Journal of Engineering, Project, and Production Management
2024, 14(3), 0022

Cost/Benefit Analysis of AIoT Image Sensing for Construction Safety Monitoring

Rong-jing Wang[1], Wen-Der Yu[2], Hsien-Chou Liao[3], Hsien-Kuan Chang[4], and Zi-Yi Lim[5]

[1]Director, Architecture and Building Research Institute, Ministry of Interior, New Taipei, 23143 Taiwan, E-mail: jing@abri.gov.tw

[2]Professor, Department of Construction Engineering, Chaoyang University of Technology, Taichung, 413310 Taiwan, E-mail: wenderyu@cyut.edu.tw (corresponding author).

[3]Professor, Department of Computer Science and Information Technology, Chaoyang University of Technology, Taichung, 413310 Taiwan, E-mail: hcliao@cyut.edu.tw

[4]Researcher, Department of Construction Engineering, Chaoyang University of Technology, Taichung, 413310 Taiwan, E-mail: hkchang@cyut.edu.tw

[5]Assistant Professor, Department of Information and Communication Engineering, Chaoyang University of Technology, Taichung, 413310 Taiwan, E-mail: zylim@cyut.edu.tw

Project Management
Received May 19, 2023; received revision May 30, 2023; accepted November 5, 2023
Available online September 27, 2024

Abstract: Rapid advances in deep learning and computer vision enable traditional cloud-based decision-making through edge computing with the Artificial Intelligent Internet of Things (AIoT) image sensors (AIoT-IS), thus improving the timeliness and security of image recognition. This study is indented to investigate the potential costs and benefits of AIoT-IS applications. This study summarizes AIoT-IS application scenarios for construction safety monitoring and proposes a cost/benefit analysis method for AIoT-IS implementation projects. According to the case study results, AIoT-IS achieves significant benefits, with a Net Present Value Index (NPVI) of 19.17% and a Benefit/Cost Ratio (BCR) of 4.65 as applied to construction site safety monitoring. Interviews with domain experts also provided qualitative feedback, pointing to the directions for future research. The proposed method is applicable for the decision-making of AIoT-IS adoption and the feasibility assessment of other innovative construction technologies.

Keywords: AIoT, construction safety, intelligent safety monitoring, benefit evaluation.

DOI 10.32738/JEPPM-2024-0022

---

1. Introduction

With the rapid development of the world population, buildings in most countries need to be built to meet the development needs. Unfortunately, many safety-related accidents happen on construction sites. Although governments worldwide have formulated strict regulations to ensure the safety of workers on-site during construction, workers may not necessarily abide by the regulations, which often leads to fatal accidents.

Construction accidents have consistently ranked first in the proportion of occupational accidents in the whole industry and the primary cause of occupational fatalities globally, posing a major threat to workers' lives and industrial productivity. The primary reason is that construction sites are highly open and dangerous. With the development of large-scale and high-rise construction projects, the risk of occupational disasters, such as falling from heights, has gradually increased. According to the Bureau of Labor Statistics in the United States (BLS, 2021), 4,764 workers died in the construction sectors from 2016 to 2020, accounting for almost 21% of all worker fatalities in the country in the year. Similarly, according to the latest statistics from the Occupational Safety and Health Administration, Ministry of Labor in Taiwan (OSHA-TW, 2021), there were 313 fatal occupational accidents in Taiwan for the whole industry from January to December 2020, of which the construction industry accounted for 46.32% (145 people). A total of 2,879 people died in major occupational accidents for all industries from 2012 to 2020, and the construction industry accounted for 47.65% (1,372 people), which is almost half of all industries. From the statistics of the previous two regions, it is evident that the hazards during construction account for a large proportion of all industries. This paper intends to apply the latest Artificial Intelligence of Things (AIoT) technology to reduce the risk of hazards during construction.

The Artificial Intelligent Internet of Things (AIoT) is a new type of Internet of Things (IoT) technology that equips IoT infrastructure with Artificial Intelligence (AI) computation power to enable high-speed IoT operation and data analysis (Dong et al., 2021). AIoT image sensing technology uses image cameras as intelligent sensing devices. The AIoT Image Sensor's (AIoT-IS) ability to see further with more details offers vast potential for decisions requiring real-time responses.

In the past decade, the fast development of Deep Learning (DL) and Computer Vision (CV) enables traditional cloud-based decision-making to be carried out with the edge-computing of AIoT-IS. It thus improves the timeliness and security of image recognition. Such a development expedites wide applications of AIoT-IS in many fields, e.g., fire detection (Santiputri and Tio, 2018), intelligent agriculture (Khoa et al., 2019), and security surveillance (Zhou et al., 2019). AIoT-IS application in the construction and building industry is just at its early stage. Some applications are found in infrastructure maintenance (Todorović and Samardžija, 2017), safety monitoring of the tunneling process (Zhang et al., 2021), or underground structures (Lin et al., 2021).

Despite the promising applications of AIoT-IS in construction engineering, they require additional costs for installation and device maintenance; moreover, usage of AIoT-IS also generates potential risks to the users and other stakeholders. It is crucial to conduct a cost/benefit analysis (CBA) on AIoT-IS application projects not only to justify the adoption of such novel technology but also to avoid the adverse effects and obstacles that may reduce or eliminate the expected benefits.

This research aims to develop a generic method to conduct the cost/benefit analysis for AIoT-IS application projects. The rest of this paper is presented as follows: the recent development of AIoT-IS technologies and their relevant applications are reviewed in the 2nd section. The research problems are discussed and stated in section 3, the CAMITA model is proposed and explained in the 4th section; after the model proposal, a case study of the CAMITA model for CBA evaluation of the application of AIoT-IS on safety monitoring of construction site is demonstrated and discussed. Finally, conclusions are drawn from the case study, and recommendations are made for future research.

2. Development and Benefit Analysis of AIoT-IS

2.1. Recent Development of AIoT-IS Technology

The fundamental concept of the Internet of Things (IoT) is that various "Things" can be connected and collaborate through unique methods to achieve specific objectives (Atzori et al., 2010). Traditional IoT can only execute programmed instructions, and the "intelligence" of traditional IoT is very limited. Most IoT devices can only transmit sensory data to servers in the cloud for processing and analysis. It takes a longer time to respond, thus limiting its application in some areas that require immediate response, such as construction safety monitoring and responses.

In order to improve the efficiency of traditional IoT technologies, researchers in recent years have devoted themselves to developing various machine learning (ML) or artificial intelligence (AI) algorithms, including supervised/unsupervised deep learning (DL) techniques, such as (artificial neural network, ANN; Convolutional Neural Network, CNN; etc.) to improve the intelligence level of IoT devices. Adding AI intelligent learning and recognition capabilities to IoT devices has created a new type of IoT technology, AIoT. The AIoT Image Sensors combine image sensors (such as cameras) with AIoT devices to realize AI recognition and response on the sensor side, becoming the 'AIoT-IS' technology.

There have been more and more commercial AIoT-IS devices supplied in the market in the last few years, e.g., NVIDIA Jetson family (Nvidia, 2022), In-Sight D900 (Cognex, 2022), NEON AI camera (ADLINK, 2022), etc. Advanced DL models are also developed to equip the AIoT-IS devices with intelligent computational power. Popular DL frameworks include: You Only Look Once (Yolo) (Redmon et al., 2016), DeepLab (Chen et al., 2017), TensorFlow (2022), etc. The improvement of AIoT-IS devices has made the task of identifying safety hazards that cannot be achieved traditionally since it is necessary to accurately and timely respond to the identified safety risks, which has become feasible nowadays.

2.2. AIoT-IS Application in Construction

With the advances of the above-mentioned hardware devices and the associated DL frameworks, many AIoT-IS applications have been developed and implemented in different fields. Due to the limitation of paper size, only the applications related to the construction field are reviewed in the following.

Zhang et al. (2021) developed an AIoT real-time monitoring system for tunnel construction safety, which estimates shield operating parameters and tunnel construction-induced settlement based on a random forest (RF) algorithm. Kanan et al. (2018) developed an IoT-based smart sensing system to support continuous project improvement and accident prevention by tracking project progress and monitoring worksites. Unlike traditional manual methods, the project monitoring method proposed by Kanan et al. (2018) shows the great potential of intelligent site management. Louis and Dunston (2018) proposed a framework to take advantage of increasingly ubiquitous devices that can be considered part of the Internet of Things (IoT) for real-time decision-making on construction sites. Decisions are made automatically based on real-time operational status and relayed to entities on the construction site through the IoT infrastructure. It improves construction efficiency by implementing programmatic decision-making through IoT infrastructure without requiring additional resources. Dong et al. (2021) presented an advanced work based on the combination of wearable sensor and artificial intelligence technologies, focusing on system-level capabilities to analyze rich sensory data, recognize events, and make corresponding decisions.

2.3. Benefit and Risk Analysis of AIoT-IS Adoption

Although some promising results have been observed from the early adoption of AIoT technologies, potential problems and risks may be induced by AIoT-IS, such as the infringement of privacy rights and information security issues. These factors may influence the decision to adopt AIoT-IS in the construction industry.

Wisdom et al. (2013) proposed an innovative technology adoption evaluation framework, including four levels: external system, organizational, innovative solutions, and individuals, with a total of 27 predictors, to analyze the acceptance of innovative technologies in the medical and health field. Their research establishes early models to investigate the potential risks and benefits associated with the application of novel technologies such as AIoT-IS. Wilson et al. (2017) surveyed 1,025 residents across the UK. They found that UK residents believed the primary benefit of smart building technology was energy management. At the same time, the highest priority risks are loss of privacy, independence, and self-control at home due to increased technological controls. They also noted that "managing energy use" and "saving energy" are the primary benefits influencing adaptors' decisions on smart building technologies. Arfi et al. (2021) proposed an extended unified theoretical framework for technology acceptance and adoption. Their model analyzed the important drivers of IoT technology acceptance in the medical industry. They identified that performance expectation, effort expectation, social influence, convenience condition, and perceived risks are the top four most important influencing factors for adopters' decisions. The study also noted that perceived risk and age factors did not influence user adoption behavior of IoT devices.

Yang et al. (2020) proposed a new activity-based costing and resource constraint optimal decision model for the decision-making of IoT-based intelligent building technology adoption. Their model combined "Decision Making Trial and Evaluation Laboratory (DEMATEL)" and "Analytic Network Process (ANP)" to evaluate the priority of different IoT-based technology alternatives in a smart building. Although this study does not provide a method for assessing the Cost Benefit Analysis (CBA) of AIoT technologies, it offers an analytical framework that can address the socioeconomic benefits assessment issues faced by most innovative technology applications. Gao et al. (2016) conducted a CBA comparison on four Chinese air pollution control policy options, including (1) a no-intervention option; (2) an energy-saving drive option; (3) an end-of-pipe pollution treatment option; and (4) an integrated option. Their research uses CBA, a traditional economic decision analysis method, to provide policymakers with clear economic indicators. In their method, each option's cost and benefit models must be established first. When constructing these two models, it is often necessary to conduct a hypothesis analysis to quantify and convert the tangible and intangible costs and benefits into monetary units before a cost-benefit analysis can be performed. This unified procedure of tangible and intangible items becomes the key treatment of innovative technology adoption in the CBA economic decision analysis model.

Although the model, as mentioned above, provided some aspects for CBA evaluation of AIoT-IS application projects, none were developed specifically for AIoT image sensors. Moreover, most previous models, except Gao et al.'s (2016), didn't provide quantitative indexes of CBA. It is inadequate to support the decision of AIoT-IS adopters in practice. It is desirable to develop a generic cost/benefit analysis method for adopting AIoT-IS to conduct the CBA for AIoT-IS application projects.

3. Point of Departure and Research Problems

The primary objective of this research is to provide AIoT-IS adopters with a decision support model that can quantify the costs and benefits of the AIoT-IS application project in construction engineering. To achieve this goal, the following research problems need to be addressed:

- First, a comprehensive framework to cover all tangible and intangible items related to the implementation of AIoT-IS must be established;
- Second, an integrated model to combine and measure the inter-relationship among the cost and benefit items needs to be proposed
- Third, a quantitative CBA analysis model needs to be developed to calculate the economic feasibility analysis indexes, e.g., cost/benefit ratio (CBR) and net present value (NPV) of the target project;
- Finally, the quantitative CBA indexes are computed for the AIoT-IS implementation case to evaluate the feasibility of the target project.

Previous literature on feasibility analysis of innovative technology adoption (Wisdom et al., 2013; Chor et al., 2015; Wilson, 2017; Yang et al., 2020) provides a list of tangible and intangible cost/benefit items related to the implementation of AIoT-IS. Yang et al. (2020) proposed that Mixed Activity-based Costing (MABC) that combines DEMATEL (Gabus and Fontela, 1972; Fontela and Gabus, 1976) and ANP (Saaty, 2001) provides a promising solution to model the inter-relationship among the cost and benefit items, except that their model only prioritizes the rankings among alternatives, rather than provide economic feasibility analysis indexes. It is inadequate for the policymakers' decision.

Based on previous models (e.g., Yang et al., 2020's MABC model), this study has two fundamental issues to address: the first is to propose a new model that can calculate economic feasibility analysis indicators such as CBR or NPV; the second is to convert intangible and qualitative cost/benefit items into tangible and quantitative items.

4. Proposed CAMITA Model

As mentioned in the previous section, the combination of DEMATEL and ANP provides a feasible basis for the cost/benefit evaluation of AIoT-IS implementation projects. This section builds the proposed CAMITA model on this basis.

4.1. Prioritize the Analysis Criteria with DEMATEL

DEMATEL is a structural decision modelling tool developed by the Science and Human Affairs Program at the Battelle Memorial Institute in Geneva between 1972 and 1976. It was intended to solve complex relationships existing in global political and economic issues (Yang et al., 2020). It generates an influential relation map (IRM) for analyzing the causal relationships of evaluation criteria. The basic analysis procedure of the DEMATEL method consists of the following steps (Yang et al., 2020; Si et al., 2018):

- Step 1: Calculate the average direct-relation matrix—in this step, the relative importance of the considered criteria are measured according to the scale of zero effect (0), low effect (1), medium effect (2), high effect (3) and extreme effect (4). Domain experts are asked to determine the relative importance of direct effects among the criteria. Finally, a square average direct-relation matrix, ***W***, is obtained, as shown in Eq. (1).

$$W = \begin{matrix} \\ C_1 \\ C_2 \\ \vdots \\ C_N \end{matrix} \begin{bmatrix} C_1 & C_2 & \cdots & C_N \\ 0 & e_{12} & \cdots & e_{1N} \\ e_{21} & 0 & \cdots & e_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ e_{N1} & e_{N2} & \cdots & 0 \end{bmatrix} \tag{1}$$

  where C_1, C_2,…, C_N, are the N considered criteria of the problem for DEMATEL; e_{ij} is the relative importance of direct impact relation for the i^{th} criterion to the j^{th} criterion; the diagonal elements equal to '0', since they have no direct impact relation to themselves.

- Step 2: Calculate the normalized direct-relation matrix—the normalized direct-relation matrix, ***N***, is calculated by dividing the average direct-relation matrix by the maximum values of each criterion, as shown in Eq. (2).

$$N = s \times W \tag{2}$$

  where ***N*** is the normalized direct-relation matrix, *s* is a normalization multiplier calculated by Eq. (3); and ***W*** is obtained from Eq. (1).

$$s = \text{Min}\left(\frac{1}{\max\limits_{1 \le i \le n} \sum_{j=1}^{n} |e_{ij}|}, \frac{1}{\max\limits_{1 \le j \le n} \sum_{i=1}^{n} |e_{ij}|} \right), \quad i, j \in \{1,2,\ldots,n\}. \tag{3}$$

  where n is the number of criteria of the problem for DEMATEL analysis; e_{ij} is defined in Eq. (1).

- Step 3: Construct the total-influence matrix—the normalized direct-relation matrix, ***N***, has been obtained from Eq. (2), and the direct relation can be obtained by the indirect effect of the problem decreases continuously along the power of N, i.e., N^2, N^3, N^4,…, $\lim_{k\to\infty} N^k = [0]_{n\times n}$; where $\boldsymbol{N} = [N_{ij}]_{n\times n}$, $0 \le N_{ij} < 1$ and $0 \le \sum_i^n n_{ij}$ or $\sum_j^n n_{ij} < 1$, only one of the columns or rows sums to 1, the others are less than 1. The 'total-relationship matrix' (***T***) can be defined as the summation of the direct effects and all of the indirect effects after obtaining the 'normalized direct-relation matrix' (***N***), as shown in Eq. (4).

$$T = N + N^2 + \cdots + N^k = N(I + N + N^2 + \cdots + N^{k-1}) = N(I - N^k)(I - N)^{-1} = N(I - N)^{-1} \tag{4}$$

  where, $\lim_{k\to\infty} N^k = [0]_{n\times n}$, ***N*** is the normalized direct-relation matrix obtained from Eq. (2), and ***T*** is the total-influence matrix, $\boldsymbol{T} = [t_{ij}]_{n\times n}$.

  From Eq. (4), $T = N(I - N)^{-1}$, where $\lim_{k\to\infty} N^k = [0]_{n\times n}$, $N^k = [n_{ij}]_{n\times n}$, $0 \le n_{ij} < 1$. If we sum each row, we can get the active influence relationship vector, ***D***; similarly, if we sum each column of ***T***, we can get the passive influence relationship vector, ***R***. These are explained in Step 4.

- Step 4: Find the active influence relationship vector (***D***) and the passive influence relationship vector (***R***), and determine the threshold values to generate the *Influential Relation Map* (**IRM**)—sum up the rows (***D***) and columns (***R***) of the total relationship matrix ***T***. The vectors ***D*** and ***R*** can be obtained by Eqs. (5) to (7):

$$\boldsymbol{T} = [t_{ij}]_{n\times n}, ij \in \{1,2,\ldots,n\} \tag{5}$$

$$\boldsymbol{D} = (D_i)_{1\times n} = \sum_{j=1}^{n} t_{ij} \tag{6}$$

$$\boldsymbol{R} = (D_j)_{1\times n} = \sum_{i=1}^{n} t_{ij} \tag{7}$$

  Where ***D*** is the sum of the rows in the matrix ***T***; the value of ***D*** represents the direct and indirect influence of criterion *i* on other criteria; ***R*** is the sum of each column in the matrix ***T***, indicating the direct and indirect passive influence relationship of criterion *i* affected by other criteria.

  Using the ***D*** and ***R*** values obtained in Eqs. (6) & (7), the ***D-R*** (prominence) and ***D+R*** (relation) are calculated. ***D-R*** implies the degree of the criterion affecting than being affected, while ***D+R*** represents the strength of the relationship between the criteria. The criterion is influential to other criteria if ***D-R*** > 0; otherwise, the criterion tends to be affected by the other criteria. Plotting ***D-R*** and ***D+R*** on the *y* and *x* axes, respectively, it gives the influential relation map (**IRM**). **IRM** offers the decision-makers a tool to quickly determine the dominant factors in the decision-making problem so that attention can be focused only on the critical factors. Moreover, IRM also shows the characteristics of the criteria in the decision problem, e.g., active or passive factors.

After calculating the values of ***D-R*** (prominence) and ***D+R*** (relation) of the total relationship matrix ***T***, it is possible to set a threshold value α to filter out the minor effects so that the critical impacts of criteria in ***T*** can be isolated and evaluated for decision making. The α value is usually set to 10% (0.1), 20% (0.2), or 30% (0.3). If the value of t_{ij} in the ***T*** matrix is less than α, it is replaced with 0; otherwise, it is retained.

4.2. Using ANP to Determine Criteria Weights

The ANP method (Saaty, 2001) was derived from the original Analytic Hierarchy Process (AHP) (Saaty, 1980) that can be used to determine the significant relative weightings among various decision criteria. The original AHP assumes independent relationships among the criteria, while ANP releases the independence restrictions between the different levels of the decision hierarchy.

Continue the DEMATEL analysis of the previous sub-section, and the ANP analysis process consists of the following:

- Step 5: Construct the ANP structure and calculate the weights of the criteria in the ANP—after defining the problem, the inter-relationships and feedback among the criteria generated from DEMATEL are used to construct the network structure of ANP. This is done through pairwise comparisons by asking the domain experts: "How important/influential is one criterion compared to the other in terms of his/her interests or preferences?" Then a questionnaire is surveyed the selected experts using a relative importance scale from 1 (equal importance) to 9 (extreme importance). The ANP criterion weighting survey results constitute an 'unweighted supermatrix,' S_{uw}.
- Step 6: Convert the unweighted supermatrix (S_{uw}) into the 'weighed supermatrix' (S_w)—the traditional method to derive S_w (Saaty, 2001) is to transform each column to sum exactly to unity. This process is required to ensure that the sum of the criterion weightings in each decision cluster of the ANP equals '1'. However, the row values in the original S_{uw} (obtained from the DEMATEL analysis) do not conform to the column-stochastic principle (Hardy, 1992). It must be converted by multiplying S_{uw}' with S_{uw}' to the power of '2k+1' (where k is an arbitrary number); if the row value sum = 1, the conversion procedure is not needed.
- Step 7: Use criterion comparison to form a relative importance weighting matrix and test the consistency ratio (CR)—

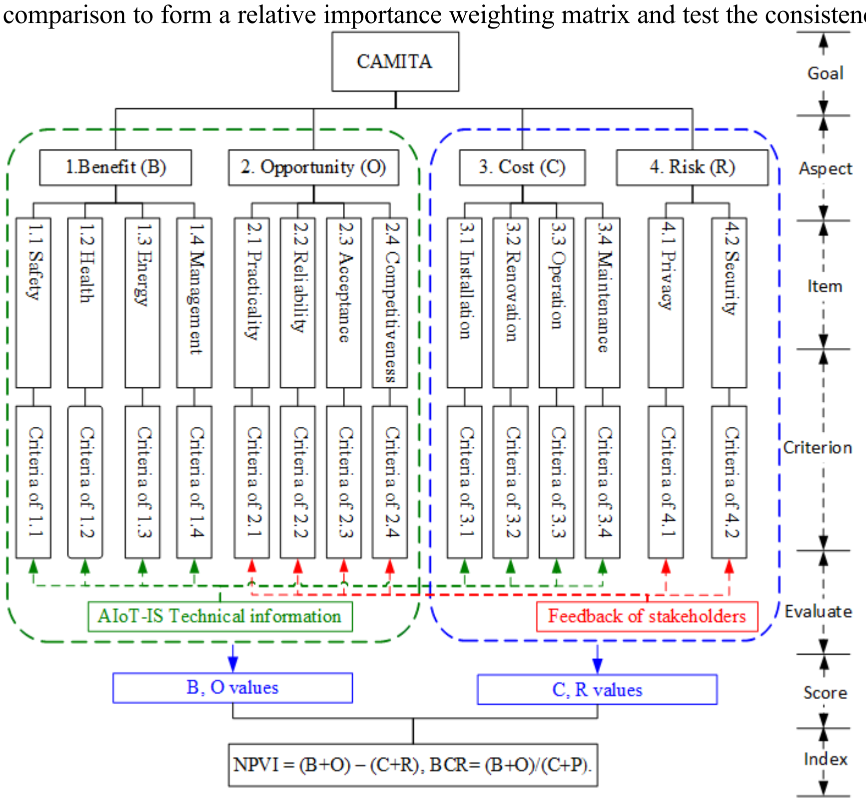

Fig. 1. Decision Hierarchy of CAMITA

pairwise comparisons by the selected experts can obtain the matrix. The CR testing process of ANP is similar to that of traditional AHP.

4.3. Decision Hierarchy of CAMITA

The decision hierarchy of the proposed CAMITA is shown in Fig. 1. It consists of five levels:

- Level 1: Goal—indicating the overall objective of the AIoT-IS implementation project.

- Level 2: Aspect (BOCR)—indicating the four most important aspects in analyzing the costs/benefits of the AIoT-IS implementation project, which are 1. Benefit (B), 2. Opportunity (O), 3. Cost (C), and 4. Risk (R).
- Level 3: Item—the items in CAMITA are selected from relevant literature. Finally, 14 items belonging to the 4 aspects are identified, e.g., four items in '1. Benefit (B)' was suggested by Wen and Yu (2019) and Chang et al. (2020): '1.1 Safety', '1.2 Health', '1.3 Energy', '1.4' Management'; four items were considered by Yang et al. (2020) in '2. Opportunity (O)': '2.1 Practicality', '2.2 Reliability', '2.3 Acceptance', and '2.4 Competitiveness'; four items need to be considered in '3. Cost (C)' as suggested by Chang (2018), Wen and Yu (2019), and Chang et al. (2020): '3.1 Installation', '3.2 Renovation', '3.3 Operation', and '3.4 Maintenance'; and two items should be considered in '4. Risk (R)' as recommended by Wilson (2017), Wisdom et al. (2013), and Chor et al. (2015): '4.1 Privacy' and '4.2 Security'.
- Level 4: Criterion—Fig. 1 provides a generic model for evaluating the cost/benefit analysis of intelligent building technology adoption, including AIoT-IS. The detailed evaluation criteria for each cost/benefit item should be tailored and broken down according to the specific conditions of the AIoT-IS implementation project. In this research, the detailed process of CAMITA criteria was accomplished by interviews with the domain experts of the AIoT-IS implementation project. This process is explained in the case study. For a construction site safety monitoring project, there are 2 criteria in '1.1 Safety': '1.1.1 Improvement of worker safety' and '1.1.2 Improvement of site environment safety'; and there are no criteria for '1.2 Heath' and '1.3 Energy'; but there are 3 criteria for '1.4 Management': '1.4.1 Labor saving', '1.4.2 Improvement of management efficiency', and '1.4.3 Improvement of precision'.
- Level 5: Score—the score of every criterion in Level 4 is determined via two methods: (1) AIoT-IS Technical information—criteria 1.1~1.4 and 3.1~3.4 are determined objectively according to the technical information of the selected AIoT-IS devices; (2) Feedback of stakeholders—criteria 2.1~2.4 and 4.1~4.1 are evaluated via the questionnaire survey from the stakeholders (i.e., the interested parties of the implementation project).

4.4. Analysis Procedure of CAMITA

In order to ensure the validity of the CAMITA model, the inter-relationship among the evaluation items and criteria in Fig. 1 should be assessed first. If the inter-relationship among the evaluation items and criteria is extremely low (i.e., the relationship between the criteria is independent of each other), AHP (Saaty, 1980) should be used; otherwise, ANP (Saaty, 2001) should be used to analyze the weights of the items.

In order to analyze the inter-relationship among the criteria, the DEMATEL is adopted in CAMITA, combined with the ANP method for cost/benefit analysis. The analysis procedure is described as follows:

- Step-1: The DEMATEL is used to decompose the BOCR aspects and the evaluation criteria according to the problem characteristics of the AIoT-IS implementation project. The inter-relationship of the BOCR items and associated evaluation criteria are assessed to determine the final framework of the CAMITA decision hierarchy.
- Step 2: Pairwise comparisons are conducted to determine the relative importance weighting of the items in CAMITA; if the inter-relationships are independent, the AHP method should be adopted for pairwise comparison. Otherwise, the ANP method should be adopted.
- Step-3: The score values of the evaluation criteria of '1. Benefit (B)' and '3. Cost (C)' is calculated based on the technical information of the adopted AIoT-IS devices; a questionnaire is surveyed with the stakeholders to obtain the score values of the evaluation criteria of '2. Opportunity (O)' and '4. Risk (R)'.
- Step-4: According to the score values of evaluation criteria, i.e., the benefit (B) and opportunity (O) scores and the cost (C) and risk (R) scores, the benefit (B+O) over cost (C+R) ratio is calculated to obtain the economic feasibility analysis indexes (e.g., CBR or NPV) using Eqs. (8) and (9), respectively.

$$CBR = \frac{B+O}{C+R}\% \tag{8}$$

$$NPVI = (B+O) - (C+R) \tag{9}$$

where B, O, C, and R are the aggregated score values obtained in Step 3; CBR is a cost/benefit ratio (%); NPVI is the surrogate index for Net Present Value (NPV) calculated by subtracting the score values of (C+R) criteria from the score values of (B+O) criteria.

5. Case Study of CAMITA for AIoT-IS in Construction Safety Monitoring

In order to demonstrate the feasibility of the proposed CAMITA model for the benefit evaluation of the AIoT-IS implementation project, an example construction project is selected for illustration.

5.1. Background of Case Project

The selected case is a public construction project located in Hsitun District, Taichung City, Taiwan, close to the CBD of the second most populated metropolitan in Taiwan. It provides public services, e.g., reading, exhibitions, and tour guides. It also offers Taichung City's library and art exhibition space resources.

The area of the project site is about 2.6 hectares, with a total floor area of 58,016 m^2. Due to the vast construction area, it not only requires many labor resources to implement traditional manual safety inspection but also easily causes blind spots that are unmonitored. As a result, this project adopts AIoT-IS technology for construction site safety management.

5.2. AIoT-IS Application Scenarios

There are 4 AIoT-IS application scenarios proposed for this project, as shown in Fig. 3 and described in the following:

- Scenario 1: Gate entrance control—facial recognition technology is used to confirm the identity and safety training qualification of the workers who enter or exit the gate; the license plate recognition system is used to control the vehicles that are allowed to enter and leave the site.
- Scenario 2: Personal Protection Equipment (PPE) monitoring—a total of 8 PTZ omnidirectional cameras are

Fig. 2. AIoT-IS Application Scenarios

installed on the construction site, which covers the entire construction working zone; moreover, the PTZ is connected to the AIoT edge computing unit (NVIDIA Jetson Nano, 2022), which perform real-time scanning and recognition on the sensor device. If an unqualified PPE is recognized, the safety management personnel immediately notifies to execute a rectification measure to prevent safety accidents.

- Scenario 3: Automatic monitoring of fall risks at the building edges or interior openings—the PTZ camera scans the construction site to inspect any unsafe situation about every 30 seconds for 24 hours a day; when a dangerous situation (e.g., unsafe facilities, unprotected openings, etc.) is identified, the system notifies site safety engineer immediately to take corrective measures to prevent safety incidents.
- Scenario 4: Lifting operation monitoring of mobile cranes—the site is equipped with mobile AIoT-IS equipment, which monitors the operation safety, e.g., the operation range of mobile cranes or the access range of construction vehicles. If a worker accidentally intrudes into the lifting area, the crane alarms and stops running, and the intruding worker is evicted immediately.

5.3. Cost/Benefit Analysis of AIoT-IS Adoption

A CAMITA analysis framework is established according to the AIoT-IS implementation project, which includes 4 aspects, 9 items, and 14 evaluation criteria.

To complete CAMITA analysis, a three-stage questionnaire survey was conducted: (1) 7 experts were surveyed for DEMATEL analysis; (2) 12 experts were surveyed for ANP analysis; (3) finally, 10 experts were interviewed to perform cost/benefit analysis. The selected experts are the personnel from participants, including the project owner, architect, project manager, safety manager, superintendent of the contractor, and sub-contractor representatives.

5.3.1. DEMATEL analysis of CAMITA criteria

The method of DEMATEL in the first stage analyzes the degree of mutual influence between different aspects or criteria. This study adopts a 5-point scale, including: '0' is no influence, '1' is a *low effect*, '2' is a *medium effect*, '3' is a *high effect*, and '4' is a *very high effect*.

After the DEMATEL analysis, the average direct-relation matrix (***W***) of CAMITA on the aspects and criteria for the case AIoT-IS implementation project is obtained and shown in Table 1 and Table 2.

Table 1. The average direct-relation matrix (W) of DEMATEL on the 4-aspect level of CAMITA

Aspect	F_1: Benefit	F_2: Opportunity	F_3:Cost	F_4:Risk
F_1: Benefit	0.00	2.57	2.86	2.14
F_2: Opportunity	2.86	0.00	3.29	2.14
F_3: Cost	3.00	2.71	0.00	2.00
F_4: Risk	1.57	1.86	1.71	0.00

The influential relation map (**IRM**) of DEMATEL is shown in Fig. 3. It is noted from Fig. 3 that all four aspects (B,O,C,R) have relatively high total effects (both direct and indirect relationship) with the other aspects. In contrast, only F_4 (Risk) has a slightly higher passive effect (i.e., it is more likely to be influenced than it can influence the other aspects).

Table 2. The average direct-relation matrix (W) of DEMATEL on the 9-criterion level of CAMITA

Aspect	F_1: Benefit		F_2: Opportunity			F_3: Cost		F_4: Risk	
Criterion	1.1 Safety	1.2 Mgmt.	2.1 Practic.	2.2 Reliab.	2.3 Accept.	3.1 Install.	3.2 Operat.	4.1 Privacy	4.2 Security
1.1	0.00	3.14	3.00	2.86	2.57	2.43	2.29	1.57	2.14
1.2	2.43	0.00	2.71	2.43	2.57	2.29	2.14	1.43	1.57
2.1	2.86	2.57	0.00	2.57	2.71	2.57	2.43	1.57	1.86
2.2	3.29	3.00	3.00	0.00	2.71	2.86	2.43	1.86	1.86
2.3	2.43	2.57	2.86	2.86	0.00	2.86	2.71	2.00	2.14
3.1	2.57	2.71	2.71	3.00	2.57	0.00	2.29	2.00	2.14
3.2	2.86	2.71	2.57	2.71	2.43	2.57	0.00	1.86	2.14
4.1	1.43	1.57	1.57	1.57	2.14	1.86	1.86	0.00	2.14
4.2	1.86	2.00	2.00	1.86	2.00	2.29	2.00	2.00	0.00

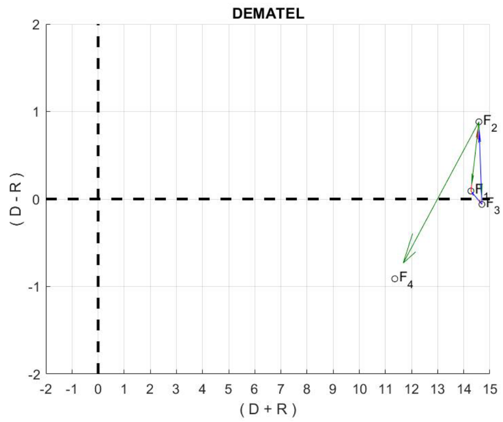

Fig. 3. Influential relation map (IRM) of DEMATEL

5.3.2. ANP analysis and weighting determination

In the second phase, we applied the 9-point scale suggested by Saaty and divided it into 5 categories: '1' indicates *equally important*; '3' indicates that the criterion is *slightly important*; '5' indicates that the criterion is *quite important*; '7' indicates that the criterion is *extremely important*; and '9' indicates that the criterion is *absolutely important*. Next is to establish a 'weighted supermatrix' (S_w), which is to conduct a preliminary weighting analysis on the questionnaire survey of all experts compared with each other and calculate the consistency ratio (**CR**). After the scale is set, the initial weight analysis is performed on the experts' questionnaire results. Then, CR is calculated. According to Saaty's suggestion, the CR value should be less than 0.1, and if it exceeds 0.1, a second evaluation is carried out by an expert until the CR value is lower than 0.1.

Table 3 shows the ANP analysis result of aspect and item level. As shown in the weightings of the 4 aspects that analysis from the experts' survey, the *most important* item is Benefit (B): '1.1 Safety' and Cost (C): '3.1 Installation', which are 16.88% and 14.94%, respectively. Conversely, the *least important* aspect is the Risk: '4.1 Personal privacy', which is 2.84%. After the ANP analysis of the aspects and items, the criterion weightings of CAMITA for the case project are shown in Table 4. Personnel safety is the *most important* criterion (12.66%), and the second and third *important* criteria are reliability and practicality of AIoT-IS, of which the weight is 12.17% and 10.88%. Then, another expert questionnaire survey is also collected and shown in Table 5, where the scores are calculated on average and then multiple by the weight calculated in Table 4. The values are shown in the "Value(%)" column. Finally, the values are summed in every aspect, listed in the "BOCR(%)" column.

Table 3. The ANP analysis result of aspect and item

Aspect	Weight (%)	Item	Weight (%)
B	29.43	1.1 Safety	16.88
		1.2 Management	12.54
O	29.62	2.1 Practicality	10.80
		2.2 Reliability	11.62

		2.3 Acceptance	7.20
C	27.97	3.1 Installation	14.94
		3.2 Operation	13.03
R	12.99	4.1 Personal Privacy	2.84
		4.2 Information Security	10.15

Table 4. The criterion weighting results of CAMITA

Aspect	Item	Criterion	Weight (%)
B	1.1 Safety	1.1.1 Personnel	12.66
		1.1.2 Environ.	4.22
	1.2 Mgmt.	1.2.1 Labor	2.50
		1.2.2 Efficiency	4.00
		1.2.3 Precision	6.05
O	2.1 Practicality		10.88
	2.2 Reliability		12.17
	2.3 Acceptance		6.58
C	3.1 Install.	3.1.1 Sensor	7.91
		3.1.2 Network	2.91
		3.1.3 Server	4.12
	3.2 Operation	3.2.1 Software	6.82
		3.2.2 Labor	6.20
R	4.1 Personal Privacy		2.84
	4.2 Information Security		10.14

Table 5. The scoring results of CAMITA

Aspect	Item	Criterion	Score	Value (%)	BOCR (%)
B	1.1 Safety	Personnel	0.75	9.49	16.72
		Environ.	0.57	2.41	
	1.2 Mgmt.	Labour	0.24	0.60	
		Efficiency	0.42	1.68	
		Precision	0.42	2.54	
O	2.1 Practicality		0.20	2.18	7.70
	2.2 Reliability		0.40	4.87	
	2.3 Acceptance		0.10	0.66	
C	3.1 Install.	Sensor	0.20	1.58	3.22
		Network	0.40	1.16	
		Server	0.10	0.41	
	3.2 Operation	Software	0.1	0.68	
		Labour	-0.1	-0.62	
R	4.1 Personal Privacy		0.00	0.00	2.03
	4.2 Inform. Security		0.20	2.03	

5.3.3. Cost/Benefit Analysis (CBA)

With the BOCR results from Table 5, it is possible to calculate the economic feasibility analysis indexes, e.g., Cost/Benefit Ratio (CBR) and Net Present Value Index (NPVI) of the considered project using Eqs. (8) and (9).

Before calculating economic feasibility indexes, the third stage questionnaire survey was conducted with 10 domain experts (i.e., stakeholders of the case project as described at the beginning of this section). Then, the CBR and NPVI are calculated as shown in Eqs. (10) and (11). The Cost/Benefit Ratio (CBR) = 4.65, and Net Present Value Index (NPVI) = 19.17% show highly economic feasibility. Thus AIoT-IS applications to four construction safety monitoring scenarios are highly feasible and recommended for implementation in the case project.

$$CBR = \frac{16.72+7.70}{3.22+2.03} = \frac{24.42}{5.25} = 4.65 \tag{10}$$

$$NPVI = 24.42\% - 5.25\% = 19.17\% \tag{11}$$

5.3.4. Qualitative Feedback from Interviewees

In addition to the quantitative survey, interviewees' feedback was collected. Some valuable perspectives are summarized in the following:

- Most concerned aspect—from the results of the questionnaire, it is found that the issue that stakeholders care most about is "Benefit (B)," accounting for 83% of all experts; the least important issue is "Risk (R)," accounting for 67%, which is still high; The stakeholders' concerns on the 4 aspects are quite consistent.
- The most desirable objective—as for the most priority objective that the stakeholders wish AIoT-IS to achieve is: 'when there is a violation of safety regulations, the message should be immediately sent to the safety personnel.' This

is reasonable since Taiwan's fines for violating construction safety regulations are very high. Construction sites may even be required to stop work due to violations of some important construction worker safety provisions.

- Future extensions—interviewees also point out two promising directions for future AIoT-IS applications: (1) it is very desirable that the AIoT-IS application can be further extended from safety issues to the security monitoring of the entire company and community; (2) other scenarios, such as the monitoring of high-risk operation areas during the operation of construction equipment, and even quality management, construction progress control, etc., also have high demands.
- Features need to be improved—three weaknesses of AIoT-IS which need to be improved are: (1) the installation cost needs to be reduced; (2) the precision rate needs to be improved; (3) it is desirable to reduce labour cost and human judgment errors.

6. Conclusions, Limitations, and Recommendations

6.1. Conclusions

This paper proposes a generic cost/benefit analysis (CBA) model, namely CAMITA, for economic feasibility analysis of adopting innovative technologies in the construction industry, e.g., Artificial Intelligence Internet of Things Image Sensors (AIoT-IS). The model consists of the four most important aspects (e.g., Benefit, Opportunity, Cost, and Risk) to analyze the feasibility of AIoT-IS implementation in real-world construction safety management. Totally 14 evaluation criteria are broken down from the BOCR aspects.

The proposed CAMITA model integrates the DEMATEL method for an inter-influential relationship among the evaluation criteria; then, the ANP method is employed to determine the relative importance weightings of the considered criteria. Finally, quantitative economic feasibility indexes, including Cost/Benefit Ratio (CBR) and Net Present Value Index (NPVI), are calculated to give the adopters of AIoT-IS adequate support for their decision.

A public construction project is selected as a case study to demonstrate the proposed method. Four application scenarios for the construction safety management of AIoT-IS are implemented including: gate entrance control, PPE monitoring for workers, monitoring of fall risks, and monitoring of lifting operation of mobile cranes. The CAMITA analysis results show that CBR = 4.65 and NPVI = 19.17%, both show very high feasibility. As a result, the AIoT-IS devices are highly recommended for implementation. It is concluded that the proposed method is applicable for the decision-making of AIoT-IS adoption and feasibility assessment of other innovative construction technologies.

In addition to quantitative economic indexes, qualitative feedback from the stakeholders was also collected to give the future research directions, including (1) function for immediately alerting of safety regulation violations to safety personnel; (2) AIoT-IS application extended from safety issues to the entire firm and community; (3) other scenarios are desirable such as monitoring of the high-risk working zones during the operation of the construction equipment; (4) application to quality management and construction schedule, etc.; and (5) cost-effectiveness issues, etc.

6.2. Limitations

This paper has presented a generic CBA model for adopting innovative construction technology, e.g., AIoT-IS, for construction safety monitoring. The proposed model can be adapted to evaluate the feasibility of other types of innovative construction technologies and other AIoT-IS application scenarios. However, tailoring the CAMITA framework to fit the specific characteristics of the problem domain is required. For example, the CAMITA framework for decision-making in construction safety monitoring consists of 4 aspects, 9 items, and 14 scoring criteria; it is expanded to 4 aspects, 11 items, and 25 scoring criteria for evaluating its application in community security monitoring (Wang et al., 2021). The second limitation of the proposed model is that only Net Present Value Index (NPVI) instead of Net Present Value (NPV) is provided to the decision-makers. This is due to the inclusion of intangible evaluation aspects and criteria, e.g., '2. Opportunity (O)' and '4. Risk (R)' and the associated items and scoring criteria. This limitation can be broken if some conversion methods from qualitative evaluation data to quantitative monetary values are adopted, e.g., the transformation of environmental impacts to monetary cost data by Gao et al. (2016). However, such conversions usually induce subjectivity and never guarantee the correctness of the results. Sometimes it is impractical to convert qualitative judgments to numerical values because qualitative judgments are highly personal, and the monetary value may differ for different evaluators. The last limitation of the proposed method lies in the respondents' judgment, and this restriction applies to all methods involving DEMATEL and AHP.

6.3. Recommendations

Some future research directions are recommended to interested researchers, including:

- Development of CAMITA framework for innovative civil engineering technologies—the CAMITA framework proposed in this paper was developed for building construction projects. The aspects, items, and criteria for innovative civil engineering technologies may differ, and future researchers are encouraged to develop a specific decision framework for evaluating innovative civil engineering technologies.
- Automated questionnaire survey and analysis system for CAMITA—due to project time and resource constraints, the research team manually conducted the tedious questionnaire survey and analysis tasks in this study. It is not only time-consuming but also error-prone. An automated questionnaire survey and analysis system is desirable for future implementation.

- Finally, more applications of CAMITA in evaluating innovative building technologies, e.g., smart building devices, are also recommended. Adopting intelligent building technologies also presents unforeseen risks and threats to human users. Before implementation, it is important to investigate risks and hazards and take precautions to avoid unforeseen impacts. The proposed CAMITA method has profound implications in the research in this direction.

Acknowledgements

The authors would also like to express our sincere gratitude for the contributions of anonymous experts from industry, government, and academia, who took their valuable time to participate in the three-phase expert interviews of this research.

Author Contributions

Director Rong-jing Wang is the Principal Investigator (PI) of the research project and provides general guidance for the research direction. Dr. Wen-der Yu is the co-PI of the study. He planned and directed the execution of research projects and drafted this article. Dr. Hsien-Chou Liao designed the research methodology and helped oversee the execution of the study. Dr. Hsien-Kuan Chang is responsible for expert interviews and data processing in construction aspects. Dr. Zi-Yi Lim is responsible for expert interviews and data processing in information and communication aspects.

Funding

This research is financially supported by the Architecture and Building Research Institute (ABRI), Ministry of Interior, Executive Yuan, Taiwan Government, and is partially funded by the Ministry of Science and Technology, Taiwan, under project No. MOST 109-2221-E-324-008-MY2.

References

ADLINK. (2022). NEON AI camera, *Website*: https://www.adlinktech.com/en/index.aspx, accessed 2022/03.

Arfi, W.B., Nasr, I.B., Khvatova, T., and Zaied, Y.B. (2021). Understanding acceptance of eHealthcare by IoT natives and IoT immigrants: An integrated model of UTAUT, perceived risk, and financial cost. *Technological Forecasting and Social Change*, 163, 120437, doi:10.1016/j.techfore.2020.120437.

Atzori, L., Iera, A., and Morabitoc, G. (2010). The Internet of Things: A survey," *Computer Networks*, 54(15): 2787-2805.

BLS- U.S. Bureau of Labor Statistics (2021). Census of Fatal Occupational Injuries Summary, 2020. *Website*: https://www.bls.gov/news.release/cfoi.nr0.htm, accessed 2022/07.

Chang, I.W. (2018). A Survey on Cost–Benefit Analysis Methods and Apply to Smart Buildings. *Report to Architecture and Building Research Institute (Project No: 107301070000G0045)*, Ministry of Interior, Taiwan. (in Chinese)

Chang, S.T., Wen, S.L., and Yu, P.J. (2020). Research on the Rationality of Quantitative Assessment of the Benefits of Office Smart Buildings. *Report to Architecture and Building Research Institute (Project No: 10915G0016)*, Ministry of Interior, Taiwan. (in Chinese)

Chen, L.-C., Papandreou, G., Kokkinos, I., Murphy K., and Yuille A. L. (2017). DeepLab: Semantic Image Segmentation with Deep Convolutional Nets, Atrous Convolution, and Fully Connected CRFs. *Computer Vision and Pattern Recognition*, arXiv:1606.00915.

Chor, K.H.B., Wisdom, J.P., Olin, S.C.S., Hoagwood, K.E., and Horwitz, S.M., Measures for Predictors of Innovation Adoption. *Administration and Policy in Mental Health and Mental Health Services Research*, 42(5):545-73. http://doi: 10.1007/s10488-014-0551-7, 2015.

Cognex. (2022). IN-SIGHT D900 visualization system, Website: https://www.cognex.com/zh-tw/products/deep-learning/in-sight-d900, accessed 2022/03.

Dong, B., Shi, Q, Yang, Y, Wen, F, Zhang, Z., and Lee, C. (2021). Technology evolution from self-powered sensors to AIoT enabled smart homes. *Nano Energy*, 79, 105414, doi:10.1016/j.nanoen.2020.105414.

Fontela, E., and Gabus, A. (1976). The DEMATEL observer, *DEMATEL 1976 reportGeneva: Battelle Geneva Research Center*, Battelle Geneva Research Centre.

Gabus, A., and Fontela, E. (1972). *World problems, an invitation to further thought within the framework of DEMATEL*. Geneva: Battelle Geneva Research Centre.

Gao, J. L., Yuan, Z. W., Liu, X. W., Xia, X.M., Huang, X. J., and Dong, Z.F. (2016). Improving air pollution control policy in China—A perspective based on cost–benefit analysis. *Science of The Total Environment*, 543(A), 307-314, doi:10.1016/j.scitotenv.2015.11.037, 2016.

Hardy, G. H. (1992). *Divergent Series*. Providence: American Mathematical Society. ISBN 978-0-8218-2649-2.

Kanan, R., Elhassan, O., and Bensalem, R. (2018). An IoT-based autonomous system for workers' safety in construction sites with real-time alarming, monitoring, and positioning strategies, *Autom. Constr.* 88, 73–86, doi:10.1016/j.autcon.2017.12.033.

Khoa, T. A., Man, M. M., Nguyen, T.-Y., Nguyen, V., and Nam, N. H. (2019). Smart Agriculture Using IoT Multi-Sensors: A Novel Watering Management System. *J. Sens. Actuator Netw.* 8(45), doi:10.3390/jsan8030045.

Lin, S.S., Shen, S.L., Zhou, A., and Xu, Y.S. (2021). Risk assessment and management of excavation system based on fuzzy set theory and machine learning methods. *Automation in Construction*, 122, 103490, doi:10.1016/j.autcon.2020.103490, 2021.

Louis, J. and Dunston, P.S. (2018). Integrating IoT into operational workflows for real-time and automated decision-making in repetitive construction operations, *Autom. Constr.* 94, 317–327, doi:10.1016/j.autcon.2018.07.005.

Nvidia. (2022). Embedded Systems Developer Kits & Modules from NVIDIA Jetson, NVIDIA Jetson, Website: https://www.nvidia.com/en-us/autonomous-machines/embedded-systems/, accessed2022/03.
OSHA- Occupational Safety and Health Administration, Ministry of Labor (2021). Annual Report of Labor Inspection Statistics in 2020. *Website*: https://www.osha.gov.tw/1106/1164/1165/1168/34345/, accessed 2022/07.
Redmon, J., Divvala, S., Girshick, R., and Farhadi, A. (2016). You only look once: Unified, real-time object detection, *Proceedings of the IEEE conference on computer vision and pattern recognition*, 779-788.
Saaty, T. L. (1980). *Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*, 1st ed., New York: McGraw-Hill.
Saaty, T. L. (2001). *The Analytic Network Process*. Pittsburgh: RWS Publications.
Santiputri, M., and Tio, M. (2018). IoT-based Gas Leak Detection Device," *Proceedings of the International Conference on Applied Engineering (ICAE 2018*), 4 pages, Oct 2018.
Si, S., L., You,X.Y., Liu, H.C., and Zhang, P. (2018). DEMATEL Technique: A Systematic Review of the State-of-the-Art Literature on Methodologies and Applications, *Mathematical Problems in Engineering*, 2018, 3696457, doi:10.1155/2018/3696457.
TensorFlow. Website: https://www.tensorflow.org/, accessed 2022/03.
Todorović, B. M., and Samardžija, D. (2017). Road lighting energy-saving system based on wireless sensor network," *Energy Efficiency*, 10, 239–247, doi:10.1007/s12053-016-9447-6, 2017.
Wang, R.J., Yu, W.D., Liao, H.C., Chang, H.K., and Lim, Z.Y. (2021) Application and Benefit Evaluation of AIoT Image Sensing for Building Safety Monitoring. *Report to Architecture and Building Research Institute (Project No: 11015B00021)*, Ministry of Interior, Taiwan. (in Chinese)
Wen, S.L. and Yu, P.J. (2019) Research on the Evaluation Framework and Criteria of Smart Buildings. *Report to Architecture and Building Research Institute (Project No: 108301070000G0024)*, Ministry of Interior, Taiwan. (in Chinese)
Wisdom, J. P., Chor, K. H. B., Hoagwood, K. E., and Horwitz, S. M. (2013). Innovation adoption: A review of theories and constructs. Administration and Policy in Mental Health and Mental Health Services Research, doi:10.1007/s10488-013-0486-4.
Wilson, C., Hargreaves, T., and Hauxwell-Baldwin, R. (2017). Benefits and risks of smart home technologies. *Energy Policy*, 103, 72–83. Doi:10.1016/j.enpol.2016.12.047.
Yang, C.H., Lee, K.C., Li, S.E. (2020). A mixed activity-based costing and resource constraint optimal decision model for IoT-oriented intelligent building management system portfolios. *Sustainable Cities and Society*, 60, 102142, doi:10.1016/j.scs.2020.102142.
Zhou, J. T., Du, J., Zhu, H., Peng, X., Liu, Y., and Goh, R. S. M. (2019) AnomalyNet: An Anomaly Detection Network for Video Surveillance. *IEEE Transactions on Information Forensics and Security*,14(10), 2537-2550, doi: 10.1109/TIFS.2019.2900907.
Zhang, P., Chen, R.P., Dai, T., Wang, Z.T., and Wu, K. (2021). An AIoT-based system for real-time monitoring of tunnel construction." *Automation in Construction*, 109, 103766, doi:10.1016/j.tust.2020.103766, 2021.

Rong-jing Wang received the Master degree from National Cheng Kung University of Taiwan in 1990. He has served as Director of the Taipei City Construction Management Engineering Office, Deputy Director of the Taipei City Government Department of Urban Development, Director of Architecture and Building Research Institute, Deputy Director of Construction and Planning Agency, Ministry of Interior, Taiwan. His research fields relate to green building, smart building, and building safety.

Wen-der Yu received his BS degree in Civil Engineering from National Central University, Taiwan, and MSCE and Ph.D. degrees from Purdue University of USA. He is currently a Professor of the Department of Construction Engineering. He served previously as Assistant Vice President for International Affairs at Chaoyang University of Technology, Taiwan. His research interests include AI application in Construction Engineering and Management, Project Management, Knowledge Management and BIM.

Hsien-Chou Liao received the B.S. and Ph.D. degrees in Computer Science and Information Engineering from National Chiao Tung University in 1991 and 1998, respectively. He is a professor, Department of Computer Science and Information Engineering, at Chaoyang University of Technology, Taiwan, R.O.C. His research interests include computer vision, artificial intelligence/deep learning, automated optical inspection, and software engineering.

Hsien-Kuan Chang is an Adjunct Assistant Professor of the Department of Construction Engineering at Chaoyang University of Technology, Taiwan. Dr. Chang received his Master in Construction Management in 2014 and Ph.D. in Civil Engineering in 2018 from Chung Hua University of Taiwan. He served as the chief professional engineer of construction companies in Taiwan more than twenty years. His research interests cover Construction Planning and Scheduling, Construction Control and Management, Artificial Intelligence Application in Construction Safety,

and Building Information Modeling.

Zi-Yi Lim is an Assistant Professor in Department of Information and Communication Engineering at Chaoyang University of Technology. He received the B.S. and M.S. degrees in Computer Science and Engineering, Ph.D. in Department of Information Management from Chaoyang University of Technology, Taichung, Taiwan in 2014, 2016, and 2020, respectively. His research interests include AIoT, cryptography, blockchain, automated optical inspection, computer vision, and software engineering.