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Assessing Health Climate in Building Construction Projects: Theory and Practice

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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 (PFAHP) was then utilised 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 C-HCA 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 assessments, Workplace hazards, Building construction projects, Pythagorean fuzzy AHP, Construction in China

INTRODUCTION

It is well recognised 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, Almeida and Dias, 2014; Umer, 2022). According to an epidemiological survey conducted by Dong, Brooks and Brown (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

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(Chen et al., 2021; Cheriyan and Choi, 2020; Dabirian, Han and Lee, 2020; Kurtz, Vi and Verma, 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, Drake and Jones, 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, Leung and Liu, 2016; 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 programmes. 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, where the construction industry is a cornerstone of national economic growth and a major sector of labour 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 RMB7,874 billion (approximately USD1,141 billion) to the economy, accounting for around 6.9% of the total gross domestic product and the number of construction practitioners was 52,829,000, contributing 6.7% of the total labour 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 article 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 (C-HCA) 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 and Wium (2020) investigated health and safety management systems found within medium-to-large construction contractor organisations in South Africa. Fuller, Hasan and Kamardeen (2022) examined the factors influencing the design and delivery of health promotion programmes implemented by construction organisations to educate workers and promote a healthy lifestyle. Lingard and Turner (2017) explored factors affecting the healthy behaviours 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, Yakubu and Govender (2022) investigated the association between alcohol use and HIV-related health behaviours in construction.

Some researchers have looked into strategies to improve the health of construction practitioners. For example, Chan et al. (2016) identified various strategies that can help improve the health of ethnic minority workers from Asian countries. Nwaogu, Chan and Naslund (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 programmes in the Australian construction industry.

With respect to mental health, Chan, Nwaogu and Naslund (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, Jin and Osei-Kyei (2023) developed a multi-level mental health management framework for project management practitioners in architecture, engineering and construction project organisations through organisational design theories. Scott-Young, Turner and Holdsworth (2020) explored sex differences in mental health and resilience in the early career pipeline of emerging built environment professionals. Kotera, Green and Sheffield (2020) explored the relationships among work-life balance, mental health, attitudes towards 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 organisational members of health management behaviours and phenomena within the organisation (Schneider, 1975). Zweber, Henning and Magley (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 organisational 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 organisation'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 favourable 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 (PFAHP) and the fuzzy comprehensive evaluation method, following the practices of Ilbahar et al. (2018) and Oppong 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.

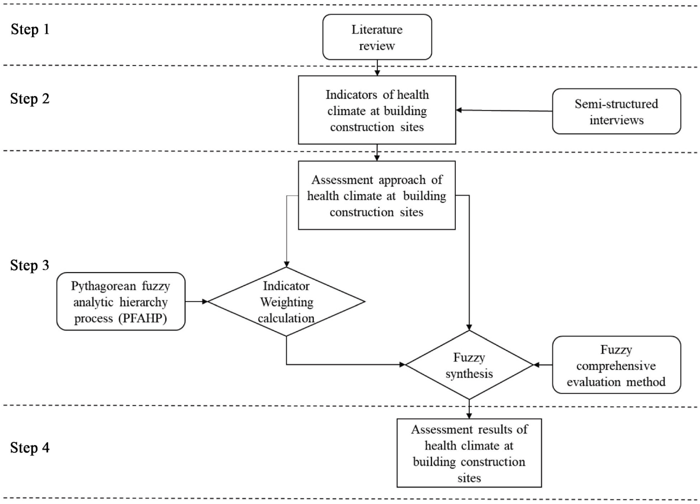

Figure 1. Flowchart of research process

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, Shan and Zhai (2023), these 15 indicators were categorised 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 finalised 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	Sources											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.	✓		✓	✓		✓		✓				4.38
		U12	Management places a high value on employee health and works quickly to prevent violations.			✓			✓						4.54
		U13	Management can invest a lot of energy in construction health training.	✓			✓				✓				3.62
		U14	The company organises occupational health examinations regularly.	✓				✓			✓				4.15
	Employee involvement (U2)	U21	Employees are fully aware of the health risks associated with their work.		✓	✓			✓			✓	✓	✓	4.00
		U22	Employees can give opinions when developing or reviewing health procedures/instructions/rules.		✓	✓						✓			3.69
		U23	Employees can wear personal protective equipment to protect personal health as required.		✓		✓					✓			4.62
		U24	Employees can always observe health regulations during the work process.		✓										4.38
		U25	Health issues are frequently discussed among colleagues throughout the work week.		✓	✓									2.37*

(*Continued on next page*)

Table 1. *Continued*

Target	Dimensions	Code	Indicators	Sources											Applicability Evaluation
				A	B	C	D	E	F	G	H	I	J	K	
	Supportive environment (U3)	U31	Management can provide all health equipment required by occupational health regulations.	✓							✓	✓			3.92
		U32	Management can listen carefully and adopt effective suggestions from employees to improve construction health.	✓	✓	✓	✓			✓	✓		✓		4.46
		U33	Colleagues can monitor and correct one other's infractions of construction health regulations.		✓		✓		✓			✓			4.38
		U34	Colleagues can understand and support each other's leave of absence due to health reasons and help with work.				✓			✓					4.38
		U35	Most of the health training provided by the company is effective.		✓		✓		✓			✓	✓		2.12*
		U36	Health training can cover all health risks associated with employees' work.			✓			✓						2.35*

Notes: A = Zohar and Luria (2005); B = Choudhry, Fang and Lingard (2009); C = Mohamed (2002); D = Brondino, Silva and Pasini (2012); E = Damman, Beek and Timmermans (2015); F = Health and Safety Executive (2002); G = Zweber, Henning and Magley (2016); H = Cheung and Zhang (2020); I = Zhou, Fang and Mohamed (2011); J = Hon, Chan and Yam (2012); K = Lin et al. (2008); *U25, U35 and U36 were dropped with an evaluation score lower than 2.5 points in the interview.

Table 2. Backgrounds of interviewed experts

No.	Employer	Position	Years of 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 ASSESSMENT

Based on the indicators refined by interview experts, a 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 Indicator 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 = {U1, U2 ... U*m*}. Since there were three dimensions and 12 second-level indicators in this study, the assessment indicator set U = {U1, U2, U3} where U1 = {U11, U12, U13, U14}, U2 = {U21, U22, U23, U24} and U3 = {U31, U32, U33, U34}.

Establishing the Judgement Set (V)

V stands for the judgement set in the comprehensive assessment, V = {V_1, V_2 ... V_n} where n = number of judgement 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 judgement set = {V_1, V_2, V_3, V_4, V_5} was established as shown in Table 3.

Table 3. Judgement 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 ... W_m} and the weight of each indicator must satisfy the condition $\sum_{i=1}^{m} w_i = 1, w_i \geq 0, i = 1, 2 \cdots m$. Many methods can be used to calculate indicator weights. The indicator weight vector of this study was obtained by adopting PFAHP.

PYTHAGOREAN FUZZY ANALYTIC HIERARCHY PROCESS

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, Nielsen and Ozdemir, 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, Nielsen and Ozdemir, 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 described contents are 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):

$$Q = \{< x, \mu_Q(x), v_Q(x) > | x \in X\} \quad \text{Eq. 1}$$

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

$$0 \le \mu_Q^2(x) + v_Q^2(x) \le 1 \quad \text{Eq. 2}$$

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 $\gamma_1 = Q(\mu_{\gamma1}, v_{\gamma1})$, $\gamma_2 = Q(\mu_{\gamma2}, v_{\gamma2})$ are two Pythagorean fuzzy numbers and , then the definition of mathematical operations on these two numbers is as below (Zeng, Chen and Li, 2015; Zhang and Xu, 2014):

$$\gamma_1 \oplus \gamma_2 = Q\left(\sqrt{\mu_{\gamma1}^2 + \mu_{\gamma_2}^2 - \mu_{\gamma1}^2 \mu_{\gamma2}^2}, v_{\gamma1} v_{\gamma2}\right) \quad \text{Eq. 3}$$

$$\gamma_1 \oplus \gamma_2 = Q\left(\mu_{\gamma1} + \mu_{\gamma2}, \sqrt{v_{\gamma1}^2 + v_{\gamma2}^2 - v_{\gamma1}^2 v_{\gamma2}^2}\right) \quad \text{Eq. 4}$$

$$\delta\gamma_1 = Q\left(\sqrt{1-(1-\mu_{\gamma1}^2)^{\delta}}, (v_{\gamma1})^{\delta}\right), \delta > 0 \quad \text{Eq. 5}$$

$$\gamma_1^{\delta} = Q\left((\mu_{\gamma1})^{\delta}, \sqrt{1-(1-v_{\gamma1}^2)^{\delta}}\right), \delta > 0 \quad \text{Eq. 6}$$

$$\delta\gamma_2 = Q\left(\sqrt{1-(1-\mu_{\gamma2}^2)^{\delta}}, (v_{\gamma2})^{\delta}\right), \delta > 0 \quad \text{Eq. 7}$$

$$\gamma_2^{\delta} = Q\left((\mu_{\gamma2})^{\delta}, \sqrt{1-(1-v_{\gamma2}^2)^{\delta}}\right), \delta > 0 \quad \text{Eq. 8}$$

Definition 3

Assuming that $\gamma_{1_i} = (\mu_1, v_{1_i})$, $i = (1, 2, \cdots, n)$ 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:

$$PFEPG(\gamma_{1_1}, \gamma_{1_2}, \cdots, \gamma_{1_n}) = \left(\left(1 - \prod_{i=1}^{n}(1-\mu_{1i}^{\ 2})^{w_i}\right)^{1/2}\right), \left(1 - \prod_{i=1}^{n}(1-v_{1_i}^{\ 2})^{w_i}\right)^{1/2} \quad \text{Eq. 9}$$

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

STEPS OF PYTHAGOREAN FUZZY ANALYTIC HIERARCHY PROCESS

The specific steps of the PFAHP method are described in this section.

Step 1

The compromised pairwise comparison matrix $C = (c_{ik})_{m \times m}$ is established in view of experts' language evaluation (as shown in 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

	C1	...	Cm
C1	< [0.1965, 0.1965], [0.1965, 0.1965] >	...	$<,[\mu_{A1m}, \mu_{B1m}],[v_{A1m}, v_{B1m}]>$
⋮	⋮	⋱	⋮
Cm	$<,[\mu_{A1m}, \mu_{B1m}],[v_{A1m}, v_{B1m}]>$	...	< [0.1965, 0.1965], [0.1965, 0.1965] >

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

Linguistic Terms	Grades	Pythagorean Fuzzy Numbers Equivalents Interval-Valued Pythagorean Fuzzy Numbers			
		μ_A	μ_B	v_A	v_A
Certainly low importance	1	–	–	0.90	1.00
Very low importance	2	0.10	0.20	0.80	0.90
Low importance	3	0.20	0.35	0.65	0.80
Below average importance	4	0.35	0.45	0.55	0.65
Average importance	5	0.45	0.55	0.45	0.55
Above average importance	6	0.55	0.65	0.35	0.45
High importance	7	0.65	0.80	0.20	0.35
Very high importance	8	0.80	0.90	0.10	0.20
Certainly high importance	9	0.90	1.00	–	–
Exactly equal	–	0.1965	0.1965	0.1965	0.1965

Step 2

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

$$d_{ik_A}=\mu_{ik_A}^2-v_{ik_B}^2 \quad \text{Eq. 10}$$

$$d_{ik_B}=\mu_{ik_B}^2-v_{ik_A}^2 \quad \text{Eq. 11}$$

Step 3

Interval multiplicative matrix $G_{ik} = (g_{ik})_{m \times m}$ is calculated using Equations 12 and 13:

$$G_{ik_A} = \sqrt{1000^{d_A}} \qquad \text{Eq. 12}$$

$$G_{ik_B} = \sqrt{1000^{d_B}} \qquad \text{Eq. 13}$$

Step 4

The determinacy value $\Delta = (\Delta_{ik})_{m \times m}$ is computed using Equation 14:

$$\Delta_{ik} = 1 - (\mu_{ik_A}^2 - \mu_{ik_B}^2) - (v_{ik_A}^2 - v_{ik_B}^2) \qquad \text{Eq. 14}$$

Step 5

The determinacy degrees are multiplied with $G_{ik} = (g_{ik})_{m \times m}$ matrix for obtaining the matrix of weight, $Z = (z_{ik})_{m \times m}$, before normalisation using Equation 15:

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

Step 6

The normalised priority weights w_i is computed using Equation 16:

$$w_i = \frac{\sum_{k=1}^{m} z_{ik}}{\sum_{i=1}^{m} \sum_{k=1}^{m} z_{ik}} \qquad \text{Eq. 16}$$

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 judgement grade in the judgement 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 standardised 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 $B = W \cdot R = (W_1, W_2, \cdots, W_m) \cdot \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix} = (B_1, B_2, \cdots, B_n)$, where B represents the assessment consequence of each indicator of the indicator set U. The adoption of the M $(\cdot, \oplus)$ 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 in this study.

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 PFWPG operator of Equation 9), the converted interval-valued

Pythagorean fuzzy numbers were aggregated. Tables 6 and 7 summarise 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 Membership, Degree of Non-membership >		
	U1	U2	U3
U1	< 0.1965, 0.1965, 0.1965, 0.1965 >	< 0.62, 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 Membership, Degree of Non-membership >			
	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 Membership, Degree of Non-membership >**			
	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, 0.1965 >	< 0.49, 0.56, 0.24, 0.30 >
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 >

(Continued on next page)

Table 7. *Continued*

Criteria of U3	Pythagorean Fuzzy Numbers: < Degree of Membership, Degree of Non-membership >			
	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	–	< 0.30, 0.48 >	< 0.31, 0.42 >
U2	< −0.48, −0.44 >	–	< 0.13, 0.34 >
U3	< −0.42, −0.41 >	< −0.34, −0.13 >	–

Table 9. Difference matrix of the indicators

Criteria of U1	U11	U12	U13	U14
U11	–	< 0.14, 0.23 >	< 0.25, 0.38 >	< 0.31, 0.41 >
U12	< −0.05, −0.24 >	–	< 0.10, 0.23 >	< 0.13, 0.25 >
U13	< −0.17, −0.34 >	< −0.30, −0.23 >	–	< 0.01, 0.07 >
U14	< −0.19, −0.37 >	< −0.31, −0.25 >	< −0.12, −0.07>	–
Criteria of U2	**U21**	**U22**	**U23**	**U24**
U21	–	< 0.08, 0.18 >	< 0.04, 0.13 >	< 0.23, 0.35 >
U22	< −0.23, 0.11 >	–	< −0.10, −0.04 >	< 0.01, 0.11 >
U23	< −0.21, 0.02 >	< −0.04, 0.04 >	–	< 0.15, 0.23 >
U24	< −0.40, −0.02 >	< −0.19, −0.11 >	< −0.26, −0.23 >	–

(Continued on next page)

Table 9. *Continued*

Criteria of U3	U31	U32	U33	U34
U31	–	< 0.08,0.17 >	< 0.20, 0.31 >	< 0.39, 0.51 >
U32	< −0.22, −0.17 >	–	< 0.11, 0.19 >	< 0.22, 0.35 >
U33	< −0.35, −0.31 >	< −0.23, −0.19 >	–	
U34	< −0.53, −0.51 >	< −0.34, −0.30 >	< −0.22, −0.18>	–

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 >	–

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 normalisation. Similarly, Tables 13 and 15 represent the indicator determinacy value matrix and the weight matrix before normalisation, respectively.

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

Δ	U1	U2	Standard Error (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

Table 14. Weight matrix of the dimensions before normalisation

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

Table 15. Weight matrix of the indicators before normalisation

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	U1	0.6191	U11	0.4643	0.2874
			U12	0.2666	0.1650
			U13	0.1461	0.0905
			U14	0.1230	0.0762
	U2	0.2582	U21	0.3726	0.0962
			U22	0.2209	0.0570
			U23	0.2610	0.0674
			U24	0.1455	0.0376
	U3	0.1227	U31	0.4770	0.0585
			U32	0.2887	0.0354
			U33	0.1366	0.0168
			U34	0.0977	0.0120

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

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

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

$$W_2 = (0.3276, 0.2209, 0.2610, 0.1455)$$

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

As shown in Table 16, U1 was the critical dimension of health climate assessment, U2 was the second most important dimension of health climate assessment and the third most important dimension of health climate assessment was the U3. In the dimension of U1, the order of weighting of the indicators was U11 > U12 > U13 > U14. In the dimension of U2, the weight order of the indicators was U21 > U23 > U22 > U24. In the dimension of 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 of U1, U2 and U3, were as follows:

$$R_1 = \begin{pmatrix} 0.54 & 0.39 & 0.05 & 0.02 & 0.00 \\ 0.55 & 0.37 & 0.05 & 0.03 & 0.00 \\ 0.22 & 0.43 & 0.22 & 0.09 & 0.04 \\ 0.44 & 0.44 & 0.08 & 0.03 & 0.01 \end{pmatrix}$$

$$R_2 = \begin{pmatrix} 0.27 & 0.51 & 0.16 & 0.05 & 0.01 \\ 0.23 & 0.32 & 0.29 & 0.11 & 0.05 \\ 0.48 & 0.43 & 0.07 & 0.02 & 0.00 \\ 0.32 & 0.54 & 0.10 & 0.03 & 0.01 \end{pmatrix}$$

$$R_3 = \begin{pmatrix} 0.30 & 0.45 & 0.19 & 0.06 & 0.00 \\ 0.26 & 0.45 & 0.20 & 0.07 & 0.00 \\ 0.32 & 0.51 & 0.14 & 0.03 & 0.00 \\ 0.41 & 0.49 & 0.08 & 0.01 & 0.01 \end{pmatrix}$$

Finally, fuzzy comprehensive assessment results were computed using the formula B = W·R. The following was the assessment result of the dimension of U1:

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

$$= (0.48, 0.40, 0.08, 0.03, 0.01)$$

In the same way, the assessment results of U2 and U3 dimensions were calculated as follows:

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

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

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 U1 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 U1 to this building construction project was above the high level. The score of U2 (4.01) ranked second in the dimensions of health climate assessment, which was between “High” and “Very High”, showing that U2 in this building construction project was also above the high level. U3 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.

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

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

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

$$= (0.42, 0.42, 0.11, 0.04, 0.11)$$

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. U1 score of 4.31 indicated that employees were satisfied with the health commitment made by management. 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 U3 was 4.00, indicating that the behaviour of employees in this project was strongly supported by management and colleagues. According to the PFAHP results, the two dimensions of U1 and U2 were core ingredients for this building construction project to form a positive health climate. 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, Azevedo and Rodrigues (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 emphasised 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 towards the violation of health regulations affects employees' perceptions of health regulations, which further influences the level of health climate. The second significant dimension was U2 and the most critical indicator in this dimension was how well employees understood the health risks at work. Zhai, Shan and Le (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 U2, 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 utilisation of personal health protective equipment by employees.

CONCLUSIONS

It is vital to assess the health climate of an ongoing building construction project because this assessment may assist in recognising 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 digitises 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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