Transdisciplinary Approach to Risk Analysis in Building Automation and Control System Projects: A Case Study

Mohammad Reza Namjoo[1,*], *Mehrzad Salahi*[2]

[1] Department of Industrial Engineering, Faculty of Engineering, Shahid Bahonar University of Kerman, Kerman, Iran

[2] Barg-e Sabz-e Nikan Co., Tehran, Iran

*Correspondence: namjoo@uk.ac.ir

Received 25 November, 2024; Revised 8 January, 2025; Accepted 9 January, 2025

Available online 9 January, 2025 at www.atlas-journal.org, doi: 10.22545/2025/00270

Abstract:*Building automation and control systems are kinds of complex systems that face a variety of risks during implementation. The negative consequences of such risks can impact the project execution and success. The origins of the risks associated with BACS implementation in the context of construction projects are diverse and include technical, economic, political, social, and cultural domains. Identifying the risk factors of BACS projects and analyzing causal relationships among them can enable project key stakeholders to define and execute timely response–to-risks strategies. With regard to complex and multifaceted context of risks in BACS projects, this paper uses a transdisciplinary risk analysis approach to identify and rank BACS Projects risk factors along with a causal analysis in a case study. The results of this paper provide comprehensive insights into BACS project risk factors and can be used in real-world projects to design actionable risk mitigation plans.*

Keywords: Transdisciplinary, BACS, Building Automation, Project Risk, DEMATEL, MCDM

1 Introduction

The deployment of Building Automation and Control Systems (BACS), also referred to as Building Management Systems (BMS), has drawn significant attention in large administrative, commercial, educational, and hospitality buildings in recent years due to the increased focus on automation and energy efficiency (van Roosmale et al., 2024a)

Reducing operating costs, lowering energy consumption, continuous energy monitoring and reporting, efficiently managing building assets, improving maintenance and repair operations, improving occupant comfort, health, security, and privacy, and enhancing the controllability and efficiency of building services are some of the most compelling reasons to use BACS in these types of buildings (van Roosmale et al., 2024b).

According to European Building Automation and Controls Association (2022), implementation of BACS can reduce energy consumption by up to 26% in educational institutions and hospitals; 41% in hotels and restaurants; 27% in residential buildings; 49% in wholesale and retail buildings; and 52% in offices and lecture. Additionally, case studies show that investment in BACS has a fast payback time of an average 3 years.

Although, BACS offers significant opportunities for building owners, facility managers, and occupants, there are various risk factors in the implementation and operational phases of the building automation and control systems (van Roosmale et al., 2024b). As will be described in the next section, BACS projects operate within a complex and multi-risk environment. They are subject to a variety of risks originating in diverse, interconnected, and dynamic contexts. The negative consequences of such risks can have disruptive impacts on the project's success in terms of quality, system performance, time, and cost. In the worst-case scenarios, these risks may result in project failure, delay, or termination. Furthermore, some BACS projects face restrictions in accessing required hardware and software, which in turn may add new risks to the existing ones.

To develop a holistic insight for risk factors of BACS projects and to empower project managers, contractors, and project owners to create and execute actionable and practical response-to-risk (R2R) strategies and plans, it is essential to identify and rank the most important risk factors as well as their interdependencies. Risk avoidance, risk mitigation, or sharing risks at affordable costs are a few examples of these solutions.

The aim of this paper is to answer three fundamental questions:

1. What are the risk factors associated with BACS projects?
2. What are the most significant risk factors in BACS projects ?
3. What are casual relationships among risk factors of BACS projects ?

To answer these questions, particularly the third question, this study makes use of a case study of a modern 19-floor complex building for financial and trade services in Tehran, Iran, with a total area of 35,000 square meters (approximately 376,700 square feet), equipped with BACS subsystems, to analyze the interdependencies and causal relationships among risk factors. This approach grounds the research in a real-world context while providing actionable and practical insights into addressing BACS project risks.

A BACS consists of several subsystems, including access control system, video surveillance system, audio systems, fire alarm system, HVAC and lighting control systems. These subsystems can function as fully integrated, semi-integrated, or standalone systems. Three main layers make up the BACS architecture (Domingues et al., 2016):

1. **Field Layer:** The lowest layer connects field devices, such as sensors and actuators, to the next layer via wired or wireless communication.
2. **Automation Layer:** Data from field devices, including sensor readings and status updates, is processed by this intermediate layer. It activates commands and alerts and performs control loops.
3. **Management Layer:** The system's top layer has a number of top-level features including trend analysis, machine learning, data storage, software integrations, operational data visualization, and the ability to define the system's rules and schedules.

A comprehensive list of essential functions, system architecture, and communication protocols used in BACS can be found in Domingues et al. (2016).

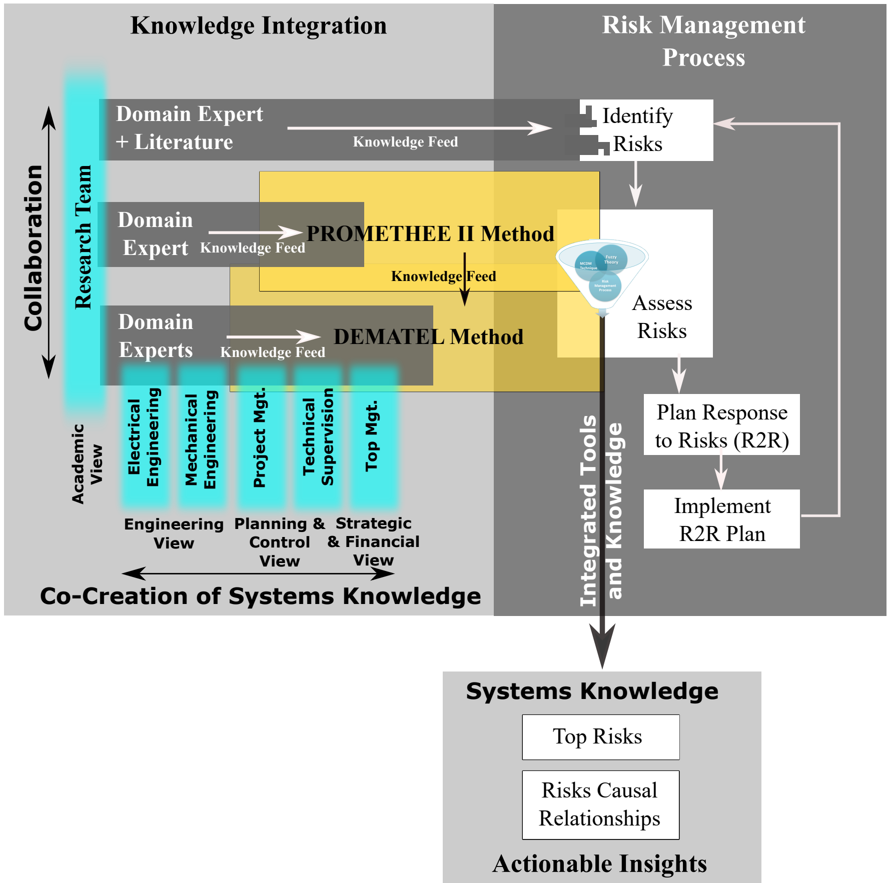


Figure 1: *Transdisciplinary research approach of this Study.*

2 Transdisciplinary Approach of this Study

By definition, in the context of transdisciplinary approach, the researchers can integrate the knowledge of individuals from multiple disciplines through a collaborative process to develop a conceptual framework for addressing a complex and common issue (Ertas, 2010). This approach can provide decision makers with holistic insights for the complex and multidimensional issues under investigation and creates actionable results for those problems in real-word by integrating different disciplinary perspectives. The applicability of transdisciplinary research process has expanded significantly in recent years and its influence has broadened from addressing limited problems, such as environmental management, to a variety of practical and complex domains, including engineering, management, energy, and safety and risk management (Hernandez-Aguilar et al., 2020; Ozsoy & Mengüç, 2024; Scholz et al., 2024; Spreng, 2014). The results achieved from applying a transdisciplinary research process can be divided into three main categories; systems knowledge useful to assess the current state of a system; orientation knowledge applicable for envisioning the desired future status of the system; and transformation knowledge vital to define strategies to move from the as-is state to the to-be state of the system under study (Hadorn et al., 2008; Lawrence et al., 2022).

There are several facts supporting the use of a transdisciplinary research (TDR) approach in this paper (see Figure 1). The first item is the complexity of risk management in BACS projects, as depicted in Figure 2. In the real world, construction projects are considered to be multi-risk environments facing a variety of internal and external risks such as technical, financial, political, social and cultural, economic, and natural

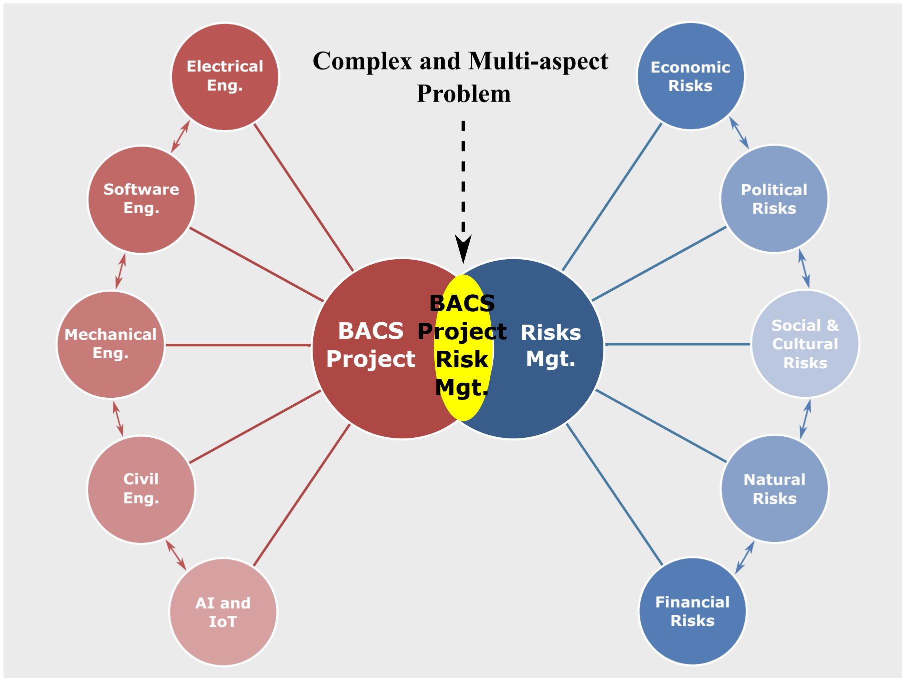


Figure 2: *Complex and multi-aspect characteristics of BACS risk management.*

risks (El-Sayegh, 2008; Mehdizadeh et al., 2013).

The occurrence of these risks and their negative consequences is rooted in a variety of factors, including human, technical, and environmental aspects, making their management a complex and multi-aspect issue. In addition, the risks within the multi-risk context are interdependent and mutually influential so that they can affect the likelihood and severity of one another and may also obstruct our gain a holistic insight and integrative perspective on the problem (Hochrainer-Stigler et al., 2023).

Moreover, these risks have a dynamic nature (Nasirzadeh et al., 2008). As the project progresses, new risks may emerge and impact the existing risks, or the impact and priority of existing risks may change. This is particularly significant in BACS projects because of the different types of stakeholders and a variety of engineering and non-engineering disciplines involved in the project.

Second is the integration principle of TDR approach (Pohl, 2010). So, the most fundamental aspect of this integration is the synthesis of knowledge in the problem-solving process in this study because achieving multifaceted and holistic results stems from this approach (Godemann, 2008). To achieve this goal, two essential prerequisites are required. The first is creating a flow of the necessary knowledge for solving the problem, sourced from expert and diverse resources, incorporating specialized perspectives from both academic and practical dimensions. This type of collaboration and diversity of knowledge leads to more realistic outcomes through the co-creation of results. In this study, perspectives are divided into engineering, planning & control, managerial, and financial sections. The research team, in addition to providing the knowledge from the literature, is also responsible for creating a collaborative working environment. The other prerequisite is the integration of tools. Here, two tools from decision making domain that are PROMETHEE II for risk factor identification and prioritization in the context of BACS projects and DEMATEL for exploring the causal relationships among risk factors are integrated with the fuzzy theory for handling uncertainties and merged into the risk management process to enable the overall process to generate actionable results through the unifying the knowledge flows (see Figure 3).

The third aspect is the actionable results, which can provide key stakeholders with a holistic and multi-faceted insight of risks in BACS projects. These results, as systems knowledge, show current state

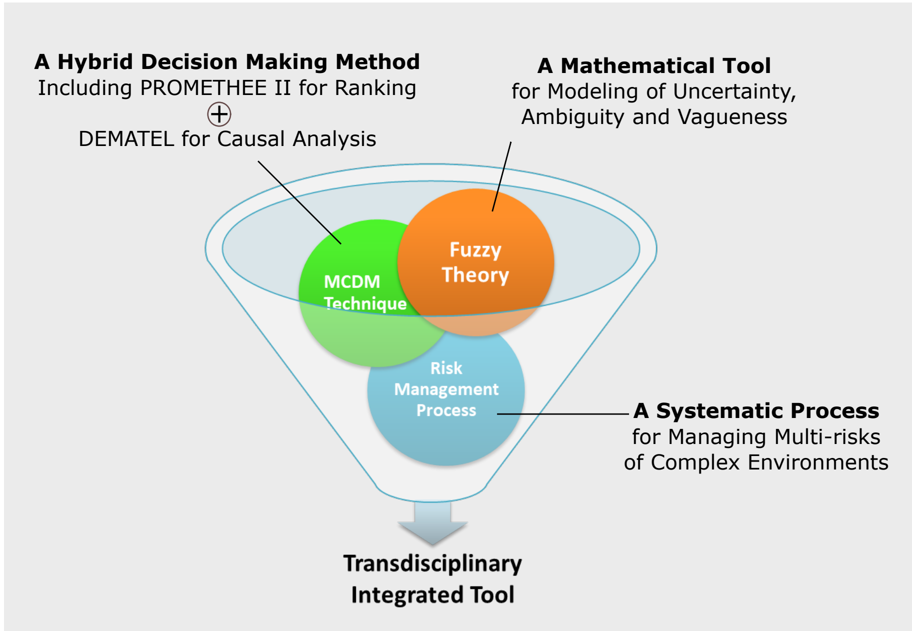


Figure 3: *Transdisciplinary integration of tools in this research.*

of the project and are achieved by the synthesis of the knowledge flow of participants in different domains through integrated tools. The TDR process results include the most influential risks and enable the BACS project managers to design and implement timely response-to-risk plans during project execution and handover phases to prevent or mitigate projects delay or failure.

3 Methodology

In this section, we describe the research methodology step by step, following of the transdisciplinary research approach of this study.

3.1 Risk Factors Identification

There are valuable review papers on risk factors in the related fields of this research topic in the literature, including construction project management, building information modeling (BIM) projects, and ICT projects. Therefore, we used the findings from these review papers to construct an initial list of risk factors. The initial list of risk factors will be presented to a domain expert for further consideration

3.2 Contextualization of Risks Factors

The definitions of risk factors in the initial list from the literature must be conceptualized in the context of BACS. This will be achieved through semi-structured meetings with domain experts to clearly define the factors within the context of BACS.

3.3 Risk Factors Prioritization with PROMETHEE II

PROMETHEE (Preference Ranking Organization Method for Enrichment of Evaluations) refers to a family of outranking methods, as listed in Table 1 (Behzadian et al., 2010). Additionally, there are many

Table 1: Different versions of PROMETHEE method.

Version	Year	Reference	Purpose/application
PROMETHEE I	1982	Brans (1982)	Partial ranking of alternative actions
PROMETHEE II	1982	Brans (1982)	Complete ranking of alternative actions
PROMETHEE III	1983	Brans et al. (1984)	Interval basis ranking
PROMETHEE IV	1984	Brans et al. (1984)	Continuous decision problems
PROMETHEE V	1992	Brans and Mareschal (1992)	Multiple selection under constraints
PROMETHEE VI	1995	Brans and Mareschal (1995)	Representation of human brain
PROMETHEE GDSS	1998	Macharis et al. (1998)	Ranking through group decision-making
PROMETHEE TRI	1994	Figueira et al. (2005)	Sorting problems
PROMETHEE CLUSTER	1994	Figueira et al. (2005)	Nominal classification

other extensions of the PROMETHEE methods in the literature that combine them with other methods, theories, and tools such as the Analytic Hierarchy Process (AHP) (Macharis et al., 2004), fuzzy set theory (Mateo, 2012), and Building Information Modeling (BIM) (Tan et al., 2021) to enhance decision-making capabilities.

The PROMETHEE bibliographical database (Mareschal, 2020) reports that more than 2,393 scientific references related to the PROMETHEE methods exist, which shows broad successful applications of the PROMETHEE as of September 12, 2020. These applications are classified as follows: theoretical foundation and development of the methods (20.6%) and various real-world decision problems (81.4%) as shown in Table 2. Additionally, the authors of this paper would like to highlight more specific applications, including industrial automation (da Cunha et al., 2022; Nasrollahi et al., 2020; Ranjbara et al., 2017), and risk management in construction projects (Chien et al., 2014; Ghandi & Roozbahani, 2020; Jato-Espino et al., 2014; Lee et al., 2009; San Cristobal, 2013).

Table 2: Applications of PROMETHEE methods in different domains (Mareschal, 2020).

#	Field of application	# of papers
1	Theoretical applications	493
2	Services and/or public applications	469
3	Environmental problems	457
4	Industrial applications	347
5	Energy	227
6	Water	153
7	Finance	124
8	Transportation	116
9	Procurement	77
10	Health care	75
11	Mining	30
12	Others	101

In this paper, we apply PROMETHEE II to determine a complete ranking of the risk factors in BACS projects. The reasons for this choice include the simplicity, clarity, and stability of the PROMETHEE methods (Behzadian et al., 2010; Brans et al., 1986), as well as its user-friendliness for evaluating a large number of actions (i.e., 32 risk factors in this study). Before describing the general steps of PROMETHEE II, we present some necessary definitions as follows (Tzeng & Huang, 2011):

Definition 1: A multi-criteria decision-making problem can be formulated as:

$$\max\{g_1(a_i), g_2(a_i), \ldots, g_j(a_i), \ldots, g_n(a_i) \mid a_i \in A\}$$

where $A = (a_i|i = 1, 2, \ldots, m)$ denotes the finite set of possible actions (risk factors) and $g_j(a_i)$ presents the performance of action a_i with regard to evaluation criterion j.

Definition 2: A preference function $f_j(a_i, a_k), a_i, a_k \in A$, represents the degree of preference of action a_i over action a_k with respect to the criterion j. The general formulation of a preference function is given by Eq. (1):

$$f_j(a_i, a_k) = f_j(g_j(a_i), g_j(a_k)) \tag{1}$$

There are several general preference functions proposed by Brans et al. (1986), including the usual criterion, quasi-criterion, criterion with linear preference, level criterion, criterion with linear preference and indifference area, and Gaussian criterion.

Definition 3: A preference index function $\pi(a_i, a_k)$ indicates the overall intensity of preference of action a_i over action a_k, considering all n criteria. The general formulation of a preference index is given by Eq. (2):

$$\pi(a_i, a_k) = \sum_{j=1}^{n} w_j f_j(a_i, a_k) \tag{2}$$

where $0 \leq \pi(a_i, a_k) \leq 1$ and w_j represents weight of the criterion j. A decision-maker may determine w_j with the assistance of appropriate MCDM techniques, such as the Analytic Hierarchy Process (AHP) Dağdeviren, M. (2008).

Definition 4: There are three types of flows in PROMETHEE II used to evaluate each action $a_i \in A$: (a) Entering flow $\phi^+(a_i)$, (b) Leaving flow $\phi^-(a_i)$, and (c) Net flow $\phi(a_i)$. They are defined by Eqs. (3)-(5), respectively.

$$\phi^+(a_i) = \sum_{a_k \in A} \pi(a_i, a_k) \tag{3}$$

$$\phi^-(a_i) = \sum_{a_k \in A} \pi(a_k, a_i) \tag{4}$$

$$\phi(a_i) = \phi^+(a_i) - \phi^-(a_i) \tag{5}$$

where $\phi^+(a_i)$ represents the preference of action a_i over all other $n-1$ actions in A, and $\phi^-(a_i)$ denotes the preference of the $n-1$ actions over a_i. Subsequently, the greater the net flow $\phi(a_i)$, the higher the overall preference of action a_i.

Considering Definitions 1-4, the complete ranking of actions can be determined by the following general steps. More details of the method are available in Behzadian et al. (2010):

Step 1: Determine $g_j(a_i)$ by scoring each action $a_i \in A$ regarding each criterion $j, j = 1, \ldots, n$ using experts' opinions within a matrix questionnaire, as depicted in Figure 4. Each expert is required to complete a separate matrix to provide their individual opinions.

Step 2: Calculate the preference function for each pair of actions a_i, a_k in set A using Eq. (1).

Step 3: Calculate the preference index function $\pi(a_i, a_k)$ for each pair of actions a_i, a_k in set A using (25).

Step 4: Calculate the net flow for each action using Eq. (5) and determine the complete ranking list of the actions by applying the following decision rules for each pair of actions a_i, a_k (Brans & Vincke, 1985):

		Evaluation Criteria (EC)		
		Criterion 1	⋯	Criterion n
Actions (risk factors)	a_1	*expert score*	*expert score*	*expert score*
	⋮	*expert score*	*expert score*	*expert score*
	a_m	*expert score*	*expert score*	*expert score*

Figure 4: *A matrix questionnaire for eliciting the experts' opinions.*

Rule 1 (Outranking): action a_i outranks action a_k if and only if $\phi(a_i) > \phi(a_k)$,
Rule 2 (Indifference): action a_i is indifferent to action a_k if and only if $\phi(a_i) = \phi(a_k)$.

3.4 Causal Analysis with Fuzzy DEMATEL

The DEMATEL method is a structural modeling technique that provides decision-makers with effective causal models for identifying and analyzing interdependence among the decision criteria of complicated multi-attribute problems. Fuzzy DEMATEL is an integration of the DEMATEL method ad Fuzzy theory to support the decision making process in complex and uncertain environments.

DEMATEL and Fuzzy DEMATEL (FDEMATEL) methods have a wide variety of applications in both academic and real-world problem analysis and group decision-making particularly in dealing with uncertainty and ambiguity (Rostamnezhad et al., 2020; Si et al., 2018). Among these, the authors would like to highlight several successful applications of these methods in related critical areas such as risk analysis and risk assessment (Kuzu, 2021; Seker & Zavadskas, 2017), construction management (Mavi & Standing, 2018), safety management (Yorulmaz & Karabulut, 2022), sustainable project management in construction (Mavi & Standing, 2018), Artificial intelligence in building (Debrah et al., 2022; Patel et al., 2021), construction supply chain management (Arshad & Zayed, 2022), and building maintenance (Desbalo et al., 2023).

The main steps of Fuzzy DEMATEL are as follows (Başhan & Demirel, 2019):

Step 1: Individual Fuzzy Direct Influence Matrix Preparation
The individual fuzzy direct influence matrix $\tilde{X}^h = \left[\tilde{x}_{ij}^h\right]_{n\times n}$, where $h = 1, 2, \ldots, H$, can be constructed by asking the hth expert $(h = 1, 2, \ldots, H)$ to evaluate the degree of influence of criterion $i, i = 1, 2, \ldots, n$ on criterion $j, j = 1, 2, \ldots, n$, using a set of linguistic variables (see Table 4) and convert them into a Triangular Fuzzy Numbers (TFN) $\tilde{x}_{ij}^h$.

Step 2: Initial Fuzzy Direct Influence Matrix Calculation
Each element of the initial fuzzy direct influence matrix $\tilde{A} = [\tilde{a}_{ij}]_{n\times n}$ is a TFN $\tilde{a}_{ij} = (\tilde{a}_{ij}^L, \tilde{a}_{ij}^M, \tilde{a}_{ij}^U)$, where $\tilde{a}_{ij}^L$, $\tilde{a}_{ij}^M$, and $\tilde{a}_{ij}^U$ show the lower bound, the most likely value, and the upper bound of $\tilde{a}_{ij}$, respectively. $\tilde{a}_{ij}$ denotes the amount of impact that criterion i has on criterion j, where $j = 1, 2, \ldots, n$ and is calculated by Eq. (6)

$$\tilde{a}_{ij} = \frac{1}{H}\sum_{h=1}^{H}\tilde{x}_{ij}^h. \tag{6}$$

All diagonal elements of $\tilde{A}$ are $(0, 0, 0)$.

Step 3: Normalized Fuzzy Direct Influence Matrix Derivation
The element $\tilde{d}_{ij}$ of the the normalized fuzzy direct influence matrix $\tilde{D} = \left[\tilde{d}_{ij}\right]_{n\times n}$ shows the initial impact that a criterion i dispatches to the other criteria in the system and receives from criterion j , where $j = 1, 2, \ldots, n$. This matrix derived by normalizing the initial fuzzy direct influence matrix $\tilde{A}$ using Eq. (7) and Eq. (8). The matrix $\tilde{D}$ can be converted to an initial impact-digraph-map that visually exposes the initial relations of each pair of criteria to the decision-maker.

$$\tilde{d}_{ij} = \frac{\tilde{a}_{ij}}{\delta} = \left(\frac{\tilde{a}_{ij}^{L}}{\delta}, \frac{\tilde{a}_{ij}^{M}}{\delta}, \frac{\tilde{a}_{ij}^{U}}{\delta} \right) \quad \delta > 0;\ i, j = 1, 2, \ldots, n \tag{7}$$

,

$$\delta = \max_{i,j} \left\{ \max_{i} \sum_{j=1}^{n} \tilde{a}_{ij}^{U}, \max_{j} \sum_{i=1}^{n} \tilde{a}_{ij}^{U} \right\} \quad i, j = 1, 2, \ldots, n. \tag{8}$$

Step 4: Fuzzy Total Influence Matrix Calculation

The element $\tilde{f}_{ij} = (\tilde{f}_{ij}^{L}, \tilde{f}_{ij}^{M}, \tilde{f}_{ij}^{U})$ of the fuzzy total influence matrix $\tilde{F} = \left[\tilde{f}_{ij}\right]_{n\times n}$ demonstrates the final impact that each criterion i for $i = 1, 2, \ldots, n$ dispatches to and receives from criterion j, where $j = 1, 2, \ldots, n$, illustrating the final structure of the system of criteria. Using the property that raising the power of the matrix $\tilde{D}$ leads to decreasing indirect impacts, $\tilde{F}$ can be calculated by using Eq. (9)

$$\tilde{F} = \tilde{D} \times (I - \tilde{D})^{-1} \tag{9}$$

where I denotes a fuzzy $n \times n$ identity matrix.

Step 5: Defuzzification of the Fuzzy Total Influence Matrix

Defuzzification of the fuzzy total influence matrix ($\tilde{F}$) refers to the process of converting fuzzy numbers $\tilde{f} = (\tilde{f}_{ij}^{L}, \tilde{f}_{ij}^{M}, \tilde{f}_{ij}^{U})$ into crisp values. In this paper, we applied CFCS method for defuzzification of $\tilde{F}$ by performing the following tasks (Opricovic & Tzeng, 2003):

1. For all criteria j, where $j = 1, 2, \ldots, n$, compute $\tilde{y}_j^{L}, \tilde{y}_j^{M}, \tilde{y}_j^{U}$ as given by Eqs. (10)-(12).

$$y_j^{L} = \frac{(\tilde{f}_{ij}^{L} - L_i^{\min})}{\Delta_{\min}^{\max}} \tag{10}$$

$$y_j^{M} = \frac{(\tilde{f}_{ij}^{M} - L_i^{\min})}{\Delta_{\min}^{\max}} \tag{11}$$

$$y_j^{U} = \frac{(\tilde{f}_{ij}^{U} - L_i^{\min})}{\Delta_{\min}^{\max}} \tag{12}$$

where $U_i^{\max} = \max_j\{\tilde{f}_{ij}^{U}\}$, $L_i^{\min} = \min_j\{\tilde{f}_{ij}^{L}\}$, and $\Delta_{\min}^{\max} = U_i^{\max} - L_i^{\min}$.

2. Compute left (ls) and right (rs) normalized values y_j^{ls} and y_j^{rs} as given by Eq. (13) and Eq. (14), respectively for all criteria j, where $j = 1, 2, \ldots, n$.

$$y_j^{ls} = \frac{x_j^{M}}{1 + x_j^{M} - x_j^{L}} \tag{13}$$

$$y_j^{rs} = \frac{x_j^{U}}{1 + x_j^{U} - x_j^{M}} \tag{14}$$

3. Compute total normalized crisp value y_j^{crisp} as given by Eq.(15) for all criteria j, where $j = 1, 2, \ldots, n$.

$$y_j^{\text{crisp}} = \frac{[y_j^{ls}(1 - y_j^{ls}) + y_j^{rs} y_j^{rs}]}{[1 - y_j^{ls} + y_j^{rs}]}. \tag{15}$$

4. Compute elements of the crisp total influence matrix $F = [f_{ij}]_{n\times n}$ as given by Eq. (16)

$$f_{ij} = L_i^{\min} + y_j^{\text{crisp}} \Delta_{\min}^{\max} \tag{16}$$

In this step, the crisp values $D = \sum_{j=1}^{n} f_{ij}$, and $R = \sum_{i=1}^{n} f_{ij}$ can be computed. These values denote the total direct and total indirect influences within the system of criteria, respectively.
Step 6: The impact-relation map achievement
By setting a suitable threshold value α using Eq. (17), the weak relations among the criteria, represented by elements f_{ij} that are less than α, can be eliminated. The final impact-relation map (IRM) is derived to expose the most important causal relationships to the decision-maker by drawing $D - R$ and $D + R$ for the remainder of f_{ij}.

$$\alpha = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} f_{ij}}{n \times n} \tag{17}$$

In the next section of this paper, we describe the data collection methods used to gather the necessary data for the PROMETHEE II and Fuzzy DEMATEL methods.

4 Data Collection Method

In this paper, data collection regarding MCDM methods is divided into two main parts, as follows:

4.1 PROMETHE II

In order to score the risk factors and create a complete ranking by applying the PROMETHEE II method, the evaluation criteria and identified risk factors were discussed with expert P_2 (see Table 3) for evaluation purposes. For this scoring process, an electronic questionnaire was prepared in a single-sheet MS Excel file with 32 rows and 7 columns. Each row included a risk factor title, while each column represented an evaluation criterion with a short description provided in the cell comment. The questionnaire was sent to the expert electronically, and the authors clarified a number of technical questions from the evaluator by phone before receiving the completed questionnaire from him. The expert rated each risk factor on each criterion using a 5-point scale, where 1 represents “very low”, and 5 denotes “very high.”

4.2 Fuzzy DEMATEL

In this section, the data collection process related is conducted to a case and is similar to that in the previous section. We focused only on the top 10 risks from the completed ranking list (see Table 6) to analyze the causal dependencies among the risk factors. For this analysis, an electronic questionnaire was prepared in MS Excel format. The questionnaires, along with some descriptions were sent to the relevant experts ($P_3 - P_7$) of the case (see Table 3) and the completed files were received within a couple of weeks, after some clarifications. Table 4 shows the Fuzzy linguistic scale used in this research (Wu & Lee, 2007).

The case study of this section is on a modern 19-floor complex building for financial and trade services in Tehran, Iran, with a total area of 35,000 square meters (approximately 376,700 square feet). The building's construction began in 2013 and was completed in 2018. A specialized contractor implemented BACS smart technologies, which include the Building Management System (BMS), intelligent in-unit office control solutions, a CCTV system, and an electronic access control system. For seamless integration of sub-systems, the project makes use of BACnet, KNX, and Modbus protocols, integrating 10,000 control points. This case offers a thorough approach for examining the risks related to the implementation of BACS projects.

Table 3: Specifications of BACS experts involved in the risk factors evaluation.

Expert Code	Involved in	Major	Degree	BACS related Exp. (years)	Description
P_1	Semi-Structured Meeting	EE	BS	15	Senior technical consultation of BACS
P_2	PROMETHEE II	EE	BS	10	BACS engineering and design, BACS technical supervision, BACS technical consultation in numerous domestic large scale and complex commercial and residential building projects, and ICEO** member
P_3	Fuzzy DEMATEL	EE	MS	12	BACS engineering and design, BACS project manager in large scale and complex commercial and residential buildings, CEO of BACS company.
P_4	Fuzzy DEMATEL	IE	PhD	25	Industrial automation systems implementation, supervision in large scale and complex projects.
P_5	Fuzzy DEMATEL	EE	MS	8	BACS engineering, design, implementation
P_6	Fuzzy DEMATEL	EE	MS	8	BACS engineering, design, implementation
P_7	Fuzzy DEMATEL	EE	BS	8	BACS engineering, design, implementation

Note: EE: Electrical Engineer, IE: Industrial Engineer, Exp.: Experience.

Table 4: The Fuzzy linguistic scale used in this research.

Code	Linguistic terms	Triangular fuzzy numbers
1	No Influence	(0,0,0.25)
2	Very Low Influence	(0,0.25,0.5)
3	Low Influence	(0.25,0.5,0.75)
4	High Influence	(0.25,0.75,1.0)
5	Very High Influence	(0.75,1.0,1.0)

5 Results and Discussions

5.1 Risk Identification

As described in Section 3.1, by analyzing the review papers in related domains, including construction project management, building information management, and information and communication technology (ICT) projects, we found 32 risks factors that can be connected to the BACS projects as shown in Table 5. These risk factors will be used in the next section to provide context-based definition for each one.

5.2 Contextualization of Risk Factors

As described in the previous section, the definitions of risk factors in the initial list which were elicited from different domains are not grounded in BACS and should be defined in the context of BACS. In this regard, the authors arranged several semi-structured meetings with an experienced BACS expert namely P_1 (see Table 3) to discuss each risk factor and agree on a context-based definition for each on. The results of these sessions are presented in this section as follows:

RF1. Inadequate project definition: unclear definition and inadequate declaration of the project's objectives, scope, budgets, governance, organization, processes, key constraints, and critical risks, as well as response to risks (R2R) strategies.

RF2. Lack of initial project documents: Critical documents that need to be developed by the BACS

Table 5: Initial list of identified risk factors of BACS projects with the supporting references ($A_1 - A_{14}$).

Code	Risk Factor	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}
RF1	Inadequate project definition	*	*						*			*	*		*
RF2	Lack of initial project documents	*												*	
RF3	Unsuitable or ambiguous contract drafting and signing	*				*		*					*	*	
RF4	Inadequate planning and control of time, cost, and budget	*	*	*			*		*	*		*		*	
RF5	Selection of the wrong contractor	*		*		*	*	*	*					*	
RF6	Numerous and ineffective subcontractors							*							
RF7	Incorrect identification of requirements		*				*			*			*		
RF8	Insufficient, deficient, or contradictory documentation			*					*					*	
RF9	Poor, incomplete, and faulty design			*			*	*	*					*	
RF10	Inadequate coordination and communication		*	*	*	*	*	*	*	*		*			*
RF11	Inadequate and untimely financing and payments			*	*			*	*	*				*	
RF12	Inflation and currency rate increases				*			*	*	*					
RF13	Selection of inadequate BACS equipment or vendors													*	
RF14	Lack of access to equipment and vendors			*	*			*			*		*	*	*
RF15	Lack of access to stable and skilled human resources		*	*	*	*	*	*	*		*	*		*	
RF16	Changes and adjustments in project			*	*	*	*	*	*	*			*	*	
RF17	Changes in key organizational managers		*												
RF18	Inefficiencies in the client's technical and executive organization			*			*	*							
RF19	Inefficiencies in the client's project management organization		*		*		*	*		*				*	
RF20	Supervision and quality control issues						*	*		*			*	*	
RF21	Absence of mandatory standards and BACS regulations			*		*						*			*
RF22	Limited perception of BACS for energy saving														
RF23	Organizational resistance to change										*	*			
RF24	Technical complexities of BACS		*	*			*	*	*		*	*			
RF25	Ineffective risk management														*
RF26	Dimensions and complexity of the building and the main project							*	*						
RF27	Installations and configurations leading to rework							*	*						
RF28	Time pressure for completing and delivering tasks		*			*	*	*					*	*	
RF29	Incidents and issues related to HSE			*	*			*	*	*					
RF30	Challenging conditions at the project site	*		*	*				*	*				*	
RF31	Inadequate ICT infrastructure						*								*
RF32	Privacy and organizational security challenges		*												*

Note: A_1: An and Shuai (2011); A_2: Arnuphaptrairong (2011); A_3: Rezakhani (2012); A_4: Renuka et al. (2014); A_5: Chien et al. (2014); A_6: Silveira et al. (2018); A_7: Siraj and Fayek (2019); A_8: Bahamid et al. (2019); A_9: Alavi and Nadir (2020); A_{10}: Ghansah et al. (2021); A_{11}: Le´sniak et al. (2021); A_{12}: Haidabrus et al. (2022); A_{13}: Khairullah et al. (2022); A_{14}: Waqar et al. (2023).

project owner before contract signing, such as the Request for Proposal (RFP) with a clear definition of general specification, and technical, operational, and financial requirements of the BACS project.

RF3. Unsuitable or ambiguous contract drafting and signing: the project owner does not pay the required attention, and does not assign the necessary resources to request and review technical and financial proposals from BACS contractors. Ambiguity in drafting the agreement, technical and operational appendices (e.g., the project management plan, work schedules, and procurement plan), unclear definition of the scope of work (e.g., work breakdown structure), lack of a matrix of responsibilities for different contractors involved in the project including, including the main contractor (responsible for its own subcontractors), and the BACS contractor (responsible for its own subcontractors), unclear definition of methodology and project delivery process, and similar issues. This item also is valid for the contracts signed with the key human resources of the BACS project.

RF4. Inadequate planning and control of time, cost, and budget: Incomplete identification and unrealistic estimation of project activity durations; inappropriate work breakdown structure (WBS); incorrect or incomplete definition of prerequisites and activity relationships, and project milestones; failure to accurately estimate, allocate, and level the project resources; unrealistic cost breakdown structure (CBS) and budget; weak cost and budget control; weak project progress monitoring and control; ineffective resource consumption control on the project site; lack of timely and accurate project status reports and analysis; ineffective on-site project control; poor communication between key entities (e.g., supervisors, planners, and project budget controllers), and other related issues in planning and controlling of time, cost, and budget.

RF5. Selecting inappropriate contractor: BACS contractors lack suitable and relevant experience, have unfit management, engineering, and supply teams, or are in financial distress. Contractors may have a kind of previous client's extreme dissatisfaction with them. In addition, contractors may have a history of extreme client dissatisfaction, and similar issues.

RF6. Numerous and ineffective subcontractors: Inappropriate and unclear assignment of works and responsibilities of the projects (main project and/or BACS project) such that multiple contractors have been involved in the projects. This is especially important for the BACS project, when each subcontractor is responsible for a piece of work, or a few number of subsystems.

RF7. Incorrect identification of requirements: misunderstanding the client's needs; inability of the BACS contractor's team to execute the requirements engineering (RE) process correctly; definition unrealistic requirements and scenarios; defining scenarios based on the technical capabilities and features of specific BACS equipment brands rather than the client's real requirements; poor scenarios with numerous errors or deficiencies.

RF8. Insufficient, deficient, or contradictory documentation: lack of or delay in providing necessary documentation for the BACS project team, such as architectural detailed drawings, mechanical and electrical installations detailed design and drawings; any kinds of deficiencies, or contradictions in the technical documents of the main project; deficiencies in procurement and supply documentation such as bill of materials (BOM) and list of materials (LOM); deficiency in BACS device installation, and operations documents, unavailability of design documents with the required level of detail. Mismanaged document control center (DCC) such that different stockholders access different version of design documentation, especially for new documents arising from design changes, execution, and similar issues.

RF9. Poor, incomplete, and faulty design: Incomplete or faulty architectural design of the main project; faulty design of mechanical and electrical installations; incomplete or inaccurate design of BACS sub-systems (i.e., drawings, specifications, and calculations); execution and implementation of the project activities and tasks without existing engineering detailed design, resulting in generating numerous as-built drawings; incompatibilities between electrical and mechanical installations design and BACS standards and design patterns.

RF10. Inadequate coordination and communication: Lack of attention to established coordination and communication procedures by the BACS contractor's team, and the client's PMO, technical office, and project manager; informal communications; lack of formal and timely sharing of critical information and documents among key project stakeholders.

RF11. Inadequate and untimely financing and payments: Late or inappropriate amounts of payments to contractors, especially in the procurement phase of BACS equipment and devices; failure to secure the necessary budget for the project; and disproportionate and unfair payments to different contractors in a project despite some contractors' financial incapacity.

RF12. Inflation and currency rate increases: Significant increase in prices; emergence of inflationary expectations; lack of BACS-related devices, materials, and services; poor market responsiveness during period of price instability; and rising currency rates, particularly when the project budget is in local currency.

RF13. Selection of inadequate BACS equipment or vendors: Selection of BACS-related equipment, software and protocols from unreliable brands and manufacturers; disregard for reputable manufacturer lists (e.g., KNX manufacturer list), selection of untrustworthy or inexperienced vendors and resellers; selection of vendors lacking official credentials or with inadequate support services; selection of BACS devices with incorrect characteristics (functional, and non-functional) regarding design requirements; selection of nonstandard devices or devices without valid product testing certifications (e.g., BACnet Testing Laboratory (BTL)); and similar issues.

RF14. Lack of access to equipment and vendors: Lack of direct and formal access to the products, and technical services from reputable and global BACS manufacturers and software providers (particularly from Western Europe and North America); economic sanctions and international trade limitations leading to issues with procuring BACS-related devices, software, and technical services (e.g., consulting services, design and engineering services, training, after-sales services); and similar issues.

RF15. Lack of access to stable and skilled human resources: Lack of skilled and certified technical workers (technicians, engineers, and configuration specialists) of the BACS-related devices and software from reputable global brands and manufacturers; strong tendency skilled workers for job abandonment, emigration, entrepreneurship, and self-employment (e.g., freelance technical consultancy); and similar issues.

RF16. Changes and adjustments in project: Changes in the main project scope; Changes in the BACS project scope; changes in the client's (project owner's) requirements, demands, and expectations; changes in the client's policies and strategies; changes in BACS-related products' technology and market; discontinuation of services or production of some sorts of BACS-related devices and software; project budget changes; arising cash flow problems for the client; engineering and design changes, especially in the main project (e.g., major changes in architectural design, building demolition and considerable rework); changes in project management and project technical teams; major revisions in project scheduling; major changes in responsibilities; rapid changes in the main project; and similar issues.

RF17. Changes in key organizational managers: Changing the key managers of the owner's organization during the project lifetime, especially those who defined the project according to their policies and provided executive support. These changes may lead to significant challenges in various fields of the owner's organization.

RF18. Inefficiencies in the client's technical and executive organization: Lack of BACS specialist(s) in the owner's project team; unfamiliarity of the owner's office engineers with common methodological and technical issues of a BACS project; unfamiliarity of the owner's project team members with modern BACS case studies, features and technologies (e.g., hardware, software, protocols, and standards); weak accountability of the technical and executive bodies; significant delays in reviewing and replying to the transmittal documents sent by contractors; inability to handle technical issues, and to clarify technical questions (TQs); significant delays in issuing necessary permits and approvals (e.g., approve of design submittals); and similar issues.

RF19. Inefficiencies in the client's project management organization: Absence of a full-time project manager assigned to the BACS project; issues with the project manager professional competencies; part-time or half-time project manager involved in multiple projects, project manager unfamiliar with BACS technology; project manager with insufficient authority; lack of timely supervision and inadequate presence of the project manager on site; absence or ineffectiveness of the project management office (PMO) and related key procedures and processes (e.g., change management, scope management, and communications management as in Carter (2017)); and other similar issues.

RF20. Supervision and quality control issues: Absence of any supervisory entity; inexpert and inexperienced technical supervisors; lack of essential supervisory plans such as inspection plans, test plans, or quality plans; lack of attention to sufficient technical and quality inspections during project execution, such as inspections of BACS-related equipment and software purchased by contractors; failure to conduct timely evaluations and technical audits during the lack of attention to nonconformity reports from audits and inspections; lack of attention to the proper storage of BACS-related equipment to prevent any kind of damage until installation; and similar issues.

RF21. Absence of mandatory standards and BACS regulations: Despite the existence of ISO 16484 series standards, there are currently no mandatory standards, technical regulations, codes, or executive guidelines available for the design, implementation, and operation of BACS, unlike those issued for mechanical and electrical installations in the country.

RF22. Limited perception of BACS for energy saving: Due to factors such as the low price of energy in the country, lack of legal requirements for energy savings through the implementation of BACS and Energy Management Systems (EMS), lack of incentives for BACS implementation, and lack of residents' willingness to save energy through BACS, and similar issues, clients and buildings owners may not have a strong belief in the important role of BACS in energy savings.

RF23. Organizational resistance to change: Organizational resistance to technological change and BACS implementation denotes any kind of resistance to the change, especially resistance from the owner's managers and staff responsible for the system operations management after BACS handover (e.g., the organization's ICT department).

RF24. Technical complexities of BACS: Diversity and complexity of BACS subsystems, components, devices, software, services, and protocols; complexity in the design, engineering, configuration, installation, and integration of multiple subsystems; existence of various technical standards; data and information management issues; and the complexity of implementation and operations management of new technologies like the Internet of Things (IoT) as a critical subsystem of modern BACS.
RF25. Ineffective risk management: Failure to deploy a risk management discipline; inability to timely identify and analyze risks; failure to develop appropriate risk response strategies and plan; lack of risk monitoring mechanisms; lack of risk-based decision analysis; and similar issues.
RF26. Dimensions and complexity of the building and the main project: Particularly in large-scale construction projects with complex and diverse spaces and areas such as administrative, accommodation, and educational spaces, and complex structural and architectural designs in the project.
RF27. Installations and configurations leading to rework: Improper BACS hardware and software configuration; inappropriate control strategy configuration; inadequate configuration of management and operator functions; issues with inadequate installation of BACS field devices and equipment; weak integration; incorrect control panels wiring; incorrect cabling; improper BACS pre-commissioning (e.g., verifications) and commissioning; and similar issues.
RF28. Time pressure for completing and delivering tasks: Various internal or external reasons may impose tightening deadlines by the project manager, client, as well as regulatory and governing organizations on the project schedule. Changes in the main project timeline can also contribute to this. In this situation, the BACS contractor has to quickly provide the necessary resources and conditions to perform project activities and coordinate appropriately with their subcontractors.
RF29. Incidents and issues related to HSE: Various safety and health incidents may occur during project execution due to inadequate planning and supervision in the HSE area on the project site. These incidents and their consequences may lead to interruptions or disruptions in project execution.
RF30. Challenging conditions at the project site: In construction projects, unforeseen issues with working conditions often arise, such as adverse weather, labor issues, and site ground problems. Although some of these factors may be predictable, they may be overlooked by the project manager, leading to impacts on the project's execution process.
RF31. Inadequate ICT infrastructure: Poorly designed and implemented information and communication technology (ICT) infrastructure of the project, including topology, passive and active network equipment, and low quality of service (QoS) of public information and communication technology services.
RF32. Privacy and organizational security challenges: Since a significant part of the smart buildings and BACS relies on ICT services of local and public platforms and infrastructure for data connectivity and exchange between its key subsystems and users, there may be concerns about unauthorized access to building data and information, as well as the potential for targeted cyberattacks on the system by the client. This issue becomes more critical with use of Internet of Things (IoT) technology in the BACS.

5.3 PROMETHEE II Results

In this section, we use the PROMETHEE II method to create a complete ranking of the identified BACS project risk factors, as described earlier in Section 3.3. In this regard, the authors defined seven evaluation criteria (EC1-EC7) based on the three critical aspects of the standard qualitative risk management process: risk probability and impact assessment for risk analysis (Tiusanen, 2017, p. 470), and risk response planning for risk treatment (Carter, 2017, p. 437). Additionally, we considered three widely recognized project success evaluation indices: time, cost, and functionality (Cuellar, 2010). The definitions of the evaluation criteria are as follows:
EC1: Severity of Impact on BACS Performance and Functionality: EC1 rates the potential impact intensity 8ptof a risk factor, in the event of its occurrence, on the performance and quality of BACS during the commissioning and operational phases. Performance refers to the quality of services (QoS) of BACS such as reliability, scalability, efficiency, response time, and operational cost.
EC2: Severity of Impact on Project Disruptions: EC2 assesses the potential impact intensity

of a risk factor, in the case of occurrence, on any disruptions to the main project (e.g., buildings and their installations), and the BACS project, such as project cancellation, interruptions in work, contractor removal or substitution, significant rework, delays in starting main project activities, and project closure.
EC3: Severity of Impact on Claim Occurrence: EC3 measures the potential impact intensity of a risk factor, in the case of occurrence, on the emergence of serious claims (e.g., delay claims, change order claims, extra cost claims, defective work claims, non-payment claims, and damages claims) from key project stakeholders.
EC4: Severity of Impact on Execution Time of Project Activities: EC4 denotes the potential impact intensity of a risk factor, in case of occurrence, on the prolongation and postponement of the BACS project activities or the main project's closure. This may lead to delays in projects handover, and consequently, delays in building commissioning and operation.
EC5: Severity of Impact on Project Cost: EC5 rates the potential impact intensity of a risk factor, in case of occurrence, on the total cost of the projects (both BACS and the main project), including direct and indirect costs. These impacts may lead to serious financing issues and changes in project's economic feasibility.
EC6: Effort and Cost Required for Risk Response: This criterion weighs the cost or effort that the project manager or other risk owners must expend to plan and implement proper risk response strategies, such as risk mitigation, risk transfer, risk sharing, and risk avoidance.
EC7: Probability of Risk Occurrence: This criterion demonstrates the likelihood that a specific risk event (from the identified list in this paper) will occur during the project life cycle.

In this study, the V-shape preference function and an absolute threshold value 2 were selected to evaluate the relative importance of the risk factors using Visual PROMETHEE Academic Edition, version 1.4.0. The reason is the need to emphasize even minor differences in risk levels, while ranking is based on the scoring with a limited scale. The weight of evaluation criteria were determined by the expert P_2 as shown in Figure 5.

The complete ranking of the 32 risk factors based on the evaluation criteria EC1-EC7 along with net flow value (ϕ_i) for each risk factor is depicted in Table 6.

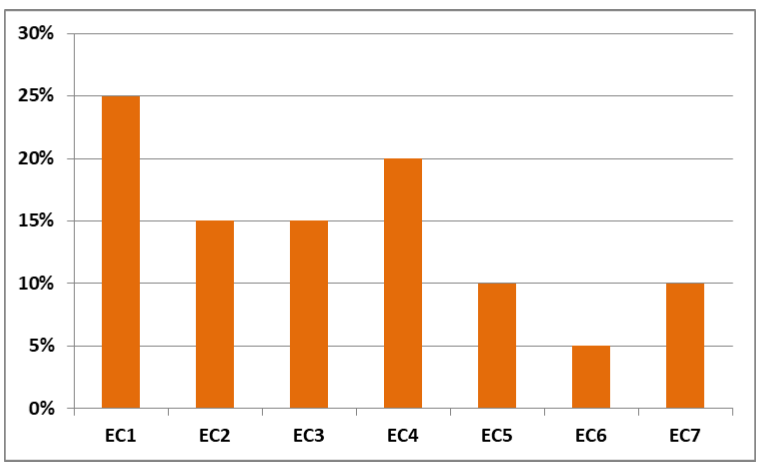


Figure 5: *Weights of the evaluation criteria (EC1-EC7).*

5.4 Fuzzy DEMATEL Analysis

In this section, we apply the Fuzzy DEMATEL method as described in Section 4.2 to identify causal relationships and interactions among the top ten risk factors (ranks 1-10 in Table 6) which we refer to as *key risk factors*. Additionally, we discuss any prominent clusters or dependencies.

Table 6: Complete ranking of the BACS projects risk factors.

Rank	Risk Factor	ϕ_i	ϕ_i^+	ϕ_i^-	Rank	Risk Factor	ϕ_i	ϕ_i^+	ϕ_i^-
1	RF13	0,5815	0,6089	0,0274	17	RF9	0,0234	0,2379	0,2145
2	RF15	0,5056	0,5331	0,0274	17	RF30	0,0234	0,2379	0,2145
3	RF11	0,4839	0,5339	0,0500	19	RF20	0,0153	0,2589	0,2435
4	RF5	0,4048	0,4710	0,0661	20	RF10	-0,0597	0,2113	0,2710
5	RF4	0,3944	0,5008	0,1065	21	RF19	-0,0935	0,2250	0,3185
6	RF6	0,2637	0,3621	0,0984	22	RF24	-0,0968	0,2008	0,2976
6	RF14	0,2637	0,3621	0,0984	22	RF28	-0,0968	0,1935	0,2903
8	RF3	0,2210	0,3919	0,1710	24	RF29	-0,2419	0,1629	0,4048
9	RF16	0,2056	0,4032	0,1976	25	RF21	-0,2532	0,1476	0,4008
10	RF18	0,1685	0,3040	0,1355	26	RF23	-0,2774	0,1306	0,4081
11	RF25	0,1685	0,3371	0,1685	27	RF8	-0,3097	0,1274	0,4371
12	RF26	0,1081	0,3242	0,2161	28	RF2	-0,3419	0,1145	0,4565
13	RF12	0,1032	0,3556	0,2524	29	RF17	-0,4710	0,0565	0,5274
14	RF31	0,0903	0,3000	0,2097	30	RF7	-0,4871	0,0500	0,5371
15	RF27	0,0548	0,3621	0,3073	31	RF32	-0,5355	0,0597	0,5952
16	RF1	0,0379	0,2677	0,2298	32	RF22	-0,8532	0,0000	0,8532

Table 7: The initial fuzzy direct influence matrix.

	RF13	RF15	RF11	RF5	RF4	RF6	RF14	RF3	RF16	RF18
RF13	(0,0,0)	(0.55,0.75,0.85)	(0.150,0.300,0.550)	(0.5,0.7,0.85)	(0.25,0.5,0.7)	(0.25,0.45,0.65)	(0.5,0.7,0.8)	(0.35,0.6,0.75)	(0.2,0.45,0.65)	(0.05,0.15,0.4)
RF15	(0.35,0.6,0.75)	(0,0,0)	(0.000,0.050,0.300)	(0.35,0.55,0.7)	(0.45,0.7,0.9)	(0.4,0.6,0.85)	(0.1,0.2,0.45)	(0.15,0.35,0.6)	(0.300,0.5,0.75)	(0.15,0.35,0.6)
RF11	(0.25,0.45,0.65)	(0.35,0.55,0.75)	(0,0,0)	(0.45,0.65,0.8)	(0.5,0.7,0.85)	(0.4,0.65,0.85)	(0.4,0.6,0.85)	(0.1,0.25,0.5)	(0.3,0.45,0.7)	(0.1,0.2,0.45)
RF5	(0.65,0.9,1)	(0.7,0.95,1)	(0.1,0.2,0.45)	(0,0,0)	(0.6,0.85,1)	(0.45,0.7,0.85)	(0.35,0.5,0.7)	(0.55,0.8,0.9)	(0.25,0.45,0.7)	(0.2,0.4,0.65)
RF4	(0.1,0.25,0.5)	(0.2,0.4,0.65)	(0.55,0.8,0.9)	(0.45,0.65,0.85)	(0,0,0)	(0.2,0.4,0.65)	(0.15,0.3,0.55)	(0.3,0.55,0.75)	(0.45,0.7,0.9)	(0.35,0.6,0.8)
RF6	(0.1,0.25,0.5)	(0.35,0.55,0.75)	(0.2,0.4,0.6)	(0.45,0.65,0.85)	(0.55,0.8,0.9)	(0,0,0)	(0.2,0.35,0.55)	(0.2,0.4,0.65)	(0.25,0.5,0.75)	(0.15,0.35,0.6)
RF14	(0.5,0.7,0.8)	(0.2,0.4,0.6)	(0.1,0.25,0.5)	(0.4,0.6,0.75)	(0.15,0.25,0.45)	(0.25,0.45,0.65)	(0,0,0)	(0.15,0.3,0.55)	(0.3,0.5,0.7)	(0.2,0.35,0.6)
RF3	(0.35,0.6,0.8)	(0.35,0.6,0.8)	(0.35,0.6,0.8)	(0.350,0.550,0.75)	(0.35,0.6,0.8)	(0.25,0.45,0.65)	(0.25,0.45,0.65)	(0,0,0)	(0.4,0.65,0.85)	(0.2,0.4,0.65)
RF16	(0.15,0.3,0.55)	(0.1,0.2,0.45)	(0.4,0.65,0.85)	(0,0,0.25)	(0.4,0.65,0.8)	(0.2,0.4,0.65)	(0.1,0.25,0.5)	(0.25,0.4,0.65)	(0,0,0)	(0.3,0.5,0.75)
RF18	(0.5,0.75,0.85)	(0.2,0.4,0.65)	(0.5,0.75,0.9)	(0.35,0.50,0.75)	(0.6,0.85,0.95)	(0.1,0.25,0.5)	(0.1,0.2,0.45)	(0.35,0.55,0.75)	(0.5,0.75,0.9)	(0,0,0)

Table 8: The normalized fuzzy direct influence matrix.

	RF13	RF15	RF11	RF5	RF4	RF6	RF14	RF3	RF16	RF18
RF13	(0,0,0)	(0.048,0.082,0.102)	(0.034,0.061,0.088)	(0.088,0.122,0.136)	(0.014,0.034,0.068)	(0.014,0.034,0.068)	(0.068,0.095,0.109)	(0.048,0.082,0.109)	(0.020,0.041,0.075)	(0.068,0.102,0.116)
RF15	(0.075,0.102,0.116)	(0,0,0)	(0.048,0.075,0.102)	(0.095,0.129,0.136)	(0.027,0.054,0.088)	(0.048,0.075,0.102)	(0.027,0.054,0.082)	(0.048,0.082,0.109)	(0.014,0.027,0.061)	(0.027,0.054,0.088)
RF11	(0.020,0.041,0.075)	(0.000,0.007,0.041)	(0,0,0)	(0.014,0.027,0.061)	(0.075,0.109,0.122)	(0.027,0.054,0.082)	(0.014,0.034,0.068)	(0.048,0.082,0.109)	(0.054,0.088,0.116)	(0.068,0.102,0.122)
RF5	(0.068,0.095,0.116)	(0.048,0.075,0.095)	(0.061,0.088,0.109)	(0,0,0)	(0.061,0.088,0.116)	(0.061,0.088,0.116)	(0.054,0.082,0.102)	(0.048,0.075,0.102)	(0.000,0.000,0.034)	(0.048,0.075,0.102)
RF4	(0.034,0.068,0.095)	(0.061,0.095,0.122)	(0.068,0.095,0.116)	(0.082,0.116,0.136)	(0,0,0)	(0.075,0.109,0.122)	(0.020,0.034,0.061)	(0.048,0.082,0.109)	(0.054,0.088,0.109)	(0.082,0.116,0.129)
RF6	(0.034,0.061,0.088)	(0.054,0.082,0.116)	(0.054,0.088,0.116)	(0.061,0.095,0.116)	(0.027,0.054,0.088)	(0,0,0)	(0.034,0.061,0.088)	(0.034,0.061,0.088)	(0.027,0.054,0.088)	(0.014,0.034,0.068)
RF14	(0.068,0.095,0.109)	(0.014,0.027,0.061)	(0.054,0.082,0.116)	(0.048,0.068,0.095)	(0.020,0.041,0.075)	(0.027,0.048,0.075)	(0,0,0)	(0.034,0.061,0.088)	(0.014,0.034,0.068)	(0.014,0.027,0.061)
RF3	(0.048,0.082,0.102)	(0.020,0.048,0.082)	(0.014,0.034,0.068)	(0.075,0.109,0.122)	(0.041,0.075,0.102)	(0.027,0.054,0.088)	(0.020,0.041,0.075)	(0,0,0)	(0.034,0.054,0.088)	(0.048,0.075,0.102)
RF16	(0.027,0.061,0.088)	(0.041,0.068,0.102)	(0.041,0.061,0.095)	(0.034,0.061,0.095)	(0.061,0.095,0.122)	(0.034,0.068,0.102)	(0.041,0.068,0.095)	(0.054,0.088,0.116)	(0,0,0)	(0.068,0.102,0.122)
RF18	(0.007,0.020,0.054)	(0.020,0.048,0.082)	(0.014,0.027,0.061)	(0.027,0.054,0.088)	(0.048,0.082,0.109)	(0.020,0.048,0.082)	(0.027,0.048,0.082)	(0.027,0.054,0.088)	(0.041,0.068,0.102)	(0,0,0)

Table 9: The fuzzy total influence matrix.

	RF13	RF15	RF11	RF5	RF4	RF6	RF14	RF3	RF16	RF18
RF13	(0.027,0.107,0.516)	(0.099,0.203,0.631)	(0.037,0.126,0.547)	(0.093,0.197,0.632)	(0.065,0.193,0.676)	(0.057,0.158,0.595)	(0.084,0.169,0.549)	(0.067,0.172,0.591)	(0.051,0.167,0.637)	(0.022,0.098,0.508)
RF15	(0.065,0.165,0.584)	(0.022,0.094,0.503)	(0.018,0.089,0.501)	(0.069,0.164,0.592)	(0.085,0.202,0.676)	(0.070,0.160,0.594)	(0.029,0.096,0.488)	(0.039,0.131,0.555)	(0.060,0.160,0.626)	(0.033,0.114,0.512)
RF11	(0.058,0.160,0.609)	(0.073,0.176,0.632)	(0.020,0.087,0.491)	(0.087,0.189,0.640)	(0.098,0.215,0.709)	(0.075,0.180,0.631)	(0.071,0.155,0.567)	(0.036,0.128,0.576)	(0.065,0.165,0.658)	(0.030,0.103,0.526)
RF5	(0.116,0.241,0.715)	(0.126,0.252,0.729)	(0.040,0.139,0.611)	(0.040,0.137,0.610)	(0.120,0.266,0.802)	(0.088,0.209,0.695)	(0.071,0.163,0.606)	(0.100,0.220,0.686)	(0.067,0.195,0.730)	(0.047,0.147,0.607)
RF4	(0.039,0.142,0.608)	(0.053,0.161,0.636)	(0.093,0.195,0.618)	(0.085,0.191,0.660)	(0.035,0.136,0.625)	(0.049,0.153,0.623)	(0.039,0.122,0.545)	(0.061,0.167,0.619)	(0.084,0.201,0.697)	(0.061,0.155,0.579)
RF6	(0.036,0.132,0.577)	(0.069,0.171,0.617)	(0.045,0.138,0.554)	(0.083,0.183,0.630)	(0.101,0.223,0.699)	(0.020,0.093,0.511)	(0.042,0.120,0.518)	(0.046,0.143,0.579)	(0.056,0.168,0.648)	(0.035,0.120,0.530)
RF14	(0.086,0.178,0.568)	(0.050,0.144,0.555)	(0.029,0.107,0.499)	(0.075,0.167,0.573)	(0.047,0.143,0.596)	(0.051,0.141,0.548)	(0.017,0.069,0.410)	(0.039,0.122,0.524)	(0.059,0.155,0.593)	(0.038,0.109,0.489)
RF3	(0.071,0.187,0.654)	(0.073,0.190,0.666)	(0.066,0.172,0.616)	(0.074,0.185,0.662)	(0.079,0.214,0.736)	(0.056,0.163,0.635)	(0.052,0.144,0.568)	(0.022,0.102,0.539)	(0.077,0.199,0.705)	(0.042,0.133,0.573)
RF16	(0.035,0.114,0.525)	(0.030,0.104,0.524)	(0.069,0.155,0.534)	(0.021,0.085,0.505)	(0.075,0.178,0.622)	(0.041,0.123,0.535)	(0.026,0.093,0.464)	(0.047,0.121,0.523)	(0.019,0.083,0.495)	(0.050,0.121,0.497)
RF18	(0.092,0.208,0.658)	(0.057,0.170,0.648)	(0.091,0.198,0.629)	(0.078,0.189,0.661)	(0.114,0.250,0.752)	(0.039,0.142,0.617)	(0.037,0.118,0.545)	(0.071,0.177,0.631)	(0.094,0.216,0.709)	(0.018,0.085,0.490)

By applying Steps 1-5 described in Section 3.4 and using data gathered as explained in Section 4.2, the initial fuzzy direct influence matrix, the normalized fuzzy direct influence matrix, the fuzzy total influence matrix, and the crisp total influence matrix were computed as Tables 7, 8, 9, and 10, respectively.

The findings of Fuzzy DEMATEL analysis (see Table 11 and Figure 6) emphasize the crucial rela-

Table 10: The crisp total influence matrix ($\alpha = 0.224$).

	RF13	**RF15**	**RF11**	**RF5**	**RF4**	**RF6**	**RF14**	**RF3**	**RF16**	**RF18**
RF13	0	0.27	0	0.263	0.269	0.228	0.229	0.238	0.242	0
RF15	0.233	0	0	0.232	0.277	0.231	0	0	0.236	0
RF11	0.233	0.25	0	0.259	0.293	0.251	0	0	0.245	0
RF5	0.309	0.32	0	0	0.342	0.281	0.232	0.287	0.276	0
RF4	0	0.238	0.258	0.262	0	0.229	0	0.239	0.277	0
RF6	0	0.243	0	0.253	0.297	0	0	0	0.244	0
RF14	0.241	0	0	0.232	0	0	0	0	0.227	0
RF3	0.259	0.264	0.24	0.257	0.294	0.238	0	0	0.276	0
RF16	0	0	0	0	0.252	0	0	0	0	0
RF18	0.276	0.246	0.261	0.26	0.324	0	0	0.248	0.29	0

Table 11: The prominence and influence the crisp values of the key risk factors ($\alpha = 0.224$).

Risk Factor	R	D	$D+R$	$D-R$
RF13	2.337	2.279	4.616	-0.057
RF15	2.384	2.078	4.462	-0.306
RF11	2.077	2.283	4.361	0.206
RF5	2.388	2.693	5.081	0.305
RF4	2.787	2.351	5.138	-0.436
RF6	2.244	2.2	4.444	-0.044
RF14	1.905	2.006	3.911	0.1
RF3	2.185	2.419	4.604	0.234
RF16	2.467	1.862	4.329	-0.605
RF18	1.863	2.467	4.33	0.603

tionships between key risk factors in BACS projects. "*Selecting inappropriate contractor* (RF5)" and "*Inadequate planning and control of time, cost, and budget* (RF4)" were identified as the most significant risks according to prominence values $(D + R)$. This demonstrates their central positions in the network of project issues. These factors are crucial to the success of the project as a whole since they not only have a significant influence on other risk factors but also receive a meaningful impact from them.

However, the net influence $(D - R)$ values shows that risk key factors "*Selecting inappropriate contractor* (RF5)" and "*Inefficiencies in the client's technical and executive organization* (RF18)" serve as critical drivers, which means they are responsible for many of the project's difficulties. On the other hand, key risk factors "*Changes and adjustments in project* (RF16)" and "*Inadequate planning and control of time, cost, and budget* (RF4)" were identified as recipients, indicating that addressing their root causes is crucial to resolving them.

To effectively respond to these risk factors, project management should focus on actionable tactics that address the main causes as well as the contributing variables. Enhancing the technical and decision-making capabilities of the client organization, along with implementing an accurate contractor selection process that considers critical parameters such as experience, dependability, and prior performance should be the main goals for addressing causal risks RF18, RF5, and RF3.

Enhancing financial planning is crucial for significant key risk factors like RF11 and RF4 through securing reliable financing sources and developing financial backup plans. To guarantee more control over time, cost, and budget variables, project planning procedures (mainly defined by the project management office (PMO) of the project owner's organization) must simultaneously integrate cutting-edge technologies and techniques. The total risk landscape of BACS projects can be better controlled by tackling these

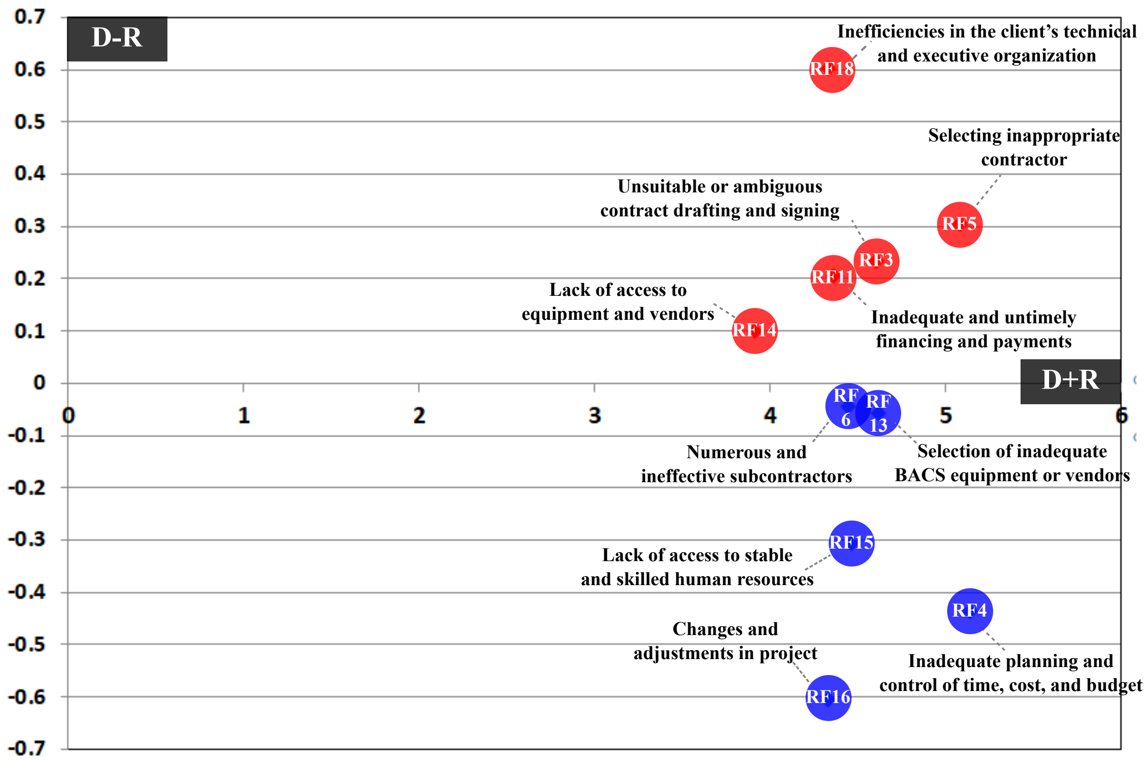


Figure 6: *The impact-relation map of the key risk factors of BACS project in the financial building case ($\alpha = 0.224$).*

risk factors in an organized and prioritized way, guaranteeing more seamless implementation and better project outcomes.

6 Conclusion

In this paper, considering the importance of BACS projects in construction of modern buildings, the identification, ranking, and causal analysis of key risk factors in these types of projects are addressed. For this purpose, an initial list of risk factors was prepared through the literature review and semi-structured interviews. A list consisting of 32 risk factors for BACS projects was identified and defined. Finally, risk factors of this list were ranked using the PROMETHEE II multi-criteria decision-making method and top ten risk factors were considered to be key risk factors. In the next stage, the causal relationships among the key risk factors were analyzed by using the Fuzzy DEMATEL method with focus on a financial services building case study.

According to the calculation results, the key risk factors in BACS projects with the highest scores are defined as:

1. Selection of inappropriate equipment or vendors
2. Lack of access to and instability of skilled and trained human resources
3. Inadequate and untimely financing
4. Selection of inappropriate and weak contractors

5. Weak planning and control of time, cost, and budget
6. Numerous and ineffective subcontractors
7. Lack of access to equipment and vendors
8. Unsuitable or ambiguous contract drafting and signing
9. Changes and adjustments in project
10. Inefficiencies in the client's technical and executive organization

The findings of the Fuzzy DEMATEL analysis emphasize the crucial relationships between key risk factors in the BACS project of the case. "*Selecting inappropriate contractor* (RF5)" and "*Inadequate planning and control of time, cost, and budget* (RF4)" were identified as the most influential risk factors according to prominence values $D + R$. This demonstrates their central positions in the network of project issues. These elements are crucial to the success of the project as a whole since they not only have a significant influence on other risk factors but also receive a meaningful impact from them.

However, the net influence $D - R$ values revealed that key risk factors "*Selecting inappropriate contractor* (RF5)" and "*Inefficiencies in the client's technical and executive organization* (RF18)" serve as critical drivers, responsible for many of the project's difficulties. On the other hand, key risk factors "*Changes and adjustments in project* (RF16)" and "*Inadequate planning and control of time, cost, and budget* (RF4)" were noted as recipients, indicating that addressing their root causes is crucial to resolving them. Based on this, project managers can design and adopt appropriate methods to control and respond to risks, thereby reducing the likelihood of failure in BACS projects.

The main limitation of this research is the limited access to sufficient number of diverse experts for scoring purposes. It is recommended that future studies expand the proposed approach by incorporating the opinions of a larger and more diverse group of experts in relevant fields.

Future research could further enhance this study. It is suggested that appropriate responses be developed for the highest-ranked and more influential risk factors, considering the specific conditions of BACS projects. This research would be particularly beneficial for project managers in preventing the risks or mitigating the effects and consequences of their occurrence during the execution phase of BACS system implementation projects.

Authors' Contribution: Mohammad Reza Namjoo contributed primarily to the research conception, design, analysis, interpretation of data, and preparing the manuscript. Mehrzad Salahi contributed to the research conception, data collection, data analysis, and revising the manuscript.

Conflicts of Interest: The authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgments: The authors would like to thank the experts who contributed to this study by participating in semi-structured meetings, completing questionnaires, and sharing their valuable insights, which greatly enriched the research.

References

Alavi, H., & Nadir, S. L. (2020). Risk analysis in construction phase of oil and gas projects: A critical literature review. *Multidisciplinary Aspects of Production Engineering,* 3.

An, H., & Shuai, Q. (2011). Analysis of risk in EPC project and the countermeasures. In *Proceedings of the 2011 International Conference on Management Science and Industrial Engineering (MSIE),* 424-428.

Arnuphaptrairong, T. (2011, March). Top ten lists of software project risks: Evidence from the literature survey. In *Proceedings of the International MultiConference of Engineers and Computer Scientists* (Vol. 1, pp. 1-6).

Arshad, H., & Zayed, T. (2022). Critical influencing factors of supply chain management for modular integrated construction. *Automation in construction,* 144, 104612.

Bahamid, R. A., Doh, S. I., & Al-Sharaf, M. A. (2019, February). Risk factors affecting the construction projects in the developing countries. In *IOP Conference Series: Earth and Environmental Science* (Vol. 244, No. 1, p. 012040). IOP Publishing.

Başhan , V., & Demirel, H. (2019). Application of fuzzy dematel technique to assess most common critical operational faults of marine boilers. *Politeknik Dergisi,* 22(3), 545–555.

Behzadian, M., Kazemzadeh, R. B., Albadvi, A., & Aghdasi, M. (2010). Promethee: A comprehensive literature review on methodologies and applications. *European journal of Operational research,* 200(1), 198–215.

Brans, J. P., & Mareschal, B. (1992). Promethee v: Mcdm problems with segmentation constraints. *INFOR: Information Systems and Operational Research,* 30(2), 85–96.

Brans, J.-P. (1982). L'ingenierie de la decision, l'laboration d'instruments d'aidea la decision. *Colloque surl'Aidea la Decision. Faculte des Sciences de l'Administration, Universite Laval*

Brans, J.-P., & Mareschal, B. (1995). The promethee vi procedure: How to differentiate hard from soft multicriteria problems. *Journal of Decision Systems,* 4(3), 213–223.

Brans, J. P., Mareschal, B., & Vincke, P. (1984). PROMETHEE: A new family of outranking methods in multicriteria analysis. In J. P. Brans (Ed.), *Operational research* (pp. 477–490). IFORS.

Brans, J.-P., & Vincke, P. (1985). Note—a preference ranking organisation method: (the promethee method for multiple criteria decision-making). *Management science,* 31(6), 647–656.

Brans, J.-P., Vincke, P., & Mareschal, B. (1986). How to select and how to rank projects: The promethee method. *European journal of operational research,* 24(2), 228–238.

Carter, S. (2017). *A guide to the project management body of knowledge.* Project Management Institute.

Chien, K.-F., Wu, Z.-H., & Huang, S.-C. (2014). Identifying and assessing critical risk factors for bim projects: Empirical study. *Automation in construction,* 45, 1–15.

Cuellar, M. (2010). Assessing project success: Moving beyond the triple constraint. In *Proceedings of the International Research Workshop on IT Project Management*, 19-28.

da Cunha, R. A., Rangel, L. A. D., Rudolf, C. A., & dos Santos, L. (2022). A decision support approach employing the promethee method and risk factors for critical supply assessment in large-scale projects. *Operations Research Perspectives,* 9, 100238.

Dağdeviren, M. (2008). Decision making in equipment selection: An integrated approach with ahp and promethee. *Journal of intelligent manufacturing,* 19, 397–406.

Debrah, C., Chan, A. P., & Darko, A. (2022). Artificial intelligence in green building. *Automation in Construction,* 137, 104192.

Desbalo, M. T., Woldesenbet, A. K., Tafesse, Z. S., Bargstadt, H.-J., & Yehualaw, M. D. (2023). Maturity model for evaluating building maintenance practice: A fuzzy-dematel approach. *Cogent Engineering,* 10(2), 2261226.

Domingues, P., Carreira, P., Vieira, R., & Kastner, W. (2016). Building automation systems: Concepts and technology review. *Computer Standards & Interfaces,* 45, 1–12.

El-Sayegh, S. M. (2008). Risk assessment and allocation in the uae construction industry. *International journal of project management,* 26(4), 431–438.

Ertas, A. (2010). Understanding of transdiscipline and transdisciplinary process. *Transdisciplinary Journal of Engineering & Science,* 1.

European Building Automation and Controls Association. (2022). Building automation and control systems (BACS): Reference cases. https://eubac.org/news/eu-bac-publishes-bacs-reference-case-booklet/ (accessed October 18, 2024).

Figueira, J. J. R., De Smet, Y., & Brans, J. P. (2005). Mcda methods for sorting and clustering problems: Promethee tri and promethee cluster. *Proceedings of the IFORS 2005 Conference.*

Ghandi, M., & Roozbahani, A. (2020). Risk management of drinking water supply in critical conditions using fuzzy promethee v technique. *Water Resources Management,* 34, 595–615.

Ghansah, F. A., Owusu-Manu, D.-G., & Ayarkwa, J. (2021). Project management processes in the adoptionof smart building technologies: A systematic review of constraints. *Smart and Sustainable Built Environment,* 10(2), 208–226.

Godemann, J. (2008). Knowledge integration: A key challenge for transdisciplinary cooperation. *Environmental Education Research,* 14(6), 625–641.

Hadorn, G. H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Hoffmann-Riem, H., Joye, D., Pohl, C., Wiesmann, U., & Zemp, E. (2008). The emergence of transdisciplinarity as a form of research. *Handbook of transdisciplinary research,* 19–39.

Haidabrus, B., Druzhinin, E., & Psarov, O. (2022). Taxonomy of risks in software development projects. it 2022 63rd International Scientific Conference on Information Technology and Management Science of Riga Technical University (ITMS), (pp. 1–7).

Hernandez-Aguilar, C., Dominguez-Pacheco, A., Martínez -Ortiz, E., Ivanov, R., Bonilla, J. L. L., Cruz-Orea, A., & Ordonez-Miranda, J. (2020). Evolution and characteristics of the transdisciplinary perspective in research: A literature review. *Transdisciplinary Journal of Engineering & Science,* 11.

Hochrainer-Stigler, S., Trogrlić , R. Š ., Reiter, K., Ward, P. J., de Ruiter, M. C., Duncan, M. J., Torresan, S., Ciurean, R., Mysiak, J., Stuparu, D., et al. (2023). Toward a framework for systemic multi-hazard and multi-risk assessment and management. *IScience,* 26(5).

Jato-Espino, D., Castillo-Lopez, E., Rodriguez-Hernandez, J., & Canteras-Jordana, J. C. (2014). A review of application of multi-criteria decision making methods in construction. *Automation in construction,* 45, 151–162.

Khairullah, N. H., Hilal, M. A., & Mohammed, A. (2022). Identification of the main causes of risks in engineering procurement construction projects. *Journal of the Mechanical Behavior of Materials,* 31(1), 282–289.

Kuzu, A. C. (2021). Risk analysis of break-in-two accident of ships using fuzzy dematel method. *Ocean Engineering,* 235, 109410.

Lawrence, M. G., Williams, S., Nanz, P., & Renn, O. (2022). Characteristics, potentials, and challenges of transdisciplinary research. *One Earth,* 5(1), 44–61.

Lee, J.-Y., Yoon, Y.-S., Jang, M.-H., & Suh, S.-W. (2009). Risk analysis using promethee method in building construction management. *International conference on construction engineering and project management,* (pp. 1364–1369).

Leśniak , A., Górka , M., & Skrzypczak, I. (2021). Barriers to bim implementation in architecture, construction, and engineering projects—the polish study. *Energies,* 14(8), 2090.

Macharis, C., Brans, J.-P., & Mareschal, B. (1998). The gdss promethee procedure. *Journal of decision systems,* 7(4), 283–307.

Macharis, C., Springael, J., De Brucker, K., & Verbeke, A. (2004). Promethee and ahp: The design of operational synergies in multicriteria analysis.: Strengthening promethee with ideas of ahp. *European journal of operational research,* 153(2), 307–317.

Mareschal, B. (2020). *The promethee bibliographical database.* https://bertrand.mareschal.web.ulb.be/PG2024/bibliographical-database.html (accessed September 10, 2024).

Mateo, J. R. S. C. (2012). *Multi criteria analysis in the renewable energy industry.* Springer Science & Business Media.

Mavi, R. K., & Standing, C. (2018). Critical success factors of sustainable project management in construction: A fuzzy dematel-anp approach. *Journal of cleaner production,* 194, 751–765.

Mehdizadeh, R., Breysse, D., Taillandier, F., & Niandou, H. (2013). Dynamic and multi perspective risk management in construction with a special view to temporary structures. *Civil Engineering and Environmental Systems,* 30(2), 115–129.

Nasirzadeh, F., Afshar, A., & Khanzadi, M. (2008). Dynamic risk analysis in construction projects. *Canadian Journal of Civil Engineering,* 35(8), 820–831.

Nasrollahi, M., Ramezani, J., & Sadraei, M. (2020). A fbwm-promethee approach for industrial robot selection. *Heliyon,* 6(5).

Opricovic, S., & Tzeng, G.-H. (2003). Defuzzification within a multicriteria decision model. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems,* 11(05), 635–652.

Ozsoy, C. M., & Mengüç , M. P. (2024). A transdisciplinary approach and design thinking methodology: For applications to complex problems and energy transition. *World,* 5(1), 119–135.

Patel, T., Bapat, H., Patel, D., & van der Walt, J. D. (2021). Identification of critical success factors (csfs) of bim software selection: A combined approach of fcm and fuzzy dematel. *Buildings,* 11(7), 311.

Pohl, C. (2010). From transdisciplinarity to transdisciplinary research. *Transdisciplinary Journal of Engineering & Science,* 1.

Ranjbara, M. S., Mahdavib, I., Choc, N., & Tavakolid, G. R. Selecting Technology Acquisition Strategy through Applying PROMETHEE Method: An Industrial Automation Equipment Manufacturer. In *Conference Management Team* (p. 83).

Renuka, S., Umarani, C., & Kamal, S. (2014). A review on critical risk factors in the life cycle of construction projects. *Journal of Civil Engineering Research,* 4(2A), 31–36.

Rezakhani, P. (2012). Classifying key risk factors in construction projects. *Buletinul Institutului Politehnic din lasi. Sectia Constructii, Arhitectura,* 58(2), 27.

Rostamnezhad, M., Nasirzadeh, F., Khanzadi, M., Jarban, M. J., & Ghayoumian, M. (2020). Modeling social sustainability in construction projects by integrating system dynamics and fuzzy-dematel method: A case study of highway project. *Engineering, construction and architectural management,* 27(7), 1595–1618.

San Cristobal, J. R. (2013). Critical path definition using multicriteria decision making: Promethee method. *Journal of Management in Engineering,* 29(2), 158–163.

Scholz, R. W., Zscheischler, J., Köckler , H., Czichos, R., Hofmann, K.-M., & Sindermann, C. (2024). Transdisciplinary knowledge integration–part i: Theoretical foundations and an organizational structure. *Technological Forecasting and Social Change,* 202, 123281.

Seker, S., & Zavadskas, E. K. (2017). Application of fuzzy dematel method for analyzing occupational risks on construction sites. *Sustainability,* 9(11), 2083.

Si, S.-L., You, X.-Y., Liu, H.-C., & Zhang, P. (2018). Dematel technique: A systematic review of the state-of-the-art literature on methodologies and applications. *Mathematical problems in Engineering,* 2018(1), 3696457.

Silveira, F. F., Russo, R. d. F. M., Júnior , I. G., & Sbragia, R. (2018). Systematic review of risks in domestic and global it projects. *Journal of Global Information Management (JGIM),* 26(1), 20–40.

Siraj, N. B., & Fayek, A. R. (2019). Risk identification and common risks in construction: Literature review and content analysis. *Journal of construction engineering and management,* 145(9), 03119004.

Spreng, D. (2014). Transdisciplinary energy research–reflecting the context. *Energy Research & Social Science,* 1, 65–73.

Tan, T., Mills, G., Papadonikolaki, E., & Liu, Z. (2021). Combining multi-criteria decision making (mcdm) methods with building information modelling (bim): A review. *Automation in Construction,* 121, 103451.

Tiusanen, R. (2017). *Qualitative risk analysis.* Handbook of Safety Principles, 463–492.

Tzeng, G.-H., & Huang, J.-J. (2011). *Multiple attribute decision making: Methods and applications.* CRC press.

van Roosmale, S., Hellinckx, P., Meysman, J., Verbeke, S., & Audenaert, A. (2024a). Building automation and control systems for office buildings: Technical insights for effective facility management-a literature review. *Journal of Building Engineering,* 110943.

van Roosmale, S., Audenaert, A., & Meysman, J. (2024b). Understanding the opportunities and challenges of building automation and control systems to support facility management–an extensive literature review. *Facilities, 42(7/8),* 677–693.

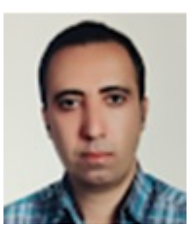
Waqar, A., Othman, I., & Gonz´alez-Lezcano, R. A. (2023). Challenges to the implementation of bim for the risk management of oil and gas construction projects: Structural equation modeling approach. *Sustainability,* 15(10), 8019.

Wu, W.-W., & Lee, Y.-T. (2007). Developing global managers' competencies using the fuzzy dematel method. *Expert systems with applications,* 32(2), 499–507.

Yorulmaz, M., & Karabulut, K. (2022). Analyzing the factors determining the effectiveness of the international safety management code applied on ships through the fuzzy dematel method. *Safety science,* 155, 105872.

About the Authors

Mohammad Reza Namjoo is an Assistant Professor in the Department of Industrial Engineering, Faculty of Engineering, Shahid Bahonar University of Kerman (SBUK), Kerman, Iran. He earned a PhD and an MS from the University of Tehran, Tehran, Iran, and a BS from Iran University of Science and Technology (IUST), Tehran, Iran, all in Industrial Engineering. His research interests include Smart Manufacturing, Cloud-based Manufacturing, Resiliency Engineering, and Production Planning and Control. He has also worked as a consultant and senior consultant in the industry, focusing on ERP systems implementation, system analysis and design, and automation. His peer-reviewed publications have been published in the International Journal of Computer Integrated Manufacturing, and the International Journal of Cloud Applications and Computing.



Mehrzad Salahi holds a Bachelor of Science in Electrical Engineering and has over a decade of extensive experience in Building Automation and Control Systems (BACS) projects. His expertise includes various roles in implementing BACS solutions for large-scale buildings, including hotels, shopping malls, and other commercial complexes. Additionally, the author has provided technical consultation in the engineering, procurement, and installation phases of BACS projects. His work has primarily been conducted within the context of Iran, contributing to numerous successful BACS implementations.