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Manuscript Title Assessing Health Climate in Building Construction Projects: Theory and Practice

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Assessing Health Climate in Building Construction Projects: Theory andPractice

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Abstract: The poor health of construction practitioners significantly affects the stable and healthy development of the construction industry. Although a large number of researchers have investigated the occupational health of construction practitioners, few have examined the assessment of the health climate in building construction projects. To bridge the knowledge gap, this study develops a fuzzy approach, namely Construction Health Climate Assessment (C-HCA), that can help assess health climate in building construction projects. First, health climate indicators spanning three dimensions were identified through a literature review and semi-structured interviews conducted with experienced experts. The Pythagorean fuzzy analytic hierarchy process was then utilized to quantify the importance of each health climate indicator, and a fuzzy comprehensive evaluation method was used to assess the level of health climate in construction projects. This approach was validated by a real-life project in China. This study contributes to the current body of knowledge by developing a construction health climate assessment approach. This approach is useful to practice as well because it can help industry practitioners gauge the level of the construction health climate in building construction projects, thereby recommending improvement accordingly.

Keywords: Health climate; construction projects; assessment; Pythagorean fuzzy AHP; China.

INTRODUCTION

It is well recognized that people working in the construction industry are more exposed to health hazards than those working in other industries, as the construction industry normally has heavier workloads and harsher conditions at project sites (Sousa et al., 2014; Umer, 2022). According to an epidemiological

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survey conducted by Dong et al. (2020), approximately 80% of construction workers worldwide suffer from musculoskeletal disorders. Jacobsen et al. (2013) conducted a cross-sectional mental health assessment of a convenience sample of construction workers and found that 16% of workers experienced substantial mental stress. In addition to musculoskeletal disorders and mental illness, pneumoconiosis, contact dermatitis, arm vibration syndrome, and hearing loss are also common occupational diseases for people working in the construction industry (Chen et al., 2021; Cheriyan and Choi, 2020; Dabirian et al., 2020; Kurtz et al., 2012; Sharma et al., 2014). Poor health conditions in the construction industries worldwide not only cause individuals bodily and emotional anguish, but also result in massive economic losses (Gibb et al., 2018; Kamardeen, 2019). Thus, in recent years, an increasing number of scholars have shifted their attention to the occupational health management of the construction industry (Chan et al., 2016b; Yasmeen et al., 2020).

Referring to the comprehensive literature review conducted by Liang and Shi (2021), the prevailing research themes of construction health management are disclosed to be specific health hazards, health data statistics, the status of health practices in the construction industry, and the evaluation of the efficacy of health programs. In contrast, limited work has been done to assess the health climate in building construction projects, which is a key aspect of resolving construction practitioners' health issues. Therefore, the aim of this study is to fill the knowledge gap by developing a systematic approach that can be used to assess the health climate in an ongoing building construction project.

The context of this study is the construction industry in China. In China, the construction industry is a cornerstone of national economic growth and a major sector of labor employment (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2022). In 2021, the Chinese construction industry contributed more than RMB 7,874 billion (approximately USD 1,141 billion) to the economy, accounting for around 6.9% of the total gross domestic product (GDP), and the number of construction practitioners was 52,829,000, contributing 6.7% of the total labor force (National Bureau of Statistics of China, 2022). However, the occupational hazards in China's construction industry are extremely serious, and the incidence of occupational diseases in the Chinese construction industry is the third highest among all sectors, second only to mining and manufacturing. According to statistics released by National Health Commission of the People's Republic of China (2022), roughly 40% of practitioners in the industry are exposed to occupational disease hazards. Thus, it is imperative for China to raise the health level of its construction industry.

The remaining parts of this paper are arranged as follows. First, a comprehensive literature review of extant construction health research is presented. Then, the details of the research methods are recorded. After that, indicators for construction health climate assessment are identified, and a fuzzy approach that can be used to assess health climate in an ongoing building construction project is developed. Lastly, the developed approach is applied in a real-world case in China, and the assessment results are fully discussed and interpreted.

LITERATURE REVIEW

Extant Research on the Health of Construction Practitioners

In recent years, research studies on the health issues of construction practitioners have been conducted from many angles, such as occupational health and safety management systems, influencing factors of occupational health status of construction practitioners, strategies to improve the health of construction practitioners, and mental health issues, etc. (Fang et al., 2021; Nnaji and Karakhan, 2020; Wang et al., 2020; Wang et al., 2022). Okonkwo Patrick and Wium (2020) investigated health and safety management systems found within medium-to-large construction contractor organizations in South Africa. Fuller et al. (2022) examined the factors influencing the design and delivery of health promotion programs implemented by construction organizations to educate workers and promote a healthy lifestyle. Lingard and Turner (2017) explored factors affecting the healthy behaviors of construction professionals in Australia. Through an in-depth review of occupational health and safety management in the construction industry, Jaafar et al. (2018) identified four main factors contributing to occupational accidents and diseases: human, workplace, management, and external. Bowen et al. (2022) investigated the association between alcohol use and HIV-related health behaviors in construction.

Some researchers have looked into strategies to improve the health of construction practitioners. For example, Chan et al. (2016a) identified various strategies that can help improve the health of ethnic minority workers from Asian countries. Nwaogu et al. (2022) evaluated the measures that can be adopted to promote the good mental health of construction personnel. Simpeh and Amoah (2023) investigated measures put in place at construction project sites to curb the spread of COVID-19 among construction site workers. Loudoun and Townsend (2017) identified possible agents and levers to trigger the development and implementation of workplace health promotion programs in the Australian construction industry.

With respect to mental health, Chan et al. (2020) systematically reviewed the existing body of knowledge on mental health in the construction industry. Nwaogu et al. (2020) conducted a scientometric review of mental health research in the construction industry. Tijani et al. (2021) developed a multi-level mental health management framework for project management practitioners in architecture, engineering, and construction project organizations through organizational design theories. Scott-Young et al. (2020) explored sex differences in mental health and resilience in the early career pipeline of emerging built environment professionals. Kotera et al. (2020) explored the relationships among work-life balance, mental health, attitudes toward mental health problems, and work schedules. Turner and Lingard (2020) explored musculoskeletal bodily pain and its impact on construction workers' mental health.

Construction Health Climate and Assessment

The health climate represents the perceptions of organizational members of health management behaviors and phenomena within the organization (Schneider, 1975). Zweber et al. (2016) defined the health climate as "Employee perceptions of active support from upper management as well as supervisors and coworkers for the physical and psychological well-being of employees, including organizational norms and values, employee attitudes, social support, and environmental condition." Currently, there is no universally accepted definition of health climate in construction. This study interprets the construction health climate as employees' perceptions of the organization's health management system, including policies, practices, and procedures that indicate how health is maintained and improved in the construction site environment. The health climate is a significant environmental factor that boosts practitioners' occupational health (Basen-Engquist et al., 1998). A favorable health climate is a necessary condition for better health, as potential health risks can be easily identified by evaluating the health climate; thus, effective health-improvement strategies could be formulated and implemented.

METHODS

The research process of this study consisted of four steps. First, a group of indicators of the health climate at building construction sites was identified in the literature review. Then, semi-structured interviews were conducted to verify the identified indicators. After that, based on the identified indicators, a fuzzy approach that can assess the health climate at building construction sites was developed. The approach was devised on the grounds of the Pythagorean fuzzy analytic hierarchy process (PHAHP) and the fuzzy comprehensive evaluation method, following the practices of Ilbahar et al. (2018) and Oppong Goodenough et al. (2021). Lastly, the approach was applied in a building construction project carried out in Hunan Province, China. A flowchart of the research process is shown in Figure 1.

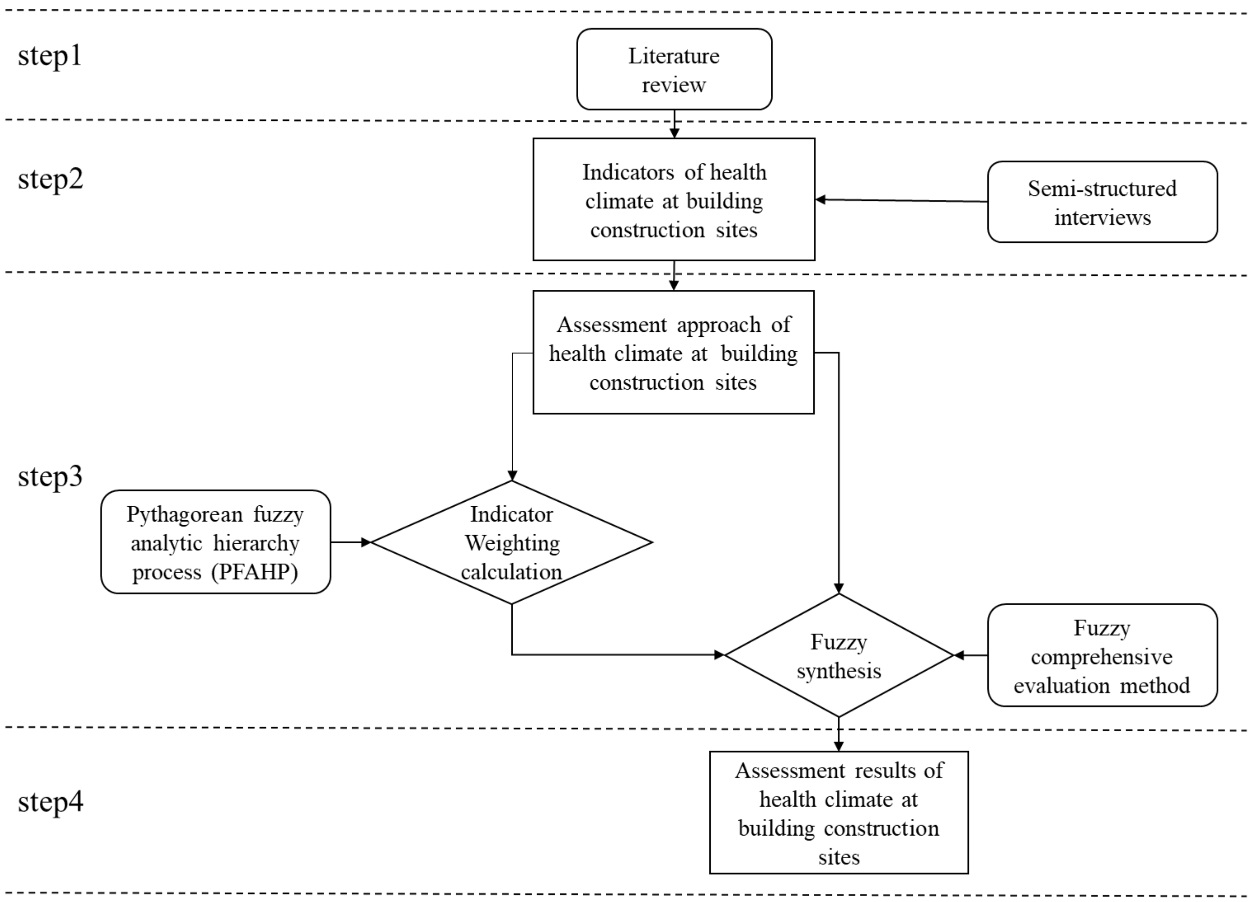

Figure. 1. Flowchart of research process

IDENTIFICATION OF INDICATORS OF CONSTRUCTION HEALTH CLIMATE

To identify indicators of construction health climate, the keywords “health climate” and “construction projects” were searched in the well-known Web of Science Core Collection database. Additionally, to include more informative literature, books related to occupational health and climate were included in the literature search. Lastly, nine journal articles and two books highly related to the construction health climate were identified, as shown in Table 1. After going through this literature, 15 indicators of construction health climate were identified, as shown in Table 1. Referring to Li et al. (2023), these 15 indicators were categorized into three dimensions: management commitment, employee involvement, and supportive environment. To check the applicability of the 15 indicators to building construction projects in China, semi-structured interviews were conducted with 13 highly experienced experts from March to April 2022. During the interviews, experts were invited to assess the 15 indicators using a five-point rating scale: 1 = strongly unsuitable, 2 = unsuitable, 3 = neutral, 4 = suitable, and 5 = strongly suitable. The mean scores of experts’ evaluations of the 15 indicators were calculated, and a threshold of 2.5 points was used to screen indicators suitable for the building construction sector in China, following the advice of Hsueh et al. (2009). According to the results shown in Table 1, three indicators received mean scores lower than 2.5 and were thus removed from the list. Finally, 12 indicators were finalized and used to assess the construction health climate in Chinese building construction projects. Table 2 presents the background information of the experts.

Table 1. Indicators of construction health climate

Target	Dimensions	Code	Indicators	Source											Applicability evaluation
				A	B	C	D	E	F	G	H	I	J	K	
Health Climate	Management Commitment (U1)	U11	Management can actively take measures to eliminate workplace health hazards for employees.	X		X	X		X		X				4.38
		U12	Management places a high value on employee health and works quickly to prevent violations.			X			X						4.54
		U13	Management can invest a lot of energy in construction health training.	X			X				X				3.62
		U14	The company organizes occupational health examinations regularly.	X				X			X				4.15
	Employee Involvement	U21	Employees are fully aware of the health risks associated with their work.		X	X			X			X	X	X	4.00

Target	Dimensions	Code	Indicators	Source A	B	C	D	E	F	G	H	I	J	K	Applicability evaluation
	(U2)	U22	Employees can give opinions when developing or reviewing health procedures/instructions/rules.		X	X						X			3.69
		U23	Employees can wear personal protective equipment to protect personal health as required.		X		X					X			4.62
		U24	Employees can always observe health regulations during the work process.		X										4.38
		U25	Health issues are frequently discussed among colleagues throughout the work week.		X	X									2.37^b
	Supportive Environment	U31	Management can provide all health equipment required by occupational health regulations.	X							X	X			3.92

Target	Dimensions	Code	Indicators	Source A	B	C	D	E	F	G	H	I	J	K	Applicability evaluation
	(U3)	U32	Management can listen carefully and adopt effective suggestions from employees to improve construction health.	X	X	X	X			X	X		X		4.46
		U33	Colleagues can monitor and correct one other's infractions of construction health regulations.		X		X		X			X			4.38
		U34	Colleagues can understand and support each other's leave of absence due to health reasons and help with work.				X			X					4.38
		U35	Most of the health training provided by the company is effective.		X		X		X			X	X		2.12^{b}
		U36	Health training can cover all health			X			X						2.35^{b}

Target	Dimensions	Code	Indicators	Source											Applicability evaluation
				A	B	C	D	E	F	G	H	I	J	K	
			risks associated with employees' work.												

[a]A = Zohar and Luria (2005); B = Choudhry Rafiq et al. (2009); C = Mohamed (2002); D = Brondino et al. (2012); E = Damman et al. (2015); F = Health and Safety Executive (HSE) (2002); G = Zweber et al. (2016); H = Cheung and Zhang (2020); I = Zhou et al. (2011); J = Hon et al. (2012); K = Lin et al. (2008).

[b]U25, U35 andU36 were dropped with an evaluation score lower than 2.5 points in the interview.

Table 2. Backgrounds of interviewed experts

Number	Employer	Position	Experience	Geographic location
1	Consultant	Engineer	15	Eastern China
2	Consultant	Engineer	17	Central China
3	Designer	Business manager	17	Central China
4	Owner	Director	17	Central China
5	Owner	Project manager	12	Central China
6	Owner	Business manager	17	Central China
7	Owner	Project manager	15	Central China
8	Contractor	Business manager	17	Eastern China
9	Contractor	Engineer	12	Eastern China
10	Contractor	Engineer	12	Eastern China
11	Contractor	Engineer	12	Eastern China
12	Contractor	Project manager	17	Central China
13	Contractor	Director	17	Eastern China

DEVELOPMENT OF CONSTRUCTION HEALTH CLIMATE ASSESSMENGT (C-HCA)

Based on the indicators refined by interview experts, a construction health climate assessment (C-HCA), a fuzzy approach that can assess the construction health climate at a given project site, was developed. The approach was designed using a two-level fuzzy comprehensive assessment method. The following are specific steps for the development of C-HCA.

Establishing the Assessment Indictor Set U

The indicators in the health climate assessment index system for construction projects are used as the assessment objects to develop the assessment indicator set $U=\{U_{1,}U_2,\ldots,U_M\}$. Since there were 3 dimensions and 12 second-level indictors in this study, the assessment indicator set $U=\{U_1,U_2,U_3\}$, where $U_1=\{U_{11},U_{12},U_{13},U_{14}\}$, $U_2=\{U_{21},U_{22},U_{23},U_{24}\}$, $U_3=\{U_{31},U_{32},U_{33},U_{34}\}$.

Establishing the Judgment Set V

V stands for the judgment set in the comprehensive assessment, $V=\{V_1,V_{2,}\ldots,V_n\}$, where n=number of judgment grades. In this study, a five-level assessment was carried out on the implementation degree of each indicator of the health climate assessment indicator system for construction projects through questionnaire survey, thus the judgment set=$\{V_1,V_{2,}V_3,V_4,V_5\}$ was established as shown in Table 3.

Table 3. Judgment set

Judgement Set	Very high	High	Medium	Low	Very low
Graded	5	4	3	2	1

Establishing Indicator Weight Vector W

W reflects the assessment indictor's relative degree of importance, and it is mostly used for weighting R. The set of indicator weights is denoted as $W=\{W_1,W_2,\ldots,W_m\}$, and the weight of each indicator must satisfy the condition $\sum_{i=1}^{m} w_i=1, w_i\geq 0, i=1,2,\ldots,m$. Many methods can be used to calculate indicator weights. The indicator weight vector of this study was obtained by adopting PFAHP.

PYTHAGOREAN FUZZY AHP

Zadeh developed fuzzy set theory in mathematics in 1965, a method used to describe fuzzy phenomena that can represent inaccurate, ambiguous, and undependable knowledge (Gunduz et al., 2015; Zadeh, 1965). Fuzzy set theory is based on the linguistic terms and membership functions of distinct grades. It permits the construction of formidable instruments for judging ambiguity and provides the chance to represent significant fuzzy conceptions articulated in natural language (Gunduz et al., 2015; Shan et al., 2015). Thus far, various fuzzy sets have been developed through various forms of extension. Zadeh (1975) proposed type-n fuzzy sets to describe the unsureness of membership functions. Subsequently, Atanassov (1986) proposed a new version of fuzzy sets, namely intuitionistic fuzzy sets, to address the issue of non-membership degree distribution. Later, Yager (2013) broadened the scope of intuitionistic fuzzy sets by introducing Pythagorean fuzzy sets, a new type of non-standard fuzzy subset. Compared with fuzzy sets and intuitionistic fuzzy sets, Pythagorean fuzzy sets can deal with uncertainty and ambiguity in decision-making processes more powerfully and flexibly by allowing experts to voice their opinions more freely on uncertainty and ambiguity in decision-making situations (Yager and Abbasov, 2013). Therefore, it is more reliable to figure out uncertainty problems (Ilbahar et al., 2018; Mohd and Abdullah, 2017).

The analytic hierarchy process (AHP) is a systematic decision-making analysis method that comprehensively considers both subjective and objective factors (Dey, 2010). It is simple, practical, and appropriate for solving complex problems that are difficult to quantify completely, and it is broadly used in the measurement of subjective parameters in various fields (Saaty, 1980). However, the rating difference in the importance of different indicators is based on personal experience, so there is a certain error in the final indicator weights (Cheung and Zhang, 2020). Owing to the limitations of AHP, it is generally necessary to use it in combination with fuzzy sets to lower the subjectivity of weight ranking and improve its credibility. Given that respondents' perceptions of evaluation indicators are commonly subjective and imprecise, this study decided to use PFAHP to establish an evaluation model. PFAHP, similar to other fuzzy AHP assessment methods, requires the creation of a comparison matrix; 0 displays the categories, descriptions, and weight values for various importance.

Some definitions must be explained before understanding the PFAHP (Yager, 2016). The sum of membership and non-membership degrees assigned by experts in Pythagorean fuzzy sets may be more than 1, but the sum of squares is less than or equal to 1 in some practical applications (Ilbahar et al., 2018; Peng and Yang, 2015; Yucesan and Kahraman, 2019). The contents described above is indicated in Definition 1.

Definition 1. Assuming that X represents a domain of discourses. A Pythagorean fuzzy set Q in X is made up of objects with the form (Yager, 2016; Zhang and Xu, 2014):

$$Q=\left\{< x,\mu_Q(x),\nu_Q(x)>| \, x\in X\right\} \qquad (1)$$

Where the function $\mu_Q\left(x\right): X\in\left[0,1\right]$ represents the degree of membership of the element $x \in X$ to the set Q, the function $v_Q(x): X \in [0,1]$ represents the degree of non-membership of the element $x \in X$ to the set Q, and for any $x \in X$, it satisfies:

$$0 \le \mu_Q^2(x) + v_Q^2(x) \le 1 \qquad (2)$$

For any Pythagorean fuzzy sets Q and $x \in X$, $\pi_Q(x) = \sqrt{1 - \mu_Q^2(x) - v_Q^2(x)}$ is regarded as the degree of hesitation of x to Q.

Definition 2. Assuming that $\gamma_1 = Q(\mu_{\gamma_1}, v_{\gamma_1})$, $\gamma_2 = Q(\mu_{\gamma_2}, v_{\gamma_2})$ are two Pythagorean fuzzy numbers and $\delta > 0 (\in R)$, then the definition of mathematical operations on these two numbers is as below (Zeng et al., 2015; Zhang and Xu, 2014):

$$\gamma_1 \oplus \gamma_2 = Q\left(\sqrt{\mu_{\gamma_1}^2 + \mu_{\gamma_2}^2 - \mu_{\gamma_1}^2 \mu_{\gamma_2}^2}\ , v_{\gamma_1} v_{\gamma_2}\right) \qquad (3)$$

$$\gamma_1 \otimes \gamma_2 = Q\left(\mu_{\gamma_1} \mu_{\gamma_2}, \sqrt{v_{\gamma_1}^2 + v_{\gamma_2}^2 - v_{\gamma_1}^2 v_{\gamma_2}^2}\right) \qquad (4)$$

$$\delta\gamma_1 = Q\left(\sqrt{1 - \left(1 - \mu_{\gamma_1}^2\right)^{\delta}}, \left(v_{\gamma_1}\right)^{\delta}\right), \delta > 0 \qquad (5)$$

$$\gamma_1^{\delta} = Q\left(\left(\mu_{\gamma_1}\right)^{\delta}, \sqrt{1 - \left(1 - v_{\gamma_1}^2\right)^{\delta}}\right), \delta > 0 \qquad (6)$$

$$\delta\gamma_2 = \mathrm{Q}\left(\sqrt{1 - \left(1 - \mu_{\gamma_2}^2\right)^{\delta}}, \left(v_{\gamma_2}\right)^{\delta}\right), \delta > 0 \qquad (7)$$

$$\gamma_2^{\delta} = Q\left(\left(\mu_{\gamma_2}\right)^{\delta}, \sqrt{1 - \left(1 - v_{\gamma_2}^2\right)^{\delta}}\right), \delta > 0 \qquad (8)$$

Definition 3. Assuming that $\gamma_{1_i} = \left(\mu_{1_i}, v_{1_i}\right), i = (1, 2, \ldots, n)$ is a collection of Pythagorean fuzzy numbers, then the Pythagorean fuzzy weighted power geometric(PFWPG) operator defined by Yager and Abbasov (2013) is as below:

$$PFWPG\left(\gamma_{1_1}, \gamma_{1_2}, \ldots, \gamma_{1_n}\right) = \left(\left(1 - \prod_{i=1}^{n}\left(1 - \mu_{1i}{}^2\right)^{w_i}\right)^{1/2}, \left(1 - \prod_{i=1}^{n}\left(1 - v_{1_i}{}^2\right)^{w_i}\right)^{1/2}\right) \qquad (9)$$

Where n represents the number of experts who assess the indictors, and $w = (w_1, w_2, \ldots, w_n)^T$ represents the weight vector of γ_{1_i}, $i = (1, 2, \ldots, n)$ with $\sum_{i=1}^{n} w_i = 1$ (Yager and Abbasov, 2013).

STEPS OF PYTHAGOREAN FUZZY AHP

The specific steps of the PFAHP method are described below.

Step 1: The compromised pairwise comparison matrix $C=\left(c_{ik}\right)_{m\times m}$ is established in view of experts' language evaluation (see Table 4). The weighting scale of the interval-valued PFAHP used in expert evaluation is shown in Table 5, which was given by (Ilbahar et al., 2018).

Table 4. Evaluation in matrix form

	C_1	$\dots$	C_m
C_1	$<[0.1965,0.1965],[0.1965,0.1965]>$	$\dots$	$<,[\mu_{A_{1m}},\mu_{B_{1m}}],[v_{A_{1m}},v_{B_{1m}}]>$
$\vdots$	$\vdots$	$\ddots$	$\vdots$
C_m	$<,[\mu_{A_{m1}},\mu_{B_{m1}}],[v_{A_{m1}},v_{B_{m1}}]>$	$\dots$	$<[0.1965,0.1965],[0.1965,0.1965]>$

Table 5. Weighting scale of the interval-valued PFAHP method

Linguistic terms	Grad es	Pythagorean Fuzzy Numbers equivalents Interval-Valued Pythagorean Fuzzy numbers			
		μ_A	μ_B	v_A	v_B
Certainly Low Importance (CLI)	1	0.00	0.00	0.90	1.00
Very Low Importance (VLI)	2	0.10	0.20	0.80	0.90
Low Importance (LI)	3	0.20	0.35	0.65	0.80

Below Average Importance (BAI)	4	0.35	0.45	0.55	0.65
Average Importance （AI）	5	0.45	0.55	0.45	0.55
Above Average Importance （AAI）	6	0.55	0.65	0.35	0.45
High Importance（HI）	7	0.65	0.80	0.20	0.35
Very High Importance（VHI）	8	0.80	0.90	0.10	0.20
Certainly High Importance （CHI）	9	0.90	1.0	0.00	0.00
Exactly Equal（EE）	/	0.1965	0.1965	0.1965	0.1965

Step 2: The difference matrices $D=\left(d_{ik}\right)_{m\times m}$ between lower and upper values of the membership and non-membership functions are computed using Eqs. (10) and (11):

$$d_{ik_A}=\mu_{ik_A}^2-v_{ik_B}^2 \qquad (10)$$

$$d_{ik_B}=\mu_{ik_B}^2-v_{ik_A}^2 \qquad (11)$$

Step 3: Interval multiplicative matrix $G_{ik}=\left(g_{ik}\right)_{m\times m}$ is calculated using Eq. (12) and (13):

$$G_{ik_A}=\sqrt{1000^{d_A}} \qquad (12)$$

$$G_{ik_B}=\sqrt{1000^{d_B}} \qquad (13)$$

Step 4: The determinacy value $\Delta=\left(\Delta_{ik}\right)_{m\times m}$ is computed using Eq. (14):

$$\Delta_{ik}=1-\left(\mu_{ik_A}^2-\mu_{ik_B}^2\right)-\left(v_{ik_A}^2-v_{ik_B}^2\right) \qquad (14)$$

Step 5: The determinacy degrees are multiplied with $G_{ik}=\left(g_{ik}\right)_{m\times m}$ matrix for obtaining the matrix of weight, $Z=\left(z_{ik}\right)_{m\times m}$, before normalization using Eq. (15):

$$z_{ik} = \left(\frac{G_{ik_A} + G_{ik_B}}{2} \right) \Delta_{ik} \qquad (15)$$

Step 6: The normalized priority weights w_i is computed using Eq. (16):

$$w_i = \frac{\sum_{k=1}^{m} z_{ik}}{\sum_{i=1}^{m} \sum_{k=1}^{m} z_{ik}} \qquad (16)$$

Establishing Fuzzy Matrix R

R is a membership matrix, which indicates the degree of membership of an evaluation indicator in the evaluation indicator set U to a certain judgment grade in the judgment set V, $R = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix}$, where r_{ij} stands for the degree of membership of the indicator I owned by the grade J. This study constructed and standardized the membership degree matrix based on the questionnaire survey findings of the health climate assessment indicators for construction projects, yielding three first-level fuzzy evaluation matrices and one second-level fuzzy evaluation matrix.

Establishing a Fuzzy Comprehensive Assessment Model

The fuzzy comprehensive method is used to construct the fuzzy assessment matrix $B = W \cdot R = (W_1 W_2, \ldots, W_M) \bullet \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix} = (B_1, B_2, \ldots, B_n)$, where B represents the assessment consequence of each indicator of the indicator set U. The adoption of the M (·, ⊕) operator is to calculate all kinds of assessment consequences in this study.

CASE STUDY AND DISCUSSION

Fifth Xiangya Hospital is a representative building construction project being constructed in Hunan Province, central part of China. The hospital was designed to provide a new world-class model for the delivery of healthcare in China, accommodating over 100,000 patients a day and housing over 2,500 patient rooms. Taking Fifth Xiangya Hospital as an example, this study assessed the health climate of this project using the assessment indicators and approaches mentioned above. Based on the semi-structured interview results, two questionnaire documents were developed in this study to obtain perception-based data on health climate assessment indicators from two perspectives. In September 2022, the first questionnaire was distributed to 13 construction industry experts, the same as those interviewed in the semi-structured interviews, to determine the weight of each assessment indicator. The second questionnaire was sent to practitioners of the Fifth Xiangya Hospital project to obtain scores for each assessment indicator. The questionnaire employed a five-point Likert scale to rate the implementation of the 12 assessment indicators of health climate: 5 = very high, 4 = high, 3 = medium, 2 = low, and 1 = very low. The electronic version of this questionnaire was delivered online to practitioners in this project between April and May 2022. To increase the dependability of the questionnaire data, the questionnaire was anonymous and self-administered. Finally, 33 valid questionnaires were received. The calculation process for the construction health climate of this project is shown below.

First, using the PFAHP to determine the weight of each dimension and each indicator of the health climate assessment was proposed in this study. The 13 experts with experience in the field of construction were requested to compare pairwise the relative importance of each dimension and each indicator of the health climate assessment using the linguistic terms in Table 4 and then convert the linguistic terms into interval-valued Pythagorean fuzzy numbers. Next, using the PFWFG operator of Eq. (9), the converted interval-valued Pythagorean fuzzy numbers were aggregated. Tables 6 and 7 summarize the aggregated pairwise comparison matrix of the dimensions and the aggregated pairwise comparison matrix of the indicators, respectively.

Table 6. Pairwise comparisons matrix of the dimensions

Criteria of Health Climate	Pythagorean fuzzy numbers: $< degree\ of\ memberiship, degree\ of\ non-membership > < \mu_A, \mu_B, v_A, v_B >$		
	U1	U2	U3
U1	$< 0.1965,0.1965,0.1965,0.1965 >$	$< 00.62,0.72,0.20,0.29 >$	$< 0.59,0.66,0.14,0.18 >$
U2	$< 0.20,0.29,0.62,0.72 >$	$< 0.1965,0.1965,0.1965,0.1965 >$	$< 0.54,0.66,0.30,0.40 >$
U3	$< 0.14,0.18,0.59,0.66 >$	$< 0.30,0.10,0.54,0.66 >$	$< 0.1965,0.1965,0.1965,0.1965 >$

Table 7. Pairwise comparisons matrix of the indicators

Criteria of U1	Pythagorean fuzzy numbers: $< degree\ of\ memberiship, degree\ of\ non-membership > < \mu_A, \mu_B, v_A, v_B >$			
	U11	U12	U13	U14
U11	$< 0.1965,0.1965,0.1965, 0.1965 >$	$< 0.49,0.57,0.23,0.31 >$	$< 0.58,0.68,0.20,0.29 >$	$< 0.61,0.69,0.18,0.25 >$

U12	$< 0.23,0.31,0.49,0.57 >$	$< 0.1965,0.1965,0.1965, 0.1965 >$	$< 0.51,0.62,0.30,0.40 >$	$< 0.52,0.62,0.26,0.36 >$
U13	$< 0.20,0.29,0.58,0.68 >$	$< 0.30,0.40,0.51,0.62 >$	$< 0.1965,0.1965,0.1965, 0.1965 >$	$< 0.40,0.47,0.32,0.40 >$
U14	$< 0.18,0.25,0.61,0.69 >$	$< 0.26,0.36,0.52,0.62 >$	$< 0.32,0.40,0.40,0.47 >$	$< 0.1965,0.1965,0.1965, 0.1965 >$

Criteria of U2	Pythagorean fuzzy numbers: $< degree\ of\ memberiship, degree\ of\ non-membership > \ < \mu_A, \mu_B, v_A, v_B >$			
	U21	U22	U23	U24
U21	$< 0.1965,0.1965,0.1965, 0.1965 >$	$< 0.48,0.57,0.31,0.39 >$	$< 0.46,0.56,0.32,0..42 >$	$< 0.58,0.68,0.24,0.32 >$
U22	$< 0.31,0.39,0.48,0.57 >$	$< 0.1965,0.1965,0.1965, 0.1965 >$	$< 0.36,0.44,0.39,0.48 >$	$< 0.46,0.56,0.35,0.45 >$
U23	$< 0.32,0.42,0.46,0.56 >$	$< 0.39,0.48,0.36,0.44 >$	$< 0.1965,0.1965,0.1965,$	$< 0.49,0.56,0.24,0.30 >$

			0.1965 >	
U24	< 0.24,0.32,0.58,0.68 >	< 0.35,0.45,0.46,0.56 >	< 0.24,0.30,0.49,0.56 >	< 0.1965,0.1965,0.1965, 0.1965 >

Criteria of U3	Pythagorean fuzzy numbers:$< degree\ of\ memberiship, degree\ of\ non-membership >$ $< \mu_A, \mu_B, v_A, v_B >$			
	U31	U32	U33	U34
U31	< 0.1965,0.1965,0.1965, 0.1965 >	< 0.47,0.55,0.29,0.37 >	< 0.54,0.63,0.21,0.30 >	< 0.66,0.74,0.14,0.20 >
U32	< 0.29,0.37,0.47,0.55 >	< 0.1965,0.1965,0.1965, 0.1965 >	< 0.48,0.56,0.28,0.35 >	< 0.56,0.66,0.22,0.31 >
U33	< 0.21,0.30,0.54,0.63 >	< 0.28,0.35,0.48,0.56 >	< 0.1965,0.1965,0.1965, 0.1965 >	< 0.47,0.54,0.26,0.33 >
U34	< 0.14,0.20,0.66,0.74 >	< 0.22,0.30,0.53,0.62 >	< 0.26,0.33,0.47,0.54 >	< 0.1965,0.1965,0.1965,

0.1965 >

Tables 8 and 9 display the difference matrix D of the dimensions and the difference matrix D of the indicators calculated from the data in Tables 6 and 7, respectively.

Table 8. Difference matrix of the dimensions

Criteria of Health Climate	U1	U2	U3
U1	$< 0.00,0.00 >$	$< 0.30,0.48 >$	$< 0.31,0.42 >$
U2	$< -0.48,-0.44 >$	$< 0.00,0.00 >$	$< 0.13,0.34 >$
U3	$< -0.42,-0.41 >$	$< -0.34,-0.13 >$	$< 0.00,0.00 >$

Table 9. Difference matrix of the indicators

Criteria of U1	U11	U12	U13	U14
U11	$< 0.00,0.00 >$	$< 0.14,0.23 >$	$< 0.25,0.38 >$	$< 0.31,0.41 >$
U12	$< -0.05,-0.24 >$	$< 0.00,0.00 >$	$< 0.10,0.23 >$	$< 0.13,0.25 >$
U13	$< -0.17,-0.34 >$	$< -0.30,-0.23 >$	$< 0.00,0.00 >$	$< 0.01,0.07 >$
U14	$< -0.19,-0.37 >$	$< -0.31,-0.25 >$	$< -0.12,-0.07 >$	$< 0.00,0.00 >$
Criteria of U2	**U21**	**U22**	**U23**	**U24**
U21	$< 0.00,0.00 >$	$< 0.08,0.18 >$	$< 0.04,0.13 >$	$< 0.23,0.35 >$
U22	$< -0.23,0.11 >$	$< 0.00,0.00 >$	$< -0.10,-0.04 >$	$< 0.01,0.11 >$
U23	$< -0.21,0.02 >$	$< -0.04,0.04 >$	$< 0.00,0.00 >$	$< 0.15,0.23 >$

U24	$< -0.40, -0.02 >$	$< -0.19, -0.11 >$	$< -0.26, -0.23 >$	$< 0.00,0.00 >$
Criteria of U3	U31	U32	U33	U34
U31	$< 0.00,0.00 >$	$< 0.08,0.17 >$	$< 0.20,0.31 >$	$< 0.39,0.51 >$
U32	$< -0.22, -0.17 >$	$< 0.00,0.00 >$	$< 0.11,0.19 >$	$< 0.22,0.35 >$
U33	$< -0.35, -0.31 >$	$< -0.23, -0.19 >$	$< 0.00,0.00 >$	$< 0.11,0.18 >$
U34	$< -0.53, -0.51 >$	$< -0.34, -0.30 >$	$< -0.22, -0.18 >$	$< 0.00,0.00 >$

The interval multiplicative matrix G of the dimensions and the interval multiplicative matrix G of the indicators are also shown in Tables 10 and 11, respectively.

Table 10. Interval multiplicative matrix of the dimensions

Criteria of Health Climate	U1	U2	U3
U1	$< 1.00,1.00 >$	$< 2.84,5.32 >$	$< 2.95,4.27 >$
U2	$< 0.19,0.22 >$	$< 1.00,1.00 >$	$< 1.58,3.23 >$
U3	$< 0.23,0.25 >$	$< 0.31,0.63 >$	$< 0.00,0.00 >$

Table 11. Interval multiplicative matrix of the indicators

Criteria of U1	U11	U12	U13	U14
U11	$< 1.00,1.00 >$	$< 1.64,2.19 >$	$< 2.37,3.66 >$	$< 2.91,4.16 >$
U12	$< 0.85,0.44 >$	$< 1.00,1.00 >$	$< 1.43,2.20 >$	$< 1.59,2.35 >$

U13	< 0.55,0.31 >	< 0.35,0.45 >	< 1.00,1.00 >	< 1.02,1.26 >
U14	< 0.51,0.28 >	< 0.34,0.42 >	< 0.66,0.79 >	< 1.00,1.00 >
Criteria of U2	U21	U22	U23	U24
U21	< 1.00,1.00 >	< 1.32,1.84 >	< 1.13,1.58 >	< 2.20,3.38 >
U22	< 0.45,1.48 >	< 1.00,1.00 >	< 0.71,0.88 >	< 1.02,1.45 >
U23	< 0.49,1.08 >	< 0.87,1.14 >	< 1.00,1.00 >	< 1.66,2.19 >
U24	< 0.25,0.93 >	< 0.52,0.69 >	< 0.41,0.46 >	< 1.00,1.00 >
Criteria of U3	U31	U32	U33	U34
U31	< 1.00,1.00 >	< 1.34,1.77 >	< 1.99,2.90 >	< 3.84,5.73 >
U32	< 0.47,0.57 >	< 1.00,1.00 >	< 1.47,1.91 >	< 2.13,3.30 >
U33	< 0.30,0.34 >	< 0.45,0.52 >	< 1.00,1.00 >	< 1.47,1.87 >
U34	< 0.16,0.17 >	< 0.31,0.35 >	< 0.47,0.54 >	< 1.00,1.00 >

Tables 12 and 14 show the determinacy value matrix Δ of the dimensions, as well as the weight matrix before normalization. Similarly, Tables 13 and 15 represent the indicator determinacy value matrix and the weight matrix before normalization, respectively.

Table 12. Determinacy value matrix (Δ) of the dimensions

Δ	U1	U2	SE
U1	1.00	0.82	0.89

U2	0.82	1.00	0.79
SE	0.89	0.79	1.00

Table 13. Determinacy value matrix (Δ) of the indicators

Δ	U11	U12	U13	U14
U11	1.00	0.88	0.83	0.87
U12	0.88	1.00	0.80	0.82
U13	0.83	0.80	1.00	0.88
U14	0.87	0.82	0.88	1.00
Δ	U21	U22	U23	U24
U21	1.00	0.85	0.83	0.83
U22	0.85	1.00	0.86	0.82
U23	0.83	0.86	1.00	0.89
U24	0.83	0.82	0.89	1.00
Δ	U31	U32	U33	U34
U31	1.00	0.87	0.85	0.86
U32	0.87	1.00	0.88	0.83
U33	0.85	0.88	1.00	0.89

U34	0.86	0.85	0.89	1.00

197 **Table 14.** Weight matrix of the dimensions before normalization

Δ	U1	U2	U3
U1	7.56	7.76	7.74
U2	3.17	3.07	3.38
U3	1.52	1.46	1.59

198 **Table 15.** Weight matrix of the indicators before normalization

Δ	U11	U12	U13	U14
U11	8.24	8.11	8.51	8.64
U12	4.74	4.64	4.90	4.96
U13	2.60	2.52	2.69	2.73
U14	2.20	2.13	2.24	2.30
Δ	U21	U22	U23	U24
U21	5.78	5.88	6.02	6.11
U22	3.49	3.51	3.55	3.55
U23	4.06	4.10	4.22	4.28
U24	2.29	2.30	2.33	2.37

Δ	U31	U32	U33	U34
U31	8.54	8.65	8.93	9.11
U32	5.15	5.25	5.43	5.49
U33	3.03	3.07	0.76	3.24
U34	1.74	1.77	1.83	1.87

Table 16. Importance weights of dimensions and indicators

Target layer	Dimensions layer	Dimensions weight	Indicators layer	Indicators weight	Total weight
Health Climate	Management Commitment (U1)	0.6191	U11	0.4643	0.2874
			U12	0.2666	0.1650
			U13	0.1461	0.0905
			U14	0.1230	0.0762
	Employee Involvement (U2)	0.2582	U21	0.3726	0.0962
			U22	0.2209	0.0570
			U23	0.2610	0.0674
			U24	0.1455	0.0376
	Supportive	0.1227	U31	0.4770	0.0585
			U32	0.2887	0.0354

Environment (U3)	U33	0.1366	0.0168
	U34	0.0977	0.0120

The obtained dimension weights and indicator weights are summarized in Table 16. The weight vectors of each dimension and indicator were expressed as follows:

$$W_{HC} = (0.6191, 0.2582, 0.1227)$$

$$W_1 = (0.4643, 0.2666, 0.1461, 0.1230)$$

$$W_2 = (0.3726, 0.2209, 0.2610, 0.1455)$$

$$W_3 = (0.4770, 0.2887, 0.1366, 0.0977)$$

As shown in Table 16, management commitment (U1) was the critical dimension of health climate assessment, employee involvement (U2) was the second most important dimension of health climate assessment, and the third most important dimension of health climate assessment was the supportive environment (U3). In the dimension of management commitment (U1), the order of weighting of the indicators was U11 > U12 > U13 > U14. In the dimension of employee involvement (U2), the weight order of the indicators was U21 > U23 > U22 > U24. In the dimension of supportive environment (U3), the indicators were weighted in the following order: U31 > U32 > U33 > U34.

Then, the degree of membership was determined using the percentage technique based on the scoring results of the construction practitioners in this project on each assessment indicator acquired by the questionnaire survey, and the fuzzy matrix R of each dimension was generated. The fuzzy matrices of dimensions, namely management commitment (U1), employee involvement (U2), and supportive environment (U3), were as follows:

$$R_1 = \begin{pmatrix} 0.54 & 0.39 & 0.05 & 0.02 & 0.00 \\ 0.55 & 0.37 & 0.05 & 0.03 & 0.00 \\ 0.22 & 0.43 & 0.22 & 0.09 & 0.04 \\ 0.44 & 0.44 & 0.08 & 0.03 & 0.01 \end{pmatrix} \quad R_2 = \begin{pmatrix} 0.27 & 0.51 & 0.16 & 0.05 & 0.01 \\ 0.23 & 0.32 & 0.29 & 0.11 & 0.05 \\ 0.48 & 0.43 & 0.07 & 0.02 & 0.00 \\ 0.32 & 0.54 & 0.10 & 0.03 & 0.01 \end{pmatrix} \quad R_3 = \begin{pmatrix} 0.30 & 0.45 & 0.19 & 0.06 & 0.00 \\ 0.26 & 0.45 & 0.20 & 0.07 & 0.02 \\ 0.32 & 0.51 & 0.14 & 0.03 & 0.00 \\ 0.41 & 0.49 & 0.08 & 0.01 & 0.01 \end{pmatrix}$$

Finally, fuzzy comprehensive assessment results were computed using the formula $B = W \cdot R$. The following was the assessment result of the dimension of management commitment (U1):

$$B_1 = W_1 \circ R_1 = (0.4643, 0.2666, 0.1461, 0.1230) \circ \begin{pmatrix} 0.54 & 0.39 & 0.05 & 0.02 & 0.00 \\ 0.55 & 0.37 & 0.05 & 0.03 & 0.00 \\ 0.22 & 0.43 & 0.22 & 0.09 & 0.04 \\ 0.44 & 0.44 & 0.08 & 0.03 & 0.01 \end{pmatrix} = (0.48, 0.40, 0.08, 0.03, 0.01)$$

In the same way, the assessment results of employee involvement (U2) and supportive environments (U3) dimensions were calculated as follows:

$$B_2 = W_2 \circ R_2 = (0.32, 0.45, 0.15, 0.05, 0.02)$$

$$B_3 = W_3 \circ R_3 = (0.30, 0.46, 0.17, 0.05, 0.01)$$

The dimensions scores were derived by combining the comprehensive assessment results and scoring standards: $B_1 = 4.31, B_2 = 4.01, B_3 = 4.00$

Comparing the scoring results and scoring standards, the score of management commitment was the highest among the dimensions of health climate assessment, 4.31, which fell between the two adjacent ranges of “high” and “very high,” indicating that management commitment to this building construction project was above the high level. The score of employee involvement (4.01) ranked second in the dimensions of health climate assessment, which was between “high” and “very high,” showing that employee involvement in this building construction project was also above the high level. Supportive environments received the third ranking, with a score of 4.00 among the dimensions of health climate assessment, and the score corresponded to a high level.

The weight vector W_{HC} was obtained according to the weight of the dimensions in 0, and then the assessment results of the dimensions were integrated into a fuzzy matrix R_{HC} to acquire the final assessment findings of the health climate of construction projects.

$$W_{HC} = (0.6191, 0.2582, 0.1227)$$

$$R_{HC} = \begin{pmatrix} 0.48 & 0.40 & 0.08 & 0.03 & 0.01 \\ 0.32 & 0.45 & 0.15 & 0.05 & 0.02 \\ 0.30 & 0.46 & 0.17 & 0.05 & 0.01 \end{pmatrix}$$

$$B_{HC} = W_{HC} \circ R_{HC} = (0.6191, 0.2582, 0.1227) \circ \begin{pmatrix} 0.48 & 0.40 & 0.08 & 0.03 & 0.01 \\ 0.32 & 0.45 & 0.15 & 0.05 & 0.02 \\ 0.30 & 0.46 & 0.17 & 0.05 & 0.01 \end{pmatrix} = (0.42, 0.42, 0.11, 0.04, 0.11)$$

Combining the assessment results and scoring criteria, the score of the construction health climate of this building construction project in China was

$B_{HC} = 4.20$, which fell into the two adjacent regions of "high" and "very high," showing that the level of construction health climate of this building construction project is relatively high.

Overall, the project Fifth Xiangya Hospital showed a good construction health climate performance. A management commitment (U1) score of 4.31 indicated that employees were satisfied with the health commitment made by management. An employee involvement (U2) score of 4.01 showed that employees in this building construction project actively participated in health work and abode by health regulations. The supportive environment score (U3) was 4.00, indicating that the behavior of employees in this project was strongly supported by management and colleagues. According to the PFAHP results, the two dimensions of management commitment (U1) and employee involvement (U2) were core ingredients for this building construction project to form a positive health climate. Management commitment (U1) was considered the most significant dimension affecting the level of the construction health climate of this building construction project. In this dimension, the most important indicator was that management can actively take measures to eliminate workplace health hazards for employees. This finding was consistent with Gill et al. (2010) and Barbosa et al. (2019) that employees' perception of management's concern for health hazards to employees is a key factor in forming a positive health climate. This dimension also emphasized the importance of management placing a high value on employee health and taking action quickly to prevent violations. Cheng (2019) and Dursun (2011) pointed out that management's attitude toward the violation of health regulations affects employees' perceptions of health regulations, which further influences the level of health climate. The second significant dimension was employee involvement (U2), and the most critical indicator in this dimension was how well employees understood the health risks at work. Zhai et al. (2020) found that employee's adequate knowledge of health-related risks is an indispensable element in forming a positive health climate, which has a significant impact on occupational health management. Whether employees could wear personal protective equipment as required was the second most important indicator under the dimension of employee involvement, which had a certain impact on the level of the construction health climate of this building construction project. This finding was supported by Man et al. (2021) who advocated that the level of the construction health climate is affected by the utilization of personal health protective equipment by employees.

CONCLUSION

It is vital to assess the health climate of an ongoing building construction project because this assessment may assist in recognizing deficiencies in occupational health management of construction projects, identifying prospective health hazards, and developing effective health risk response strategies in advance. This study developed a comprehensive fuzzy approach, namely C-HCA, to assess the level of health climate in an ongoing building construction project in China. First, 12 indicators of the construction health climate were identified from a comprehensive literature review and semi-structured interviews with 13 experienced experts. These indicators cover three dimensions: management commitment, employee involvement, and supportive environment. Then, the weight of each dimension and indicator was calculated using PFAHP. Next, each assessment indicator was assessed by 33 practitioners working in the construction industry of Hunan Province, China, regarding the degree of implementation of the indicators. Subsequently, a fuzzy comprehensive assessment method was used to assess the overall health climate level of the building construction project. This assessment approach adopts Pythagorean fuzzy sets to solve the issues of vagueness, subjectivity, and uncertainty in the process of health climate assessment and digitizes the linguistic terms used for pairwise comparisons between assessment indicators. Lastly, the assessment approach was used in a real building construction project in China with an exhaustive application process, and the results showed that the health climate of the project is high. In particular, the results show that employees actively participate in health work, abide by health regulations, and are satisfied with the health commitment made by management. Moreover, the results show that management commitment is the most significant dimension affecting the level of the construction health climate. In this dimension, the most important indicator is that management can actively take measures to eliminate workplace health hazards for employees. The second significant dimension affecting the level of the construction health climate is employee involvement, and the most critical indicator in this dimension is how well employees understand the health risks at work.

Although the aim of the study is achieved, there are some limitations. First, research studies on the assessment of the health climate of building construction projects are still limited, which undermines the comprehensiveness of the health climate framework proposed in this study. Second, the limited number of respondents in this study may have resulted in biased findings. Lastly, the assessment approach developed in this study is featured in the context of China, which may have applicability issues when applied to other countries.

Despite these limitations, this study is valuable. It investigates health climate assessment in building construction projects, a topic that has rarely been discussed in the extant literature. Thus, it contributes to the current body of knowledge. Moreover, the developed approach could be used by construction practitioners to gauge the level of health climate in the construction projects they are working on. Hence, this study is beneficial to the industry as well. For future research, a cross-regional study may be considered based on the approach developed in this study to check the compare and health climate levels of building construction projects in different areas.

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DATA AVAILABILITY STATEMENT

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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