains one of the most important challenges. However, due to resource limitations and the lack of specialized experts, obtaining funding for this project and justifying it to government agencies for possible return on investment is challenging. In addition, short-term monitoring for five years requires careful planning, advanced monitoring tools, and coordination between stakeholders.

The impact of this scenario, which results from the combination of passive and active solutions, the use of green space, and the Persian garden, is the potential for a reduction in energy consumption; however, its effectiveness depends on resource and technological constraints. Additionally, the adaptive reuse of the KIF, in line with sustainable solutions and green space design, can help create a relaxing and pleasant environment for people and improve the quality of life and health.

7.2.3. Scenario 3: Failure and Inaction (Probable Future)

In this scenario, it is assumed that, by 2050, the Iranian economy will have remained in recession, and the government will have had very limited financial resources for revitalizing and adapting the reuse of the KIF. In addition, climate threats such as global warming, air pollution, earthquake management, etc., have remained unresolved in Karaj, intensifying their destructive effects. The population of Karaj has continued to increase due to migration without proper management. On the other hand, sustainable energy management policies and programs for the adaptive reuse of the KIF in Karaj have not been implemented effectively due to the lack of sustainable energy management.

The uncertainties of this scenario are based on resource shortages, lack of effective management, and worsening economic conditions. The extent of the deterioration of Iran's economic situation and inflation is unknown. It is also unclear how the government will approach the adaptive reuse of the KIF in the event of an economic downturn. On the other hand, the cooperation between different government departments and the prioritizing of adapting reuse of the KIF in those economic conditions is under question. Also, the physical condition of the existing buildings may have deteriorated to such an extent that reconstruction is no longer possible, and the adaptive reuse of the KIF is not economically justified.

Given that energy efficiency policies in Iran cannot be properly implemented in this scenario, solutions often tend to focus on low-carbon strategies. Due to the increasing number of uncertainty items, systematic planning and implementation are very difficult, and among the sustainability dimensions, economic and social aspects play a more prominent role in the process of adaptive reuse. Also, in this scenario, it is necessary to form an independent design committee to preserve and restore the existing buildings of the KIF (PRO7). Moreover, due to the increased role of people in decision-making processes and the impact of user behavior, their activities' impact on energy efficiency solutions after reuse should be predicted in advance (PRO2). In addition, to incorporate people's opinions and participation in decision-making, it is first necessary to raise awareness about historical interpretation. For example, the aesthetic interpretation of a heritage site may differ from the perspective of people about a rough concrete building. Citizens deal with urban issues every day, and based on their real experiences, they know where the obstacles are. In addition, due to the increase in climate risks, natural disasters, and fires, the KIF needs to be secured against these threats (SITE1). Moreover, the energy systems of the buildings need to be removed from private control and changed to an integrated manner. In this scenario, participants were uncertain about the use of passive solutions, but emphasized the greening of open spaces and using Iranian vernacular architecture to mitigate climate impacts (PRO4). Given the prominent role of economic aspects in this scenario, it is necessary to plan for different users with different needs to enhance the return on investment and economic justification. Therefore, the site can be used continuously over time to maintain the economic viability of the project (ECO3).

The challenges of this scenario include the lack of justification by the executive bodies for the return on the investment. In addition, air pollution and negative climate effects, such as humidity and heat, can accelerate the deterioration of structures. In addition, the uncontrolled population growth in Karaj has placed significant pressure on urban infrastructure, and the 18-hectare KIF site may be considered for urgent urban needs, such as housing.

If this project is successful in this scenario, despite limited resources, it can be a model for other similar projects in the country. Additionally, raising public awareness about the historical value of the site, attracting their participation, and incorporating their opinions and suggestions can strengthen the sense of belonging to the site and prevent further deterioration of the energy efficiency situation.

8. Discussion

This research aimed to provide low-carbon and energy solutions with a futuristic perspective for an ARIH. The case study was the KIF in Iran. The scenarios were made through the FD-DoA methods, synergistically. Future design methods created intergenerationally equitable scenarios through IFG role-playing, while DoA provided a systematic structure through futures studies protocols. The descriptive framework, including scenarios, uncertainties, challenges, and the impact of strategies, was inspired by DoA, and the imagination process of the future scenarios and activating the participants' futurability was shaped through the future design methodology, ensuring creative balance for KIF in the future.

The results of the research showed that due to the need to consider a comprehensive perspective in decision-making, it is necessary to first extract indicators related to the sustainable ARIH, then make decisions using an interdisciplinary futures studies research method through the opinions of future generations. In this research, considering the rapid population growth in Karaj, as well as the threats caused by climate change, it is necessary to plan for different futures of the KIF. Holding a future design workshop with the experts showed that the plausible, possible, and probable urban futures of the city of Karaj depend on factors such as the impact of climate change, optimizing energy consumption, and sociocultural factors such as demographic issues. Additionally, analyzing the scenarios through TDA made it easier to identify relationships among them and figure out their similarities and differences. The common solutions for preserving and revitalizing the KIF focus on sustainability and energy efficiency solutions, continuous monitoring of operations, complex planning and implementation challenges, the necessity of public participation, green space design, and reducing environmental impacts in the construction or reconstruction process. The most important differences between the scenarios can be found in the characteristics of the economic and social situation, the quality of implementation and energy efficiency solutions, public participation approaches, the role of green space, the level of access to financial resources and technology, and the performance of the KIF on an urban scale after renovation (Figure 7).

Although adaptive reuse of the KIF in the scenarios is dependent on economic conditions and inflation in Iran, from the perspective of the IFGs, this issue is not among the goals, while focusing on non-monetary aspects in economic dimensions is a priority. Unlike Yang et al. (2025), who focus on carbon reduction through smart and active energy systems, the presented scenarios, even in Scenario 3, emphasize Iranian vernacular strategies and passive systems like Persian gardens and site orientation. Also, since the KIF has never been active, its historical aspects become more highlighted in the second scenario. Unlike other industrial heritage sites that have been active in the past, KIF does not have many stories to tell and has a high potential for making history to be transferred to future generations. On the other hand, due to the diversity of existing structures, incompleteness of the structures, and the suitable urban location, there is the possibility of integration into the urban fabric in the future, and it can serve as an urban catalyst for future developments.

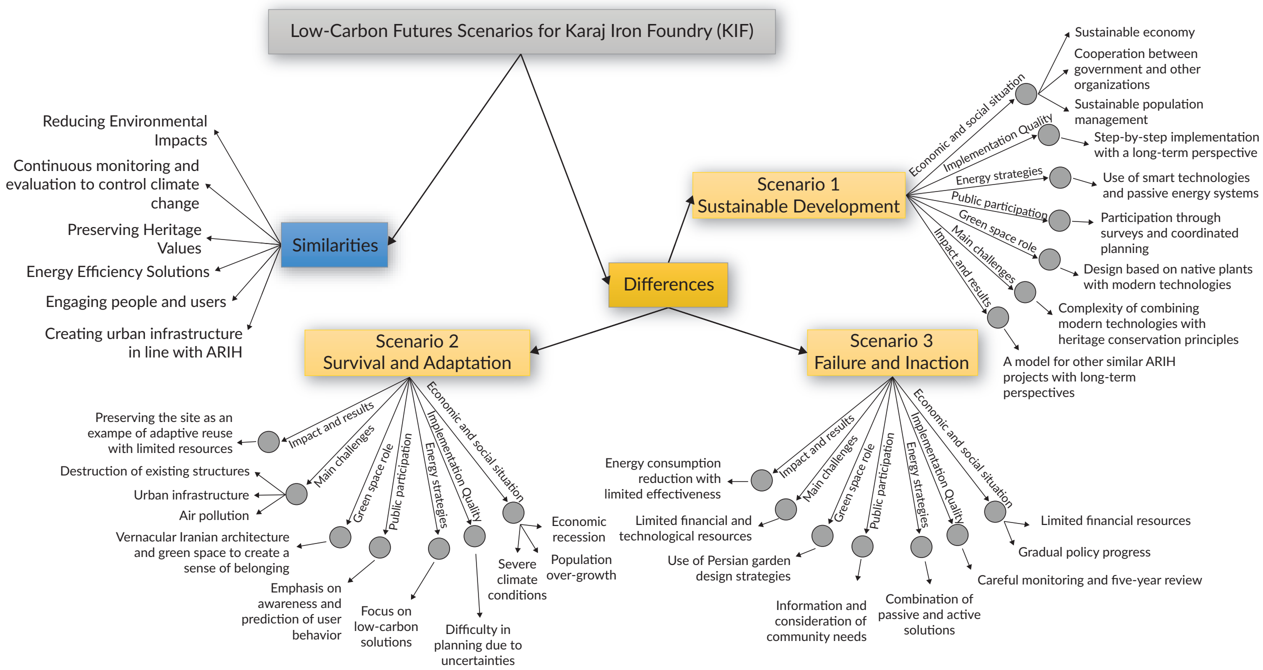

Figure 7. TDA for defining similarities and differences between scenarios based on the future design workshop session.

Previous studies on providing energy efficiency solutions for ARIH have ignored future generations' needs and have achieved different results. Sotodeh and Ghobadian (2023) used a similar method to extract indicators for the KIF adaptive reuse, but the weighting of the indicators and the priorities differ from the results of the present study. The priority of the indicators in their study is: "environment," "economy," "socio-cultural," "technology," and "process." While in our study, on the other hand, in which the perspectives of IFGs were used, the "process" category is of priority. Additionally, Sotodeh and Ghobadian (2022) presented modernisation solutions for adaptive reuse of the KIF, which reflect the perspective of the current generation. In addition, this study recommends using skylight as a strategy without explaining what problem this solves. Moreover, financing is proposed as a solution, whereas in our study, securing financial resources for adaptive reuse is one of the main challenges and a key factor for shaping the scenarios.

The authors conducted interviews with two environmental experts to ensure that the scenarios are in line with environmental issues and reflect a more comprehensive approach to technical aspects. The insights of the experts highlighted the need to address issues such as wastewater management, waste disposal, and urban sewage systems in the later stages of scenario making, especially by further analyzing uncertainties. Furthermore, the findings of the interviews emphasized the importance of assessing noise and air pollution after determining the final use of each building. Moreover, the integration of carbon sequestration strategies into the vegetation design of the Iranian garden in Scenarios 2 and 3 was identified as a pivotal element for reducing carbon dioxide emissions. Proposed strategies align with Iran's national climate policies, including the National Climate Change Strategy Program (National Climate Change Office et al., 2016), the Seventh Development Plan developed by the Islamic Council Research Center (2023), and the RCICA (2023).

Visioning through scenario-making with the perspective of the IFGs and examining urban and climate issues are among the key factors in the process of ARIH. The results of the present study are useful for policymaking bodies to integrate and complete the national heritage conservation laws of Iran. In particular, the 2050 scenarios propose futuristic strategies in different scenarios for the adaptive reuse of the industrial heritage of Iran, which helps the Cultural Heritage, Handcrafts, and Tourism Organization of Iran manage the budget by the weighted indicators. Moreover, the FD-DoA method provides an innovative research method for long-term, futuristic decision-making for ARIH. The innovation of this study lies in a balanced perspective, which provides energy efficiency solutions of industrial heritage in line with urban future scenarios and enables researchers to make better decisions at each stage.

While the expert-centric future design workshop ensures the technical and academic rigor for KIF adaptive reuse, it still needs the policymakers and local citizens' opinions as IFGs. However, this process was not feasible in this study because of the need for public education and raising local citizens' awareness. This limitation can be addressed in the next phases of the project.

Future research could incorporate embodied carbon calculations when data on material usage, renovation plans, and final use of each building become more specific. This would complement the current qualitative scenario analysis and provide a more comprehensive quantitative evaluation of adaptive reuse projects.

9. Conclusion

The results were able to show how the ARIH site—the KIF—can play a role in creating a low-carbon city and achieving the goal of energy efficiency. Common sustainable futuristic solutions for preserving and adaptive reuse of such valuable heritage, applicable across all future scenarios, were presented in five categories: the quality of implementation, access to resources, energy strategies, public participation, and the role of green space. Also, due to the complexity of this process, the novel mix methodology presented in this article (FD-DoA) is effective in long-term creative visioning, considering future climate predictions. The extracted indicators show the necessity for Iran to adopt phased adaptive reuse programs (2025–2050). Moreover, the results of this study provide a clear roadmap for Iranian policymakers to establish a national industrial heritage conservation charter. To reach this aim, capacity-building programs with multi-stakeholder collaboration and the FD-DoA decision-making method are highly recommended. Therefore, by implementing the futuristic methods in KIF, Iranian policymakers can create a replicable model for other valuable industrial heritage sites in Iran to contribute to a low-carbon future through ARIH. Moreover, the results necessitate redefining sustainability in heritage contexts: from "do not harm" to "active legacy-building," where current generations manage heritage as a treasure for future generations, which shows a paradigm shift in line with the "futurability" framework. In this regard, the current generations must sacrifice their desires for the interests of future generations and avoid actions that have immediate results.

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Conflict of Interests

The authors declare no conflict of interests.

Data Availability

Data from the questionnaires and workshop sessions in this study are not publicly available due to privacy considerations, but are available upon reasonable request from the corresponding author.

LLMs Disclosure

LLM tools were used in this work.

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