REVIEW OF APPLICATION OF ANALYTIC HIERARCHY PROCESS (AHP) IN CONSTRUCTION

ABSTRACT

The analytic hierarchy process (AHP) has gained increasing attention in construction management (CM) domain as a technique to analyze complex situations and make sound decisions. However, AHP *per se* or its potential applications on CM problems are ill-defined within extant literature. The present paper reviews 77 AHP-based papers published in eight selected peer-reviewed CM journals from 2004 to 2014 to better define and delineate AHP application areas and decision-making problems solved within CM. The findings indicated that risk management and sustainable construction were the most popular AHP application areas in CM. It was also revealed that AHP (1) is flexible and can be used as a stand-alone tool or in conjunction with other tools to resolve construction decision-making problems; and (2) is widely used in Asia. In addition, the most prominent justifications for using AHP were found to be small sample size, high level of consistency, simplicity and availability of user-friendly software. This paper provides a useful reference for researchers and practitioners interested in the application of AHP in CM. Future research is needed to compare and contrast between AHP and other multicriteria decision-making methods; such work could reveal which techniques provide optimized solutions under various decision-making scenarios.

KEYWORDS

Analytic hierarchy process (AHP); Multicriteria decision-making; Application; Construction management; Literature review.

INTRODUCTION

Decision-making is defined as the process of determining the best alternative among all possible choices but in practice, achieving an optimized result can be problematic as decision makers are often confronted with various decision-making problems (Angelis and Lee, 1996). Multicriteria decision-making (MCDM) is one of the most important branches of decision theory and is used to identify the best solution from all possible solutions available (Huang et al., 2015; Işıklar and Büyüközkan, 2007). Several methods have been developed to enable improvements in MCDM, including: analytic hierarchy process (AHP) (Saaty, 1980); superiority and inferiority ranking (SIR) technique (Xu, 2001); Simos' ranking method (Marzouk et al., 2013); multi-attribute utility theory (MAUT) (Chan et al., 2001); elimination and choice corresponding to reality (ELECTRE) (Roy, 1991); preference ranking organization method for enrichment evaluations (PROMETHEE) (Brans et al., 1986); and choosing by advantages (CBA) (Suhr, 1999). These MCDM methods are frequently used to facilitate the resolution of real-world decision-making problems.

Saaty's (1980) AHP represents a popular MCDM method that has attracted considerable attention throughout industry, including construction, over the past two decades. Construction decision-making problems in particular, have been characterized as being complex, ill-defined and uncertain (Chan et al., 2009). Al-Harbi (2001) further suggests that elements of construction-related decision-making problems are numerous and that the interrelationships between these elements are complicated and often nonlinear. Consequently, the ability to make sound decisions is crucial to the success of construction activities and operations. AHP provides a powerful means of making strategic and sound construction decisions (Jato-Espino et al., 2014); it allows decision makers to employ multiple criteria in a quantitative manner to evaluate potential alternatives and then select the optimal option.

Because of AHP's inherent ability to deal with various types of decisions, it has been widely applied in construction management (CM) research over the past two decades (Nassar and AbouRizk, 2014; Akadiri et al., 2013; Ruiz et al., 2012; Zou and Li, 2010; Chan et al., 2006). However, there has been a notable dearth of comprehensive reviews of AHP applications within the CM domain with Jato-Espino et al.'s (2014) study of 22 different MCDM methods representing a rare exception. At present, no review has specifically focused on AHP applications in CM. This paper aims to fill this void and provide a deeper understanding of the decision areas and decision problems that AHP could efficiently deal with. Concomitant objectives are to: summarize the existing literature related to AHP applications in CM; identify the popular AHP application areas and problems; and provide directions for future AHP application. To achieve these objectives, 77 relevant AHP-based papers published in eight selected peer-reviewed CM journals from 2004 to 2014 were identified through a systematic desktop search and reviewed. This paper provides a useful reference for researchers and practitioners interested in the application of AHP to analyze and model construction-related decisions. AHP decision support systems and models developed for the construction industry are myriad and scattered throughout the existing literature. Researchers and practitioners may experience some difficulty locating these systems and models, hence this paper will provide clear signposting to potentially useful decision support systems and models, which in turn may trigger greater usage in practice.

AHP DECISION-MAKING METHOD

AHP was created by Saaty (1980) to deal with decision-making problems in complex and multicriteria situations (c.f. Dyer and Forman, 1992; Saaty, 1990). Therefore, this research is not concerned with explicating specific details about the method but rather the basic concepts of it. AHP assists in making decisions that are characterized by several interrelated and often competing criteria, and it establishes priorities amongst decision criteria when set within the context of the decision goal (Shapira and Goldenberg, 2005). A key aspect is that decision criteria are assessed with respect to their relative importance in order to allow trade-offs between them.

The AHP consists of three steps: (1) *hierarchy formation* – the first level of the hierarchy contains the decision goal, whereas the subsequent lower levels represent the progressive breakdown of the decision criteria, sub-criteria, and the alternatives for reaching the decision goal; (2) *pairwise comparisons* – decision makers (who are often domain experts) are asked to complete pairwise comparisons of the elements at each level of the hierarchy, assuming the elements are independent of each other. In this regard and considering the decision goal, comparisons are made between the relative importance of every two criteria at the second level of the hierarchy. Every two sub-criteria under the same criterion (at level two) are also compared, and so on and so forth. These pairwise comparisons are often based on a nine-point scale, as shown in Table 1 (Saaty, 1980); and (3) *verification of consistency* – expert judgments are necessary for determining the relative importance of each criterion and any alternative to achieving the decision goal. Because AHP allows subjective judgments by decision makers, consistency of the judgments is not automatically guaranteed. Therefore, consistency verification is essential to ensuring optimized outcome. Saaty (2000) mentioned that to control the consistency of pairwise comparisons, a computation of consistency ratio should be performed. At this stage, decision makers are required to revise their initial judgments if the computed consistency ratio exceeds the threshold of 0.1 (Saaty, 2000). After all of the necessary pairwise comparisons, and revisions have been made, and the consistency ratio has also been found to be less than 0.1, the judgments can then be synthesized to prioritize the decision criteria together with their corresponding sub-criteria.

[Insert Table 1 about here]

RESEARCH METHODOLOGY

The present study was based upon the AHP literature published in eight selected CM journals from 2004 to 2014. These journals were: (1) *ASCE's Journal of Construction Engineering and Management (JCEM);* (2) *Automation in Construction (AIC);* (3) *Construction Management and Economics (CME);* (4) *ASCE's Journal of Management in Engineering (JME);* (5) *International Journal of Project Management (IJPM);* (6) *Engineering, Construction and Architectural Management (ECAM);* (7) *Building and Environment (BE);* and (8) *Building Research and Information (BRI*). The first six journals were deemed to be high quality based on Chau's (1997) ranking of CM journals, while the last two journals are widely regarded as top-quality journals in CM (Chan et al., 2009). Major search engines such as ASCE Library, Science Direct, Taylor and Francis, and Emerald were used to search for the keyword *"analytical hierarchy process"* in the advanced search section of the selected journals. An initial search conducted was limited to papers published from 2004 to 2014 and resulted in the identification of 194 research papers. However, not all of these papers used AHP as a primary or secondary decision-making tool as some simply mentioned AHP in the literature review and/or recommended its application for future research. A review of each paper's contents was then undertaken to filter out unrelated papers; 77 papers were eventually considered valid for further analysis. Table 2 shows the number of relevant papers collected from each of the selected journals. It reveals that 25 of the papers were from JCEM, 13 were from AIC, 10 were from BE and nine were from CME, in total representing 74% of the sample. The remaining papers were distributed across the other four journals.

[Insert Table 2 about here]

The next sections offer an overview of the benefits of applying AHP to construction-related decision-making problems, identifying the specific decision areas and decision problems to which AHP could be applicable or useful. Moreover, a concise review of the literature (based on the top six identified decision areas) is provided to demonstrate the versatility and worth of AHP in diverse construction situations. Where applicable, the application cases reviewed in a certain decision area are divided into stand-alone and integrated approaches – depending upon whether the AHP was used in a particular case as a sole method or in combination with other notable methods. This approach will help to elucidate upon the inherent flexibility of AHP in terms of combining it with other methods to analyze and model construction-related decisions.

REVIEW OF AHP APPLICATIONS IN CM

Identification of Decision Areas and Decision Problems

As the most commonly used MCDM method, AHP attracts the most attention from decision makers because of the availability of extensive literature on its application (Jato-Espino et al., 2014). It is thus essential to better understand the specific decision problems that AHP can resolve. Such an understanding would greatly stimulate interest in AHP applications within the wider areas of CM.

Table 3 presents all of the 77 identified papers and provides a quick reference guide and meaningful information about the applications of AHP in CM. The table was developed based on information extracted from the reviewed papers. First, the papers' research interests/ topics aided the identification of the decision areas. Based upon this, AHP has been found to be applicable to many different areas of CM. Second, the papers' research aims/ objectives presented the decision problems that AHP was used to address. This showed that AHP has been applied to numerous construction-related decision-making problems. These findings suggest that AHP is useful in enabling strategic and sound decision-making in a wide range of CM areas, which is consistent with the viewpoint of Jato-Espino et al. (2014). Following the identification of the decision areas and problems, the reviewed papers were then grouped, based upon the decision problems, under the decision areas. Each paper was assigned to only one decision area, thus if a paper appears to have multiple research interests [e.g., Lai and Yik's (2009) paper addressed both sustainability and housing/residential building issues], it was assigned to the best-fit decision area, as suggested by Hong et al. (2012). Although deciding on the best-fit decision area for a paper may seem subjective and associated with some level of uncertainty, it is believed that variations were minimized. Lastly, the authors and years of publication of the reviewed papers, and other methods combined with AHP in some of the papers are also presented in the table.

[Insert Table 3 about here]

Descriptive Analysis

A descriptive analysis of the papers was also undertaken to illustrate insightful trends in the application of AHP in CM. Of the 77 papers, 14 papers were published in the years before 2007 and during 2007, a peak of 13 papers was evident (Fig. 1) which appears to be a purely random occurrence given a lack of any 'special issue' that could easily explain it. In recent years (2009 to 2013), relatively stable trend was observed with an average of seven papers published every year – however, in 2014 this trend significantly reduced. This outcome might be because many more MCDM methods have emerged in recent years, giving the AHP tight competition in terms of MCDM methods application.

[Insert Fig. 1 about here]

With regard to geographical origins, the US and Taiwan accounted for the highest number of AHP-based papers published with 11 and 10 papers, respectively, as shown in Table 4. This finding suggests that the application of AHP in CM within these two developed countries is relatively more mature than that in other countries. Although some developing countries, such as China (6 papers) and India (4 papers), have made good progress in the application of AHP in CM, there are still opportunities to conduct more studies.

[Insert Table 4 about here]

Finally, the papers were also viewed from a regional perspective. Fig. 2 shows that there is a relatively large number of AHP applications in Asia (45 papers, 61%) – a finding that concurs with the earlier research of Jato-Espino et al. (2014). In light of the extent of construction development in many Asian countries, it could be that the wide application of AHP in enhancing construction decisions has been significantly helpful. This wide usage of AHP in Asia should encourage other regions outside Asia to pursue AHP application in CM.

[Insert Fig. 2 about here]

AHP APPLICATIONS IN IDENTIFIED CM AREAS

Table 3 summarizes the AHP literature relating to CM and reveals that risk management, sustainable construction, transportation, housing, contractor prequalification and selection, and competitive advantage were the top six application areas. Papers in these areas used AHP explicitly for different applications and so each area will now be discussed in further detail.

Risk Management

Risk management is a major CM area comprising defects, misalignments, and crises that can lead to inflated risks, project conflicts, and other negative performance outcomes (Zheng et al., 2016). Risk management decisions are often made using multiple criteria. Interestingly, all the AHP applications within the risk management area involved integrated approaches to combine AHP with other techniques.

AHP Combined with Fuzzy Sets Theory

Subramanyan et al. (2012) designed a model for construction project risk assessment by using a combination of fuzzy sets theory (FSs) and AHP. During the process of designing the model, FSs was used to capture both subjectivity and linguistic terms, while AHP was applied to weight and prioritize various risk factors. Li and Zou (2011) also developed a FSs-AHP-based risk assessment method for improving the accuracy of project risk assessment. FSs-AHP was used to pairwise compare between different risk criteria – after which the pairwise comparisons were synthesized to obtain risk priorities. Li and Zou (2011) proved the validity of this FSs-AHP-based method to assess risks in public-private partnership (PPP) projects, by exhibiting its applicability in an actual PPP expressway project. Other applications of FSs-AHP in the area of risk management were presented by Zhang and Zou (2007), Zeng et al. (2007), and Zou and Li (2010).

AHP Combined with Fuzzy Sets Theory and Delphi

Khazaeni et al. (2012) used FSs-AHP together with the Delphi method to resolve the problem of unbalanced allocation of risks among contracting parties. Specifically, the fuzzy adaptive decision-making model presented (*ibid*) was used to select the most appropriate allocation of risks among contracting parties. FSs was used in the model for the quantification and reasoning of linguistic principles. A Delphi team consisting of subject matter experts was employed to pairwise compare various risk allocation criteria using fuzzy values. FSs-AHP was then used to derive priority weights for the risk allocation criteria.

AHP Combined with Fuzzy Sets Theory and Failure Mode and Effect Analysis

Failure mode and effect analysis (FMEA) is a useful risk analysis technique, although it has some limitations. Abdelgawad and Fayek (2010) combined FSs-AHP and FMEA with the aim to overcome the limitations of the traditional FMEA-based risk management in CM. Their work (*ibid*) formed a model for assessing the criticalities of construction risk events and recommending corrective measures. A case study was presented, which confirmed the applicability and usefulness of this approach in providing valid and reliable risk management results.

AHP Combined with Utility Theory

Hsueh et al. (2007) applied a combination of AHP and utility theory (UT) to develop a multicriteria risk assessment model for contractors to reduce risks in joint ventures. AHP was first used to weight a set of risk criteria. Utility functions were then used to convert risks into numerical rates for ascertaining the expected utility values of various scenarios.

AHP Combined with Ontology

Tserng et al. (2009) explored an approach for conducting knowledge extraction by the establishment of an ontology-based risk assessment framework for enhancing risk management in building projects. In developing the framework, risk class and subclass weights were established, which was achieved by using AHP to capture experts' assessment of the risks. Subsequent application in a real project indicated that the framework greatly increased the effectiveness and efficiency of the project risk management plan.

Sustainable Construction

Sustainable construction represents another popular area of AHP application in CM. In this area, both stand-alone and integrated AHP applications were identified.

Stand-alone AHP Studies

Ali and Al Nsairat (2009) used AHP to develop a green building rating tool. After identifying the green building assessment criteria, the criteria were weighted and prioritized using AHP. Similarly, Lai and Yik (2009) applied AHP to identify the significant indoor environmental quality areas in high-rise residential buildings. Specifically, AHP was used to derive importance weights for various indoor environmental quality attributes. The researchers (*ibid*) claimed that the results can assist facility managers in managing buildings within constrained budgets. Likewise, Alwaer et al. (2010) developed a sustainability assessment model to assess the performance of intelligent building systems in the construction industry. The assessment of the model was based upon the use of AHP to assign relative importance weights to different sustainability issues; the research sought to help stakeholders choose the most suitable indicators for intelligent buildings.

Integrated Approaches

AHP Combined with Life-Cycle Assessment and Life-Cycle Cost Analysis

Lee et al. (2013) developed a rating system for assessing the economic and environmental sustainability of highways using life-cycle assessment (LCA) and life-cycle cost analysis (LCCA) as measurement methods for quantifying environmental impact and economic impact, respectively. AHP was used to weight different sustainability indexes as a means of encouraging recycling of materials, which is a vital component of a holistic sustainable development (*ibid*).

AHP Combined with Top-Down Direct Rating, Bottom-Up Direct Rating, and Point Allocation

Pan et al. (2012) presented construction firms with value-based decision criteria and quantified the relative importance of these for the purpose of assessing sustainable building technologies. Different combinations of AHP, top-down direct rating (TDR), bottom-up direct rating (BDR), and point allocation (PA) were used in different cases to weight various decision criteria by pairwise comparisons. Case studies involving six UK construction firms sought to examine decision criteria for the selection of sustainable building technologies and verified the effectiveness of the method developed.

AHP Combined with Geographic Information System and Netweaver

Ruiz et al. (2012) studied the problems of planning, designing, and delivering a sustainable industrial area and developed a multicriteria spatial decision support system that incorporated a geographic information system (GIS) platform, NetWeaver, and AHP. While the GIS platform stores and manages geographical data in the system, the NetWeaver provides an environment for developing expert systems that provide an interface for defining 'knowledge.'

The main function of AHP in the system was to obtain the variables' structure and determine the variables' respective weights.

AHP Combined with Mathematical Models

El-Anwar et al. (2010) suggested a combination of AHP and mathematical functions (such as sustainability index and environmental performance index) to tackle the issue of maximizing the sustainability of post-disaster housing recovery and construction. To help decision makers quantify and maximize the sustainability of post-natural disaster integrated housing recovery efforts, sustainability metrics were computed and incorporated into an optimization model. AHP was used to identify the relative importance of different sustainability metrics. Mostafa (2014) also presented a stakeholder-sensitive, social welfare-oriented sustainability benefit analysis model to evaluate infrastructure project alternatives. A key component of the model is AHP that was used to compute stakeholder benefit preference weights.

Transportation

Transportation has seen various AHP applications, while MCDM methods more generally, have had major applications in roads and highways construction (Jato-Espino et al., 2014).

Stand-alone AHP Studies

Wakchaure and Jha (2012) used AHP to resolve the conundrum of optimizing bridge maintenance using limited resources. Specifically, AHP was used to determine the relative importance weights of bridge components as a first step towards developing a bridge health index. This index can be applied by stakeholders to rank bridges that need maintenance and optimally allocate resources for the maintenance of the bridges. Dalal et al. (2010) also used

AHP in group decision-making to rank rural roads for optimal allocation of funds for upgrading purposes.

Integrated Approaches

AHP Combined with Data Envelopment Analysis

Wakchaure and Jha (2011) sought to prioritize bridge maintenance planning based on efficient allocation of limited funds. The researchers utilized data envelopment analysis (DEA) to evaluate the efficiency scores of different bridges, while the relative importance weights and condition ratings of the components and sub-components of the bridges were ascertained through AHP.

AHP Combined with FSs and Delphi

Pan (2008) proposed a FSs-AHP-based model to select the most suitable bridge construction method. Various bridge selection criteria were weighted through pairwise comparisons using a Delphi approach, under the following five main criteria: cost; duration; quality; safety; and bridge shape. A case study of a new bridge construction project was presented to illustrate the usefulness and capability of the model.

AHP Combined with Monte Carlo Simulation

Minchin et al. (2008) proposed a construction quality index for highway construction by combining AHP with Monte Carlo Simulation (MCS). The developed index addresses quality factors for the major components of pavement construction (e.g., rigid pavements, base course, embankment, subgrade, and flexible pavements). Weighting criteria representing the relative importance of construction quality metrics on pavement performance were established using AHP, while MCS predicted the pavement life.

Housing

Similar to the risk management area, all of the application cases identified in the area of housing involved integrated AHP approaches.

AHP Combined with Delphi and Analysis of Variance

Hyun et al. (2008) tackled performance evaluation of housing project delivery methods by combining the AHP and Delphi methods with an analysis of variance (ANOVA) test. This approach sought to devise objective standards and contents for quantitative evaluation of the impacts of project delivery methods on design performance in multifamily housing projects. First, AHP and a three-round Delphi were used to develop an evaluation standard and calculate the weights of different evaluation items. Second, an ANOVA test was performed to explore the influences of different project delivery methods on design performance.

AHP Combined with Sensitivity Analysis

Mahdi et al. (2006) used AHP to design a decision model for reducing the construction cost and waiting time caused by conflict encountered when economic versus quality decisions have to be made in selecting delivery alternatives for housing projects. The effects of different criteria on the selection of proper housing delivery alternatives were analyzed using AHP, after which sensitivity analysis (SA) was performed to investigate the sensitivity of the final decision to possible changes in judgments.

AHP Combined with Geographic Information System, Utility Theory, and Online Analytical Processing

Ahmad et al. (2004) created a decision support system for property developers and builders to tackle the problem of selecting the most appropriate site for residential housing development. The system was based upon an integration of AHP with GIS software, an online analytical processing (OLAP) concept, and the expected utility value theorem. The GIS software performed geographical analyses of the available sites; OLAP analysis was performed using AHP; and the expected utility value theorem was used to convert monetary values into equivalent utility functions. An application example was presented to exhibit the applicability of the decision support system.

AHP Combined with Mathematical Models

El-Anwar and Chen (2013) established a methodology for quantifying and minimizing the displacement distance equivalents for families that are assigned temporary housing following a natural disaster. The methodology used AHP and mathematical models (e.g., Haversine formula) to compute displacement distances.

Contractor Prequalification and Selection

Contractor prequalification is an important task in the field of CM. This task aims at selecting competent contractors for the bidding process. The identification of AHP applications in the contractor prequalification and selection area corroborates the viewpoint of Al-Harbi (2001) that AHP is a practical and effective decision-making tool to prequalify and select contractors.

Stand-alone AHP Studies

Abudayyeh et al. (2007) employed AHP to develop a decision-making tool for contractor prequalification. Specifically, the technique was used to find the relative weights of various prequalification criteria, which were subsequently used to rank contractors to select the top-ranked contractor for the project. Similarly, Topcu (2004) proposed an AHP-based decision model to prequalify and select contractors based on preference ranking.

Integrated Approaches

AHP Combined with Neural Network, Genetic Algorithm, and Delphi

El-Sawalhi et al. (2007) suggested a combination of AHP, neural network (NN), genetic algorithm (GA), and Delphi to analyze and improve the accuracy of contractor prequalification and selection. This hybrid approach was proposed mainly to offset the limitations of one technique with the strengths of others, and was used to collect the importance weights of prequalification criteria through a Delphi process.

AHP Combined with Sensitivity Analysis

El-Sayegh (2009) developed a multicriteria decision support model to assist owners/clients in selecting the most appropriate construction firm to deliver a project through the construction management at risk project delivery method. AHP was used to establish the decision criteria and compare candidate firms, while SA was used to determine the break-even or trade-off values among different firms.

Competitive Advantage

Stand-alone AHP Studies

Sha et al. (2008) used AHP within a bespoke system to define and measure competitiveness in the construction industry. The system can help construction enterprises better evaluate their overall performance and improve their competence. The indicators at the different levels of the system were weighted using AHP.

Integrated Approaches

AHP Combined with Cluster Analysis

Shen et al. (2006) established key competitiveness indicators for assessing contractor competitiveness. After formulating a list of contractor competitiveness indicators, a combination of AHP and cluster analysis (CA) was applied to determine the weights of project success criteria.

AHP Combined with Sensitivity Analysis and Delphi

Wu et al. (2007) adopted the modified Delphi method, AHP, and SA to present an AHP-based evaluation model for selecting the optimal location of hospitals. The modified Delphi method was applied to define the evaluation criteria and sub-criteria that were used to construct a hierarchy based upon which pairwise comparison matrices were established using AHP. SA was performed to examine the model's response to changes in the importance of the criteria. Hsu et al. (2008) also presented an optimal model to evaluate the resource-based allocation for enterprises who sought competitive advantage in the senior citizen housing sector. The modified Delphi method was adopted to accumulate and integrate expert opinions to devise the competitive advantage criteria before AHP was applied to determine the importance weight of each competitive advantage criterion.

DISCUSSION

This review illustrates that risk management and sustainable construction are the two most popular AHP application areas in CM. As Table 3 shows, risk management and sustainable construction had the highest number of papers on AHP applications (9 papers, 11.69%). While the risk management issues were primarily concerned with the effective identification, assessment, and allocation of risks, the sustainable construction issues focused on improving sustainable development decisions within the construction industry. It is not a surprise to find that risk management and sustainable construction problems attracted the greatest attention in AHP application within CM. Risk management and sustainable construction are probably the most delicate areas of CM, as their activities are likely to affect the well-being of humans, the environment, and the construction industry as a whole. The presence of risk events within the construction industry could impede the success of construction operations. Conversely, sound sustainable construction decisions could help enhance human health and the environment. Thus, the widespread application of AHP for integrated and holistic assessments toward risk management- and sustainable construction-related decisions is crucial.

AHP applications were also found in other important areas of CM, such as transportation (5 papers, 6.49%), housing (4 papers, 5.19%), contractor prequalification and selection (4 papers, 5.19%), competitive advantage (4 papers, 5.19%), plant and equipment management (3 papers, 3.90), building design (3 papers, 3.90) and dispute resolution (3 papers, 3.90). This suggests that AHP is practically applicable to decision-making problems in a broad range of CM areas. Generally, decision-making in the identified CM areas requires thorough analysis of multiple economic, social, environmental, and technical factors whose knowledge could be arduous to quantify and process. Moreover, a lack of objectivity is almost inevitable in these construction-related decision-making problems due to the need to consider subjective criteria. These may explain the reason why AHP has become popular and successful in CM. AHP can be used to validate subjective judgments and provide a high level of consistency.

This review not only demonstrates the usefulness and versatility of AHP and how it fits well into the nature of dealing with various construction-related decision-making problems, but it also demonstrates AHP's flexibility and simplicity of application. The review results suggest that AHP is useful and allows construction decision makers to implement it either as a stand-alone tool or integrate it with other advanced decision-making methods to ensure a more reliable decision-making process. Also, AHP (stand-alone and integrated) has frequently been used as a method to easily identify the most important aspects of construction-related decision problems, affirming its appropriateness for such problems. Other decision-making methods (e.g., the analytic network process (ANP) and DEA) might be useful for similar purposes, however, they are more stringent and time-consuming, giving AHP a significant advantage (Jato-Espino et al., 2014). For example, although ANP is considered a general form of AHP (Saaty, 1996), its ability to allow interdependencies among decision criteria makes it time-consuming and hence difficult to apply amongst busy practitioners or decision makers.

Regarding the nature of application, Table 3 shows that AHP was mainly applied in combination with other methods, with FSs being the most common method in the integrated AHP approaches. This could be attributed to the popular belief that AHP is incapable of handling the imprecision and uncertainty involved in construction decisions and hence combining it with FSs enhances its capability (Zadeh, 1965). The presence of many other methods (e.g., DEA, MCS, UT, LCCA, and MAUT) in the integrated AHP approaches further indicates that the integration of AHP with other methods can be implemented in many diverse ways to conform to the nature and environment of the construction decision problem. Consequently, it would be useful if researchers and practitioners continue to apply AHP to organize, analyze, and model complex construction decisions to develop more useful models to support decision-making in wide-ranging areas of CM.

When and Why to Use AHP

AHP can help researchers and practitioners explore multicriteria decisions. However, because of other alternative MCDM methods, the use of AHP often requires further justification as illustrated in some of the reviewed papers. Although this paper does not intend to provide an in-depth review of these justifications, a brief review of them could be useful for those interested in applying AHP inside and outside the CM field. Thus, the three most prominent justifications given within the extant literature reviewed are discussed below.

Small Sample Size

Small sample size can adversely affect several aspects of any research, including the data analysis and concomitant interpretation of results. The major advantage of AHP over other MCDM methods is that it does not require a statistically significant (large) sample size to achieve sound and statistically robust results (Doloi, 2008; Dias and Ioannou, 1996). Some researchers argue that AHP is a subjective method for research focusing on a specific issue, hence it is not necessary to employ a large sample (Lam and Zhao, 1998). Others argue that because AHP is based on expert judgments, judgments from even a single qualified expert are usually representative (Golden et al., 1989; Tavares et al., 2008; Abudayyeh et al., 2007). Moreover, it may be unhelpful to use AHP in a study with a large sample size because 'cold-called' experts are likely to provide arbitrary answers, which could significantly affect the consistency of the judgments (Cheng and Li, 2002). Much of the popularity of AHP in CM could be attributed to its ability to handle small sample sizes.

The extant literature on AHP applications in CM indicates that there is no strict requirement on the minimum sample size for AHP analysis. Some studies used sample sizes ranging from four to nine (Akadiri et al., 2013; Chou et al., 2013; Pan et al., 2012; Li and Zou, 2011; Dalal et al., 2010; Zou and Li, 2010; Pan, 2008; Lam et al., 2008; Hyun et al., 2008; Zhang and Zou, 2007). Only a few studies used sample sizes greater than 30 (El-Sayegh, 2009; Ali and Al Nsairat, 2009). These findings suggest that AHP can be performed with small sample size to achieve useful decision results and models, which often makes it a more preferred method in CM research than other MCDM methods. However, it is still imperative for researchers to treat the choice of AHP sample size with special attention, because the possible impact of an optimally selected sample size on the decision outcomes cannot be undermined.

High Level of Consistency

Although AHP has been criticized for incorporating subjective judgments into the decision-making process, it has been proved of decreasing bias and ensuring that subjective judgments are validated using consistency analysis (Saaty, 1980; Saaty and Vargas, 1991). Analysis of the reviewed papers showed that this is one of the most prominent reasons why researchers selected AHP (Hsu et al., 2008; Abudayyeh et al., 2007; Shapira and Goldenberg, 2005; Cheung et al., 2004). AHP is capable of using both subjective and objective data for proper decision-making. This capability makes AHP important for construction-related decision-making, as subjective judgments from different experts form a crucial part of construction decision-making (Hsu et al., 2008). This review suggests that in construction-related decision-making, AHP can help ensure a high level of consistency among the judgements obtained from multiple experts who might have different perceptions, experiences, and understanding of the decision criteria. This paper argues that if the reliability of decision results matters, then the consistency of expert judgments also matters.

Simplicity and User-Friendly Software

Other prominent reasons stated for using AHP relate to its simplicity of implementation and the availability of user-friendly software, Expert Choice, for analyzing AHP data (El-Anwar and Chen, 2013; Hsu et al., 2008; El-Sawalhi et al., 2007; Ahmad et al., 2004; Topcu, 2004; Cheung et al., 2004). These aforementioned researchers argue that AHP helps to easily and effectively break down a complex construction decision problem into a hierarchy that provides a deeper understanding of all the criteria involved. Using this hierarchy, decision makers are able to pairwise compare the criteria, rather than assess the relative importance of the large number of tangible and intangible criteria simultaneously. This provides a structured and analytic, yet simple approach that does not require any special skills from the decision makers to determine the best solution.

FUTURE AHP APPLICATIONS IN CM

Reviewing the literature revealed that AHP has not been extensively applied in certain areas of CM and hence warrants future research attention. In this study, any CM area where only one paper on AHP application was found is considered as an area requiring additional attention in the future AHP applications; albeit areas with more than one paper may also require additional investigation. As shown in Table 3, CM decision areas where only one paper applying AHP was found include, but not limited to, quality management, knowledge management, planning and scheduling, pricing, and bidding of construction operations. This implies that more AHP applications in modeling and improving different types of decisions in these areas of CM are required.

In the area of quality management, for example, only one related AHP study was found (Lam et al., 2008). Yet, quality is a critical issue for almost all construction stakeholders and one of the key criteria for measuring project success in construction. Thus, more AHP applications in analyzing quality management decisions are needed. Future research could expand on the work of Lam et al. (2008) in order to develop more decision support systems to help solve quality problems in construction projects. The development of such decision support systems should focus on incorporating and assessing not only criteria that can help achieve better quality, but also those that can help attain higher client satisfaction and higher productivity. Quality, client satisfaction, and productivity are key issues that can directly affect the overall project success (Lam et al., 2008). Furthermore, future AHP applications could focus on developing quality performance measurement models to help assess and measure the quality performance of different stakeholders within the construction industry. As Lam et al. (2008) mentioned, their developed self-assessment quality management system is a “tailor-made” system for Hong Kong contractors to assess and improve their quality performance. Hence, there is scope to develop AHP-based quality measurement models/systems for international contractors and other construction stakeholders to improve their quality performance.

Knowledge management represents another promising direction for future AHP applications in CM. Knowledge management is about creating value from the intangible assets of an organization and facilitating knowledge sharing and integration (Alavi and Leidner, 1999). Over the last two decades, knowledge management has received increasing attention from practitioners; consequently, many organizations and individuals have developed multiple frameworks for knowledge management in different industries (Rubenstein-Montano et al., 2001). Undoubtedly, many construction organizations lack such frameworks. Accordingly, future AHP applications could focus on developing knowledge management frameworks for identifying the processes, mechanisms, cultures, and technologies essential for implementing knowledge strategies in construction organizations. Such frameworks can assist construction organizations leverage knowledge both inside their organizations and externally among their shareholders and customers (Rubenstein-Montano et al., 2001). Although future AHP applications are needed in many other areas of CM (Table 3), the above discussion is limited to quality management and knowledge management because of brevity.

LIMITATIONS OF THIS STUDY

This study forms the initial phase of a literature study that has been initiated to fully review the AHP application in CM from different perspectives. This research identifies the AHP application areas in CM, but does not present application examples to illustrate how AHP can be used 'step-by-step' to address specific problems within the identified areas. However, the papers reviewed provide a useful reference point to understand how AHP was used to tackle specific problems. In addition, future review will include papers published beyond 2014 and use software tools such as *VOSviewer* (Centre for Science and Technology Studies, 2018) to construct bibliometric networks to better understand the literature. Moreover, although it was relatively straightforward to use the topic coverage of the reviewed papers to identify and categorize AHP application areas in CM, the process was largely dependent on the authors' subjective judgments. Finally, research is needed to differentiate between AHP and other MCDM methods through comparing their merits and demerits to determine which methods are superior to the others in various CM circumstances (c.f. Arroyo et al., 2014).

CONCLUSIONS

AHP has become a popular method for organizing, analyzing, and modeling complex decisions within the CM field. This paper attempted to review AHP application in CM so as to improve understanding of the decision areas and decision problems that AHP could efficiently resovle. The paper's objectives were to: summarize existing literature related to AHP applications in CM; identify the popular AHP application areas and problems; and provide directions for future AHP application. To achieve these objectives, 77 relevant AHP-based papers published in eight selected peer-reviewed CM journals from 2004 to 2014 were identified through a systematic desktop search and reviewed.

The findings revealed that risk management and sustainable construction were the most popular AHP application areas in CM. In addition, it was identified that AHP is flexible and can be used as a stand-alone tool or in conjunction with other tools to rigorously tackle construction-related decision-making problems. Moreover, a descriptive analysis of the reviewed papers showed a wide application of AHP in Asia. Reasons behind the wide adoption of AHP are that it does not require large sample size, it can achieve a high level of consistency, and it is easy to implement. Based upon the findings presented, directions for future AHP applications were proposed. To summarize, the findings suggested that AHP (whether stand-alone or integrated) can help researchers and practitioners address a variety of decision-making problems that matter. As such, construction researchers, practitioners, and institutions are advised to consider AHP applications when the need to analyze multicriteria decisions in wide-ranging areas of CM arises.

This paper could be useful for researchers and practitioners interested in the application of AHP to analyze and model construction decisions. For researchers, this paper provides a comprehensive review of past AHP-based studies in CM, which is necessary for conducting future studies. In addition, this paper could help practitioners better understand and judge the usefulness of AHP in tackling specific decision-making problems in CM, which could encourage its wider use in CM. Notably, decision support systems and models developed for the construction industry are myriad as a result of AHP usage. However, practitioners may not find it easy to locate these systems and models, as they are scattered throughout the extant literature. With the help of this review paper, practitioners could readily become familiar with the potentially useful decision support systems and models, which in turn might trigger attempts to use them in practice.

DISCLOSURE STATEMENT

The authors report no potential conflict of interest.

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Tables

Table 1. AHP pairwise comparison scale.

Weight	Definition
1	Equal importance
3	Weak importance of one over other
5	Essential or strong importance
7	Very strong importance
9	Absolute importance
2,4,6,8	Intermediate values between the two adjacent judgments
Reciprocals of previous values	If factor *"i"* has one of the previously mentioned numbers assigned to it when compared to factor *"j"*, then *j* has the reciprocal value when compared to *i*.

Table 2. Number of papers from selected journals.

No.	Name of Journal	Number of papers	Percentage
1	ASCE Journal of Construction Engineering and Management (JCEM)	25	32
2	Automation in Construction (AIC)	13	17
3	Building and Environment (BE)	10	13
4	Construction Management and Economics (CME)	9	12
5	ASCE Journal of Management in Engineering (JME)	8	11
6	International Journal of Project Management (IJPM)	5	6
7	Engineering, Construction and Architectural Management (ECAM)	5	6
8	Building Research and Information (BRI)	2	3
Total		77	100

Table 3. Summary of applications of AHP in construction management.

Decision areas	Decision problems	Author(s)	Year	Other methods
Risk management (9 papers, 11.69%)	Decision making for balanced risk allocation selection	Khazaeni, G., Khanzadi, M., and Afshar, A.	2012	Fuzzy sets theory; Delphi
	Assessment of the risk condition in the construction industry	Subramanyan, H., Sawant, P.H., and Bhatt, V.	2012	Fuzzy sets theory
	Improving risk assessment accuracy in PPP projects	Li, J., and Zou, P.X.W.	2011	Fuzzy sets theory
	Exploring a knowledge extraction method through the establishment of project risk ontology	Tserng, H.P., Yin, S.Y.L., Dzeng, R.J., Wou, B., Tsai, M.D., and Chen, W.Y.	2009	Ontology
	Appraising risk environment of joint venture (JV) projects to support rational decision-making	Zhang, G., and Zou, P.X.W.	2007	Fuzzy sets theory
	Decreasing the risk of JVs in China for global contractors	Hsueh, S.L., Perng, Y.H., Yan, M.R., and Lee, J.R.	2007	Utility Theory
	Improving project risk assessment for coping with risks in complicated construction situations	Zeng, J., An, M., and Smith, N.J.	2007	Fuzzy reasoning techniques
	Enhancing risk management through effective decisions and proactive corrective actions	Abdelgawad, M., and Fayek, A.R.	2010	Fuzzy logic; FMEA
	Facilitating the identification and assessment of risk at the initial stage of subway projects	Zou, P.X.W., and Li, J.	2010	Fuzzy sets theory
Sustainable or green construction (9 papers, 11.69%)	Lifecycle assessment of economic and environmental sustainability of highway designs	Lee, J., Edil, T.B., Benson, C.H., and Tinjum, J.M.	2013	LCA; LCCA
	Sustainable building materials selection	Akadiri, P.O, Olomolaiye, P.O., and Chinyio, E.A.	2013	Fuzzy sets theory
	Achieving more informed corporate decisions regarding the management of sustainable technologies	Pan, W., Dainty, A.R.J., and Gibb, A.G.F.	2012	TDR; BDR; PA method
	Analysis of influential location factors of sustainable industrial areas	Ruiz, M.C., Romero, E., Pérez, M.A., and Fernández, I.	2012	GIS software; NetWeaver
	Sustainability enhancement of integrated housing recovery efforts after natural disasters	El-Anwar, O., El-Rayes, K., and Elnashai, A.S.	2010	Mixed functional (mathematical) equations
	Exploring and prioritizing key performance indicators (KPIs) for assessing sustainable intelligent buildings	ALwaer, H., and Clements-Croome, D.J.	2010	-
	Maximizing infrastructure system decision-making to maximize economic, social, and environmental benefits to stakeholders	Mostafa, M.A., and El-Gohary, N.M.	2014	Social welfare function
	A green building assessment tool development	Ali, H.H., and Al Nsairat, S.F.	2009	-

	Improving the performance of indoor environmental quality of residential buildings	Lai, J.H.K., and Yik, F.W.H.	2009	-
Transportation (5 papers, 6.49%)	Developing a bridge health index (BH) for optimum allocation of resources for maintenance actions	Wakchaure, S.S., and Jha, K.N.	2012	-
	Evaluating the efficiency of and improving fund allocation for bridge maintenance	Wakchaure, S.S., and Jha, K.N.	2011	DEA
	Appropriate bridge construction method selection	Pan, N.F.	2008	Fuzzy sets theory
	Prioritizing rural roads for funds allocation	Dalal, J., Mohapatra, P.K.J., and Mitra, G.C.	2010	-
	To develop an effective and practical quality index for highway construction	Minchin, R.E., Hammons, M.I., and Ahn, J.	2008	MCS
Housing (4 papers, 5.19%)	Helping developers to select appropriate sites for residential housing development	Ahmad, I., Azhar, S., and Lukauskis, P.	2004	OLAP; GIS; Utility Theory
	Exploring mass housing and its conflicts during the production process	Mahdi, I.M., Al-Reshaid, K., and Fereig, S.M.	2006	SA
	Design performance level evaluation for quantitative evaluation of quality performance in housing projects	Hyun, C., Cho, K., Koo, K., Hong, T., and Moon, H.	2008	Delphi; ANOVA
	Optimization in temporary housing projects	El-Anwar, O., and Chen, L.	2013	Haversine formula
Contractor prequalification and selection (4 papers, 5.19%)	An advanced model for contractor prequalification and selection	El-Sawalhi, N., Eaton, D., and Rustom, R.	2007	NN; GA; Delphi
	Facilitating effective decision-making in selecting highway construction contractors	Abudayyeh, O., Zidan, S.J., Yehia, S., and Randolph, D.	2007	-
	Assisting owners' decisions in selecting contractors for construction management at risk projects	El-Sayegh, S.M.	2009	SA
	A decision support system for contractor selection in Turkey	Topcu, Y.I.	2004	-
Competitive advantage/competitiveness assessment	Measuring the competitiveness of construction enterprises	Sha, K., Yang, J., and Song, R.	2008	-
(4 papers, 5.19%)	Key competitiveness indicators (KCIs) for evaluating contractor competitiveness	Shen, L.Y., Lu, W.S., and Yam, M.C.H.	2006	Cluster analysis
	Increasing the competitive advantage of hospitals through optimal location selection	Wu, C.R., Lin, C.T., and Chen, H.C.	2007	SA; Delphi
	Increasing the competitive advantage of enterprises in senior citizen housing industry	Hsu, P.F., Wu, C.R., and Li, Z.R.	2008	Delphi
Plant and equipment management	Enhancing equipment selection decisions	Goldenberg, M., and Shapira, A.	2007	-
(3 papers, 3.90%)	Enhancing equipment selection decisions	Shapira, A., and Goldenberg, M.	2005	-

	Evaluation and selection of concrete pumps for a project	Tam, C.M., Tong, T.K.L., and Wong, Y.W.	2004	SIR method
Building design (3 papers, 3.90%)	Improving decision-making at the early stage of the design process	Schade, J., Olofsson, T., and Schreyer, M.	2011	MAUT
	Provision of a decision support environment for evaluating and selecting design alternatives	Cariaga, I., El-Diraby, T., and Osman, H.	2007	FAST; QFD; DEA
	Improving design decisions to affect building performance	Hopfe, C.J., Augenbroe, G.L.M., and Hensen, J.L.M.	2013	Simulation
Dispute resolution (3 papers, 3.90%)	Exploring key features of alternative dispute resolution (ADR) for effective implementation	Cheung S.O., Suen, H.C.H., Ng, S.T., and Leung, M.Y.	2004	-
	Helping parties to significantly analyze issues in a conflict more logically	Al-Tabtabai, H.M., and Thomas, V.P.	2004	-
	Selection of dispute resolution methods for international construction projects	Chan, E.H.W., Suen, H.C.H., and Chan, C.K.L.	2006	MAUT
Health and safety management (2 papers, 2.60%)	Measurement and evaluation of crane-related safety hazards on construction sites	Shapira, A., and Simcha, M.	2009	Probabilities
	Computation of overall index for realistic reflection of site safety levels due to tower crane operations	Shapira, A., Simcha, M., and Goldenberg, M.	2012	-
Construction productivity (2 papers, 2.60%)	Predicting the impact of a technology on productivity	Goodrum, P.M., Haas, C.T., Caldas, C., Zhai, D., Yeiser, J., and Homm, D.	2011	Historical analysis
	Exploring and assessing factors that have impact on workers' productivity improvement	Doloi, H.	2008	SA
Project delivery systems selection (for projects in general) (2 papers, 2.60%)	Assisting owners to make effective decisions in the selection of optimal project delivery systems	Mafakheri, F., Dai, L., Slezak, D., and Nasiri, F.	2007	Linear programming
	Assisting decision makers to select the most suitable delivery method for their projects	Mahdi, I.M., and Alreshaid, K.	2005	SA
Office projects delivery (2 papers, 2.60%)	Classifying offices for reliable practitioners' assessment	Daud, M.N., Adnan, Y.M., Mohd, I., and Aziz, A.A.	2011	-
	Selection of planning and design alternatives for public office projects	Hsieh, T.Y., Lu, S.T., and Tzeng, G.H.	2004	Fuzzy sets theory
Facilities management (2 papers, 2.60%)	Evaluation of facility management services buildings	Lai, J.H.K., and Yik, F.W.H.	2011	-
	Assisting complex decision-making in building maintainability (BM).	Das, S., Chew, M.Y.L., and Poh, K.L.	2010	-
Fire safety management (2 papers, 2.60%)	Optimal selection of fire origin room (FOR)	Tavares, R.M., Tavares, J.M.L., and Parry-Jones, S.L.	2008	-
	Fire safety evaluation of existing hotel buildings	Chen, Y.Y., Chuang, Y.J., Huang, C.H., Lin, C.Y., and Chien, S.W.	2012	-

Contractor performance evaluation (at company level) (2 papers, 2.60%)	Classifying contractors and assessing their performance using proper measures	Nassar, K., and Hosny, O.	2013	Fuzzy clustering
	Assessing and comparing the performance of construction companies	Yu, I., Kim, K., Jung, Y., and Chin, S.	2007	Performance scores; coefficient of variance
Procurement/purchasing[a]	Enhancing purchasing strategies in construction companies	Arantes, A., Ferreira, L.M.D.F., and Kharlamov, A.A.	2014	KPM; MDS; linear transformation
Bidding[a]	Improving bidding strategies of construction firms and supporting bid or no bid decisions	Chou, J.S., Pham, A.D., and Wang, H.	2013	Fuzzy sets theory; MCS
Planning and scheduling[a]	Scheduling multiple projects with competing priorities in the face of organizational constraints	Goedert, J.D., and Sekpe, V.D.	2013	-
Information management[a]	Knowledge sharing and supporting decisions relating to route selection for buried urban utilities	Osman, H.M., and El-Diraby, T.E.	2011	Ontology modelling approach; fuzzy inference system
Earned value management[a]	Providing project managers with a system to assess project performance and monitor progress	Chou, J.S., Chen, H.M., Hou, C.C., Lin, C.W.	2010	MCS
Benchmarking[a]	How to determine the most suitable process to benchmarked company	Cheng, M.Y., Tsai, M.H., and Sutan, W.	2009	Semantic similarity analysis; trend model method
Quality management[a]	Helping contractors to solve quality problems	Lam, K.C., Lam, M.C.K., and Wang, D.	2008	Fuzzy sets theory
Knowledge management[a]	Assisting organizations in determining their achievement levels towards a learning culture	Chinowsky, P.S., Molenaar, K., and Bastias, A.	2007	-
International expansion[a]	Company executives' decisions to enter into international markets or not; evaluation of key decision factors	Gunhan, S., and Arditi, D.	2005	-
Contractors' self-performance measurement (at project level)[a]	Assisting contractors to measure their performance in relation to critical project objectives during the construction phase	Nassar, N., and AbouRizk, S.	2014	-
Earthmoving projects delivery[a]	Determination of optimal layout of a haul route for large-scale earthmoving projects	Kang, S., and Seo, J.	2013	Least-cost path analysis; Linear interpolations; Linguistic evaluations
High-rise building[a]	Improving the set-based design (SBD) procedure for high-rise building construction through effective selection of alternatives	Lee, S.I., Bae, J.S., and Cho, Y.S.	2012	S-BIM
Pricing[a]	Supporting decisions for the selection of appropriate pricing system for a project	Kaka, A., Wong, C., and Fortune, C., and Langford, D.	2008	-
Public projects delivery[a]	Procedural determination of budgets for government projects	Lai, Y.T., Wang, W.C., and Wang, H.H.	2008	Simulation
Build-operate-transfer (BOT) infrastructure projects[a]	Evaluation of critical decision/success factors of BOT projects	Salman, A.F.M., Skibniewski, M.J., and Basha, I.	2007	-

Value engineering[a]	Identification of the most leveraging features of a project	Cha, H.S., and O’Connor, J.T.	2006	Fuzzy sets theory; mathematical equations
Value enhancement in crucial decisions[a]	Analysis and evaluation of various aspects of decision making in subway construction in Barcelona	Ormazabal, G., Viñolas, B., and Aguado, A.	2008	Value functions
Design of ETO (Engineer-To-Tender) products[a]	Exploring approaches to better support ETO product design process	Pandit, A., and Zhu, Y.	2007	Ontology approach; process models
Drilling; differential settlement[a]	Understanding the effects of construction factors on the development of surface heave during installation of horizontal directional drilling (HDD)	Lueke, J.S., and Ariaratnam, S.T.	2005	Factorial experiment

Note: [a] Decision areas with one paper on AHP application, representing 1.30% of the total sample; S-BIM = Structural building information modelling; MAUT = Multi-attribute utility theory; SA = Sensitivity analysis; ANOVA = Analysis of variance; FAST = Functional analysis system technique; QFD = Quality function deployment; DEA = Data envelopment analysis; SIR = Superiority and inferiority ranking; OLAP = Online analytical processing; GIS = Geographical information system; LCA = Life-cycle assessment; LCCA = Life-cycle cost analysis; TDR = Top-down direct rating; BDR = Bottom-up direct rating; PA = Point allocation; FMEA = Failure mode and effect analysis; KPM = Kraljic purchasing portfolio matrix; MDS = multidimensional scaling; MCS = Monte Carlo simulation; NN = Neural Network; and GA = Genetic Algorithm.

Table 4. Country-wise application of AHP.

No.	Country	Number of papers
1	US	11
2	Taiwan	10
3	UK	8
4	Hong Kong	6
5	Korea	6
6	China	6
7	Canada	5
8	India	4
9	Israel	4
10	Kuwait	3
11	Spain	2
12	United Arab Emirates	2
13	Egypt	1
14	Saudi Arabia	1
15	Portugal	1
16	Singapore	1
17	Sweden	1
18	Australia	1
19	Malaysia	1
20	Iran	1
21	Jordan	1
22	Turkey	1

Figures

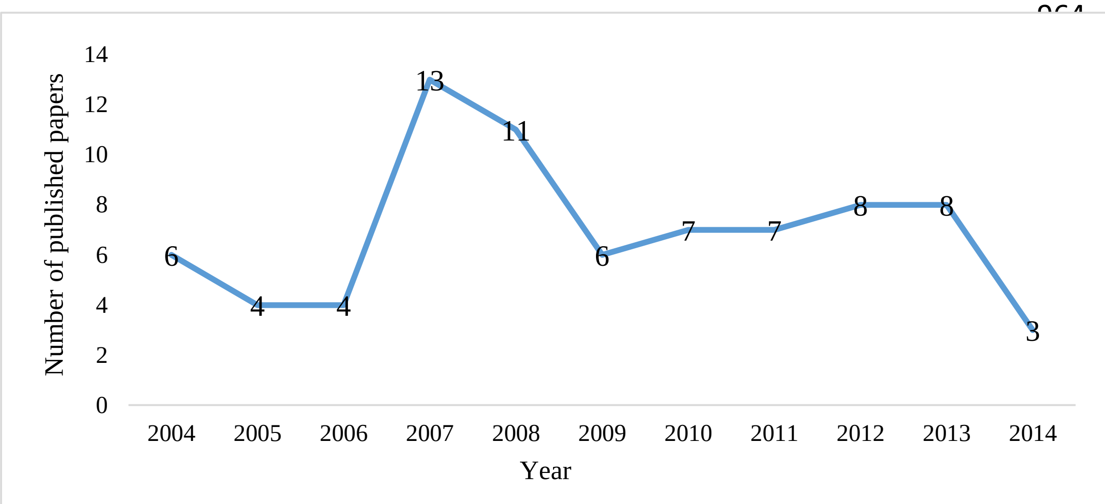

Fig. 1. Year-wise distribution of the reviewed AHP-based papers.

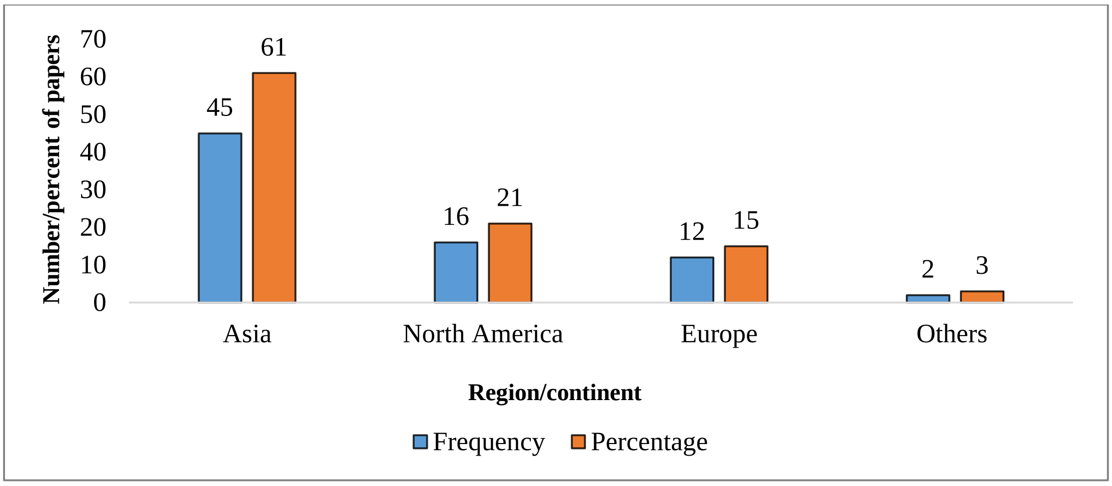

Fig. 2. Region-wise application of AHP.

REVIEW OF APPLICATION OF ANALYTIC HIERARCHY PROCESS (AHP) IN CONSTRUCTION

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ABSTRACT

The analytic hierarchy process (AHP) has gained increasing attention in construction management (CM) domain as a technique to analyze complex situations and make sound decisions. However, AHP *per se* or its potential applications on CM problems are ill-defined within extant literature. The present paper reviews 77 AHP-based papers published in eight selected peer-reviewed CM journals from 2004 to 2014 to better define and delineate AHP application areas and decision-making problems solved within CM. The findings indicated that risk management and sustainable construction were the most popular AHP application areas in CM. It was also revealed that AHP (1) is flexible and can be used as a stand-alone tool or in conjunction with other tools to resolve construction decision-making problems; and (2) is widely used in Asia. In addition, the most prominent justifications for using AHP were found to be small sample size, high level of consistency, simplicity and availability of user-friendly software. This paper provides a useful reference for researchers and practitioners interested in the application of AHP in CM. Future research is needed to compare and contrast between

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AHP and other multicriteria decision-making methods; such work could reveal which techniques provide optimized solutions under various decision-making scenarios.

KEYWORDS

Analytic hierarchy process (AHP); Multicriteria decision-making; Application; Construction management; Literature review.

INTRODUCTION

Decision-making is defined as the process of determining the best alternative among all possible choices but in practice, achieving an optimized result can be problematic as decision makers are often confronted with various decision-making problems (Angelis and Lee, 1996). Multicriteria decision-making (MCDM) is one of the most important branches of decision theory and is used to identify the best solution from all possible solutions available (Huang et al., 2015; Işıklar and Büyüközkan, 2007). Several methods have been developed to enable improvements in MCDM, including: analytic hierarchy process (AHP) (Saaty, 1980); superiority and inferiority ranking (SIR) technique (Xu, 2001); Simos' ranking method (Marzouk et al., 2013); multi-attribute utility theory (MAUT) (Chan et al., 2001); elimination and choice corresponding to reality (ELECTRE) (Roy, 1991); preference ranking organization method for enrichment evaluations (PROMETHEE) (Brans et al., 1986); and choosing by advantages (CBA) (Suhr, 1999). These MCDM methods are frequently used to facilitate the resolution of real-world decision-making problems.

Saaty's (1980) AHP represents a popular MCDM method that has attracted considerable attention throughout industry, including construction, over the past two decades. Construction decision-making problems in particular, have been characterized as being complex, ill-defined and uncertain (Chan et al., 2009). Al-Harbi (2001) further suggests that elements of construction-related decision-making problems are numerous and that the interrelationships between these elements are complicated and often nonlinear. Consequently, the ability to make sound decisions is crucial to the success of construction activities and operations. AHP provides a powerful means of making strategic and sound construction decisions (Jato-Espino et al., 2014); it allows decision makers to employ multiple criteria in a quantitative manner to evaluate potential alternatives and then select the optimal option.

Because of AHP's inherent ability to deal with various types of decisions, it has been widely applied in construction management (CM) research over the past two decades (Nassar and AbouRizk, 2014; Akadiri et al., 2013; Ruiz et al., 2012; Zou and Li, 2010; Chan et al., 2006). However, there has been a notable dearth of comprehensive reviews of AHP applications within the CM domain with Jato-Espino et al.'s (2014) study of 22 different MCDM methods representing a rare exception. At present, no review has specifically focused on AHP applications in CM. This paper aims to fill this void and provide a deeper understanding of the decision areas and decision problems that AHP could efficiently deal with. Concomitant objectives are to: summarize the existing literature related to AHP applications in CM; identify the popular AHP application areas and problems; and provide directions for future AHP application. To achieve these objectives, 77 relevant AHP-based papers published in eight selected peer-reviewed CM journals from 2004 to 2014 were identified through a systematic desktop search and reviewed. This paper provides a useful reference for researchers and practitioners interested in the application of AHP to analyze and model construction-related decisions. AHP decision support systems and models developed for the construction industry are myriad and scattered throughout the existing literature. Researchers and practitioners may experience some difficulty locating these systems and models, hence this paper will provide clear signposting to potentially useful decision support systems and models, which in turn may trigger greater usage in practice.

AHP DECISION-MAKING METHOD

AHP was created by Saaty (1980) to deal with decision-making problems in complex and multicriteria situations (c.f. Dyer and Forman, 1992; Saaty, 1990). Therefore, this research is not concerned with explicating specific details about the method but rather the basic concepts of it. AHP assists in making decisions that are characterized by several interrelated and often competing criteria, and it establishes priorities amongst decision criteria when set within the context of the decision goal (Shapira and Goldenberg, 2005). A key aspect is that decision criteria are assessed with respect to their relative importance in order to allow trade-offs between them.

The AHP consists of three steps: (1) *hierarchy formation* – the first level of the hierarchy contains the decision goal, whereas the subsequent lower levels represent the progressive breakdown of the decision criteria, sub-criteria, and the alternatives for reaching the decision goal; (2) *pairwise comparisons* – decision makers (who are often domain experts) are asked to complete pairwise comparisons of the elements at each level of the hierarchy, assuming the elements are independent of each other. In this regard and considering the decision goal, comparisons are made between the relative importance of every two criteria at the second level of the hierarchy. Every two sub-criteria under the same criterion (at level two) are also compared, and so on and so forth. These pairwise comparisons are often based on a nine-point scale, as shown in Table 1 (Saaty, 1980); and (3) *verification of consistency* – expert judgments are necessary for determining the relative importance of each criterion and any alternative to achieving the decision goal. Because AHP allows subjective judgments by decision makers, consistency of the judgments is not automatically guaranteed. Therefore, consistency verification is essential to ensuring optimized outcome. Saaty (2000) mentioned that to control the consistency of pairwise comparisons, a computation of consistency ratio should be performed. At this stage, decision makers are required to revise their initial judgments if the computed consistency ratio exceeds the threshold of 0.1 (Saaty, 2000). After all of the necessary pairwise comparisons, and revisions have been made, and the consistency ratio has also been found to be less than 0.1, the judgments can then be synthesized to prioritize the decision criteria together with their corresponding sub-criteria.

[Insert Table 1 about here]

RESEARCH METHODOLOGY

The present study was based upon the AHP literature published in eight selected CM journals from 2004 to 2014. These journals were: (1) *ASCE's Journal of Construction Engineering and Management (JCEM);* (2) *Automation in Construction (AIC);* (3) *Construction Management and Economics (CME);* (4) *ASCE's Journal of Management in Engineering (JME);* (5) *International Journal of Project Management (IJPM);* (6) *Engineering, Construction and Architectural Management (ECAM);* (7) *Building and Environment (BE);* and (8) *Building Research and Information (BRI*). The first six journals were deemed to be high quality based on Chau's (1997) ranking of CM journals, while the last two journals are widely regarded as top-quality journals in CM (Chan et al., 2009). Major search engines such as ASCE Library, Science Direct, Taylor and Francis, and Emerald were used to search for the keyword *"analytical hierarchy process"* in the advanced search section of the selected journals. An initial search conducted was limited to papers published from 2004 to 2014 and resulted in the identification of 194 research papers. However, not all of these papers used AHP as a primary or secondary decision-making tool as some simply mentioned AHP in the literature review and/or recommended its application for future research. A review of each paper's contents was then undertaken to filter out unrelated papers; 77 papers were eventually considered valid for further analysis. Table 2 shows the number of relevant papers collected from each of the selected journals. It reveals that 25 of the papers were from JCEM, 13 were from AIC, 10 were from BE and nine were from CME, in total representing 74% of the sample. The remaining papers were distributed across the other four journals.

[Insert Table 2 about here]

The next sections offer an overview of the benefits of applying AHP to construction-related decision-making problems, identifying the specific decision areas and decision problems to which AHP could be applicable or useful. Moreover, a concise review of the literature (based on the top six identified decision areas) is provided to demonstrate the versatility and worth of AHP in diverse construction situations. Where applicable, the application cases reviewed in a certain decision area are divided into stand-alone and integrated approaches – depending upon whether the AHP was used in a particular case as a sole method or in combination with other notable methods. This approach will help to elucidate upon the inherent flexibility of AHP in terms of combining it with other methods to analyze and model construction-related decisions.

REVIEW OF AHP APPLICATIONS IN CM

Identification of Decision Areas and Decision Problems

As the most commonly used MCDM method, AHP attracts the most attention from decision makers because of the availability of extensive literature on its application (Jato-Espino et al., 2014). It is thus essential to better understand the specific decision problems that AHP can resolve. Such an understanding would greatly stimulate interest in AHP applications within the wider areas of CM.

Table 3 presents all of the 77 identified papers and provides a quick reference guide and meaningful information about the applications of AHP in CM. The table was developed based on information extracted from the reviewed papers. First, the papers' research interests/ topics aided the identification of the decision areas. Based upon this, AHP has been found to be applicable to many different areas of CM. Second, the papers' research aims/ objectives presented the decision problems that AHP was used to address. This showed that AHP has been applied to numerous construction-related decision-making problems. These findings suggest that AHP is useful in enabling strategic and sound decision-making in a wide range of CM areas, which is consistent with the viewpoint of Jato-Espino et al. (2014). Following the identification of the decision areas and problems, the reviewed papers were then grouped, based upon the decision problems, under the decision areas. Each paper was assigned to only one decision area, thus if a paper appears to have multiple research interests [e.g., Lai and Yik's (2009) paper addressed both sustainability and housing/residential building issues], it was assigned to the best-fit decision area, as suggested by Hong et al. (2012). Although deciding on the best-fit decision area for a paper may seem subjective and associated with some level of uncertainty, it is believed that variations were minimized. Lastly, the authors and years of publication of the reviewed papers, and other methods combined with AHP in some of the papers are also presented in the table.

[Insert Table 3 about here]

Descriptive Analysis

A descriptive analysis of the papers was also undertaken to illustrate insightful trends in the application of AHP in CM. Of the 77 papers, 14 papers were published in the years before 2007 and during 2007, a peak of 13 papers was evident (Fig. 1) which appears to be a purely random occurrence given a lack of any 'special issue' that could easily explain it. In recent years (2009 to 2013), relatively stable trend was observed with an average of seven papers published every year – however, in 2014 this trend significantly reduced. This outcome might be because many more MCDM methods have emerged in recent years, giving the AHP tight competition in terms of MCDM methods application.

[Insert Fig. 1 about here]

With regard to geographical origins, the US and Taiwan accounted for the highest number of AHP-based papers published with 11 and 10 papers, respectively, as shown in Table 4. This finding suggests that the application of AHP in CM within these two developed countries is relatively more mature than that in other countries. Although some developing countries, such as China (6 papers) and India (4 papers), have made good progress in the application of AHP in CM, there are still opportunities to conduct more studies.

[Insert Table 4 about here]

Finally, the papers were also viewed from a regional perspective. Fig. 2 shows that there is a relatively large number of AHP applications in Asia (45 papers, 61%) – a finding that concurs with the earlier research of Jato-Espino et al. (2014). In light of the extent of construction development in many Asian countries, it could be that the wide application of AHP in enhancing construction decisions has been significantly helpful. This wide usage of AHP in Asia should encourage other regions outside Asia to pursue AHP application in CM.

[Insert Fig. 2 about here]

AHP APPLICATIONS IN IDENTIFIED CM AREAS

Table 3 summarizes the AHP literature relating to CM and reveals that risk management, sustainable construction, transportation, housing, contractor prequalification and selection, and competitive advantage were the top six application areas. Papers in these areas used AHP explicitly for different applications and so each area will now be discussed in further detail.

Risk Management

Risk management is a major CM area comprising defects, misalignments, and crises that can lead to inflated risks, project conflicts, and other negative performance outcomes (Zheng et al., 2016). Risk management decisions are often made using multiple criteria. Interestingly, all the AHP applications within the risk management area involved integrated approaches to combine AHP with other techniques.

AHP Combined with Fuzzy Sets Theory

Subramanyan et al. (2012) designed a model for construction project risk assessment by using a combination of fuzzy sets theory (FSs) and AHP. During the process of designing the model, FSs was used to capture both subjectivity and linguistic terms, while AHP was applied to weight and prioritize various risk factors. Li and Zou (2011) also developed a FSs-AHP-based risk assessment method for improving the accuracy of project risk assessment. FSs-AHP was used to pairwise compare between different risk criteria – after which the pairwise comparisons were synthesized to obtain risk priorities. Li and Zou (2011) proved the validity of this FSs-AHP-based method to assess risks in public-private partnership (PPP) projects, by exhibiting its applicability in an actual PPP expressway project. Other applications of FSs-AHP in the area of risk management were presented by Zhang and Zou (2007), Zeng et al. (2007), and Zou and Li (2010).

AHP Combined with Fuzzy Sets Theory and Delphi

Khazaeni et al. (2012) used FSs-AHP together with the Delphi method to resolve the problem of unbalanced allocation of risks among contracting parties. Specifically, the fuzzy adaptive decision-making model presented (*ibid*) was used to select the most appropriate allocation of risks among contracting parties. FSs was used in the model for the quantification and reasoning of linguistic principles. A Delphi team consisting of subject matter experts was employed to pairwise compare various risk allocation criteria using fuzzy values. FSs-AHP was then used to derive priority weights for the risk allocation criteria.

AHP Combined with Fuzzy Sets Theory and Failure Mode and Effect Analysis

Failure mode and effect analysis (FMEA) is a useful risk analysis technique, although it has some limitations. Abdelgawad and Fayek (2010) combined FSs-AHP and FMEA with the aim to overcome the limitations of the traditional FMEA-based risk management in CM. Their work (*ibid*) formed a model for assessing the criticalities of construction risk events and recommending corrective measures. A case study was presented, which confirmed the applicability and usefulness of this approach in providing valid and reliable risk management results.

AHP Combined with Utility Theory

Hsueh et al. (2007) applied a combination of AHP and utility theory (UT) to develop a multicriteria risk assessment model for contractors to reduce risks in joint ventures. AHP was first used to weight a set of risk criteria. Utility functions were then used to convert risks into numerical rates for ascertaining the expected utility values of various scenarios.

AHP Combined with Ontology

Tserng et al. (2009) explored an approach for conducting knowledge extraction by the establishment of an ontology-based risk assessment framework for enhancing risk management in building projects. In developing the framework, risk class and subclass weights were established, which was achieved by using AHP to capture experts' assessment of the risks. Subsequent application in a real project indicated that the framework greatly increased the effectiveness and efficiency of the project risk management plan.

Sustainable Construction

Sustainable construction represents another popular area of AHP application in CM. In this area, both stand-alone and integrated AHP applications were identified.

Stand-alone AHP Studies

Ali and Al Nsairat (2009) used AHP to develop a green building rating tool. After identifying the green building assessment criteria, the criteria were weighted and prioritized using AHP. Similarly, Lai and Yik (2009) applied AHP to identify the significant indoor environmental quality areas in high-rise residential buildings. Specifically, AHP was used to derive importance weights for various indoor environmental quality attributes. The researchers (*ibid*) claimed that the results can assist facility managers in managing buildings within constrained budgets. Likewise, Alwaer et al. (2010) developed a sustainability assessment model to assess the performance of intelligent building systems in the construction industry. The assessment of the model was based upon the use of AHP to assign relative importance weights to different sustainability issues; the research sought to help stakeholders choose the most suitable indicators for intelligent buildings.

Integrated Approaches

AHP Combined with Life-Cycle Assessment and Life-Cycle Cost Analysis

Lee et al. (2013) developed a rating system for assessing the economic and environmental sustainability of highways using life-cycle assessment (LCA) and life-cycle cost analysis (LCCA) as measurement methods for quantifying environmental impact and economic impact, respectively. AHP was used to weight different sustainability indexes as a means of encouraging recycling of materials, which is a vital component of a holistic sustainable development (*ibid*).

AHP Combined with Top-Down Direct Rating, Bottom-Up Direct Rating, and Point Allocation

Pan et al. (2012) presented construction firms with value-based decision criteria and quantified the relative importance of these for the purpose of assessing sustainable building technologies. Different combinations of AHP, top-down direct rating (TDR), bottom-up direct rating (BDR), and point allocation (PA) were used in different cases to weight various decision criteria by pairwise comparisons. Case studies involving six UK construction firms sought to examine decision criteria for the selection of sustainable building technologies and verified the effectiveness of the method developed.

AHP Combined with Geographic Information System and Netweaver

Ruiz et al. (2012) studied the problems of planning, designing, and delivering a sustainable industrial area and developed a multicriteria spatial decision support system that incorporated a geographic information system (GIS) platform, NetWeaver, and AHP. While the GIS platform stores and manages geographical data in the system, the NetWeaver provides an environment for developing expert systems that provide an interface for defining 'knowledge.' The main function of AHP in the system was to obtain the variables' structure and determine the variables' respective weights.

AHP Combined with Mathematical Models

El-Anwar et al. (2010) suggested a combination of AHP and mathematical functions (such as sustainability index and environmental performance index) to tackle the issue of maximizing the sustainability of post-disaster housing recovery and construction. To help decision makers quantify and maximize the sustainability of post-natural disaster integrated housing recovery efforts, sustainability metrics were computed and incorporated into an optimization model. AHP was used to identify the relative importance of different sustainability metrics. Mostafa (2014) also presented a stakeholder-sensitive, social welfare-oriented sustainability benefit analysis model to evaluate infrastructure project alternatives. A key component of the model is AHP that was used to compute stakeholder benefit preference weights.

Transportation

Transportation has seen various AHP applications, while MCDM methods more generally, have had major applications in roads and highways construction (Jato-Espino et al., 2014).

Stand-alone AHP Studies

Wakchaure and Jha (2012) used AHP to resolve the conundrum of optimizing bridge maintenance using limited resources. Specifically, AHP was used to determine the relative importance weights of bridge components as a first step towards developing a bridge health index. This index can be applied by stakeholders to rank bridges that need maintenance and optimally allocate resources for the maintenance of the bridges. Dalal et al. (2010) also used AHP in group decision-making to rank rural roads for optimal allocation of funds for upgrading purposes.

Integrated Approaches

AHP Combined with Data Envelopment Analysis

Wakchaure and Jha (2011) sought to prioritize bridge maintenance planning based on efficient allocation of limited funds. The researchers utilized data envelopment analysis (DEA) to evaluate the efficiency scores of different bridges, while the relative importance weights and condition ratings of the components and sub-components of the bridges were ascertained through AHP.

AHP Combined with FSs and Delphi

Pan (2008) proposed a FSs-AHP-based model to select the most suitable bridge construction method. Various bridge selection criteria were weighted through pairwise comparisons using a Delphi approach, under the following five main criteria: cost; duration; quality; safety; and bridge shape. A case study of a new bridge construction project was presented to illustrate the usefulness and capability of the model.

AHP Combined with Monte Carlo Simulation

Minchin et al. (2008) proposed a construction quality index for highway construction by combining AHP with Monte Carlo Simulation (MCS). The developed index addresses quality factors for the major components of pavement construction (e.g., rigid pavements, base course, embankment, subgrade, and flexible pavements). Weighting criteria representing the relative importance of construction quality metrics on pavement performance were established using AHP, while MCS predicted the pavement life.

Housing

Similar to the risk management area, all of the application cases identified in the area of housing involved integrated AHP approaches.

AHP Combined with Delphi and Analysis of Variance

Hyun et al. (2008) tackled performance evaluation of housing project delivery methods by combining the AHP and Delphi methods with an analysis of variance (ANOVA) test. This approach sought to devise objective standards and contents for quantitative evaluation of the impacts of project delivery methods on design performance in multifamily housing projects. First, AHP and a three-round Delphi were used to develop an evaluation standard and calculate the weights of different evaluation items. Second, an ANOVA test was performed to explore the influences of different project delivery methods on design performance.

AHP Combined with Sensitivity Analysis

Mahdi et al. (2006) used AHP to design a decision model for reducing the construction cost and waiting time caused by conflict encountered when economic versus quality decisions have to be made in selecting delivery alternatives for housing projects. The effects of different criteria on the selection of proper housing delivery alternatives were analyzed using AHP, after which sensitivity analysis (SA) was performed to investigate the sensitivity of the final decision to possible changes in judgments.

AHP Combined with Geographic Information System, Utility Theory, and Online Analytical Processing

Ahmad et al. (2004) created a decision support system for property developers and builders to tackle the problem of selecting the most appropriate site for residential housing development. The system was based upon an integration of AHP with GIS software, an online analytical processing (OLAP) concept, and the expected utility value theorem. The GIS software performed geographical analyses of the available sites; OLAP analysis was performed using AHP; and the expected utility value theorem was used to convert monetary values into equivalent utility functions. An application example was presented to exhibit the applicability of the decision support system.

AHP Combined with Mathematical Models

El-Anwar and Chen (2013) established a methodology for quantifying and minimizing the displacement distance equivalents for families that are assigned temporary housing following a natural disaster. The methodology used AHP and mathematical models (e.g., Haversine formula) to compute displacement distances.

Contractor Prequalification and Selection

Contractor prequalification is an important task in the field of CM. This task aims at selecting competent contractors for the bidding process. The identification of AHP applications in the contractor prequalification and selection area corroborates the viewpoint of Al-Harbi (2001) that AHP is a practical and effective decision-making tool to prequalify and select contractors.

Stand-alone AHP Studies

Abudayyeh et al. (2007) employed AHP to develop a decision-making tool for contractor prequalification. Specifically, the technique was used to find the relative weights of various prequalification criteria, which were subsequently used to rank contractors to select the top-ranked contractor for the project. Similarly, Topcu (2004) proposed an AHP-based decision model to prequalify and select contractors based on preference ranking.

Integrated Approaches

AHP Combined with Neural Network, Genetic Algorithm, and Delphi

El-Sawalhi et al. (2007) suggested a combination of AHP, neural network (NN), genetic algorithm (GA), and Delphi to analyze and improve the accuracy of contractor prequalification and selection. This hybrid approach was proposed mainly to offset the limitations of one technique with the strengths of others, and was used to collect the importance weights of prequalification criteria through a Delphi process.

AHP Combined with Sensitivity Analysis

El-Sayegh (2009) developed a multicriteria decision support model to assist owners/clients in selecting the most appropriate construction firm to deliver a project through the construction management at risk project delivery method. AHP was used to establish the decision criteria and compare candidate firms, while SA was used to determine the break-even or trade-off values among different firms.

Competitive Advantage

Stand-alone AHP Studies

Sha et al. (2008) used AHP within a bespoke system to define and measure competitiveness in the construction industry. The system can help construction enterprises better evaluate their overall performance and improve their competence. The indicators at the different levels of the system were weighted using AHP.

Integrated Approaches

AHP Combined with Cluster Analysis

Shen et al. (2006) established key competitiveness indicators for assessing contractor competitiveness. After formulating a list of contractor competitiveness indicators, a combination of AHP and cluster analysis (CA) was applied to determine the weights of project success criteria.

AHP Combined with Sensitivity Analysis and Delphi

Wu et al. (2007) adopted the modified Delphi method, AHP, and SA to present an AHP-based evaluation model for selecting the optimal location of hospitals. The modified Delphi method was applied to define the evaluation criteria and sub-criteria that were used to construct a hierarchy based upon which pairwise comparison matrices were established using AHP. SA was performed to examine the model's response to changes in the importance of the criteria. Hsu et al. (2008) also presented an optimal model to evaluate the resource-based allocation for enterprises who sought competitive advantage in the senior citizen housing sector. The modified Delphi method was adopted to accumulate and integrate expert opinions to devise the competitive advantage criteria before AHP was applied to determine the importance weight of each competitive advantage criterion.

DISCUSSION

This review illustrates that risk management and sustainable construction are the two most popular AHP application areas in CM. As Table 3 shows, risk management and sustainable construction had the highest number of papers on AHP applications (9 papers, 11.69%). While the risk management issues were primarily concerned with the effective identification, assessment, and allocation of risks, the sustainable construction issues focused on improving sustainable development decisions within the construction industry. It is not a surprise to find that risk management and sustainable construction problems attracted the greatest attention in AHP application within CM. Risk management and sustainable construction are probably the most delicate areas of CM, as their activities are likely to affect the well-being of humans, the environment, and the construction industry as a whole. The presence of risk events within the construction industry could impede the success of construction operations. Conversely, sound sustainable construction decisions could help enhance human health and the environment. Thus, the widespread application of AHP for integrated and holistic assessments toward risk management- and sustainable construction-related decisions is crucial.

AHP applications were also found in other important areas of CM, such as transportation (5 papers, 6.49%), housing (4 papers, 5.19%), contractor prequalification and selection (4 papers, 5.19%), competitive advantage (4 papers, 5.19%), plant and equipment management (3 papers, 3.90), building design (3 papers, 3.90) and dispute resolution (3 papers, 3.90). This suggests that AHP is practically applicable to decision-making problems in a broad range of CM areas. Generally, decision-making in the identified CM areas requires thorough analysis of multiple economic, social, environmental, and technical factors whose knowledge could be arduous to quantify and process. Moreover, a lack of objectivity is almost inevitable in these construction-related decision-making problems due to the need to consider subjective criteria. These may explain the reason why AHP has become popular and successful in CM. AHP can be used to validate subjective judgments and provide a high level of consistency.

This review not only demonstrates the usefulness and versatility of AHP and how it fits well into the nature of dealing with various construction-related decision-making problems, but it also demonstrates AHP’s flexibility and simplicity of application. The review results suggest that AHP is useful and allows construction decision makers to implement it either as a stand-alone tool or integrate it with other advanced decision-making methods to ensure a more reliable decision-making process. Also, AHP (stand-alone and integrated) has frequently been used as a method to easily identify the most important aspects of construction-related decision problems, affirming its appropriateness for such problems. Other decision-making methods (e.g., the analytic network process (ANP) and DEA) might be useful for similar purposes, however, they are more stringent and time-consuming, giving AHP a significant advantage (Jato-Espino et al., 2014). For example, although ANP is considered a general form of AHP (Saaty, 1996), its ability to allow interdependencies among decision criteria makes it time-consuming and hence difficult to apply amongst busy practitioners or decision makers.

Regarding the nature of application, Table 3 shows that AHP was mainly applied in combination with other methods, with FSs being the most common method in the integrated AHP approaches. This could be attributed to the popular belief that AHP is incapable of handling the imprecision and uncertainty involved in construction decisions and hence combining it with FSs enhances its capability (Zadeh, 1965). The presence of many other methods (e.g., DEA, MCS, UT, LCCA, and MAUT) in the integrated AHP approaches further indicates that the integration of AHP with other methods can be implemented in many diverse ways to conform to the nature and environment of the construction decision problem.

Consequently, it would be useful if researchers and practitioners continue to apply AHP to organize, analyze, and model complex construction decisions to develop more useful models to support decision-making in wide-ranging areas of CM.

When and Why to Use AHP

AHP can help researchers and practitioners explore multicriteria decisions. However, because of other alternative MCDM methods, the use of AHP often requires further justification as illustrated in some of the reviewed papers. Although this paper does not intend to provide an in-depth review of these justifications, a brief review of them could be useful for those interested in applying AHP inside and outside the CM field. Thus, the three most prominent justifications given within the extant literature reviewed are discussed below.

Small Sample Size

Small sample size can adversely affect several aspects of any research, including the data analysis and concomitant interpretation of results. The major advantage of AHP over other MCDM methods is that it does not require a statistically significant (large) sample size to achieve sound and statistically robust results (Doloi, 2008; Dias and Ioannou, 1996). Some researchers argue that AHP is a subjective method for research focusing on a specific issue, hence it is not necessary to employ a large sample (Lam and Zhao, 1998). Others argue that because AHP is based on expert judgments, judgments from even a single qualified expert are usually representative (Golden et al., 1989; Tavares et al., 2008; Abudayyeh et al., 2007). Moreover, it may be unhelpful to use AHP in a study with a large sample size because 'cold-called' experts are likely to provide arbitrary answers, which could significantly affect the consistency of the judgments (Cheng and Li, 2002). Much of the popularity of AHP in CM could be attributed to its ability to handle small sample sizes.

The extant literature on AHP applications in CM indicates that there is no strict requirement on the minimum sample size for AHP analysis. Some studies used sample sizes ranging from four to nine (Akadiri et al., 2013; Chou et al., 2013; Pan et al., 2012; Li and Zou, 2011; Dalal et al., 2010; Zou and Li, 2010; Pan, 2008; Lam et al., 2008; Hyun et al., 2008; Zhang and Zou, 2007). Only a few studies used sample sizes greater than 30 (El-Sayegh, 2009; Ali and Al Nsairat, 2009). These findings suggest that AHP can be performed with small sample size to achieve useful decision results and models, which often makes it a more preferred method in CM research than other MCDM methods. However, it is still imperative for researchers to treat the choice of AHP sample size with special attention, because the possible impact of an optimally selected sample size on the decision outcomes cannot be undermined.

High Level of Consistency

Although AHP has been criticized for incorporating subjective judgments into the decision-making process, it has been proved of decreasing bias and ensuring that subjective judgments are validated using consistency analysis (Saaty, 1980; Saaty and Vargas, 1991). Analysis of the reviewed papers showed that this is one of the most prominent reasons why researchers selected AHP (Hsu et al., 2008; Abudayyeh et al., 2007; Shapira and Goldenberg, 2005; Cheung et al., 2004). AHP is capable of using both subjective and objective data for proper decision-making. This capability makes AHP important for construction-related decision-making, as subjective judgments from different experts form a crucial part of construction decision-making (Hsu et al., 2008). This review suggests that in construction-related decision-making, AHP can help ensure a high level of consistency among the judgements obtained from multiple experts who might have different perceptions, experiences, and understanding of the decision criteria. This paper argues that if the reliability of decision results matters, then the consistency of expert judgments also matters.

Simplicity and User-Friendly Software

Other prominent reasons stated for using AHP relate to its simplicity of implementation and the availability of user-friendly software, Expert Choice, for analyzing AHP data (El-Anwar and Chen, 2013; Hsu et al., 2008; El-Sawalhi et al., 2007; Ahmad et al., 2004; Topcu, 2004; Cheung et al., 2004). These aforementioned researchers argue that AHP helps to easily and effectively break down a complex construction decision problem into a hierarchy that provides a deeper understanding of all the criteria involved. Using this hierarchy, decision makers are able to pairwise compare the criteria, rather than assess the relative importance of the large number of tangible and intangible criteria simultaneously. This provides a structured and analytic, yet simple approach that does not require any special skills from the decision makers to determine the best solution.

FUTURE AHP APPLICATIONS IN CM

Reviewing the literature revealed that AHP has not been extensively applied in certain areas of CM and hence warrants future research attention. In this study, any CM area where only one paper on AHP application was found is considered as an area requiring additional attention in the future AHP applications; albeit areas with more than one paper may also require additional investigation. As shown in Table 3, CM decision areas where only one paper applying AHP was found include, but not limited to, quality management, knowledge management, planning and scheduling, pricing, and bidding of construction operations. This implies that more AHP applications in modeling and improving different types of decisions in these areas of CM are required.

In the area of quality management, for example, only one related AHP study was found (Lam et al., 2008). Yet, quality is a critical issue for almost all construction stakeholders and one of the key criteria for measuring project success in construction. Thus, more AHP applications in analyzing quality management decisions are needed. Future research could expand on the work of Lam et al. (2008) in order to develop more decision support systems to help solve quality problems in construction projects. The development of such decision support systems should focus on incorporating and assessing not only criteria that can help achieve better quality, but also those that can help attain higher client satisfaction and higher productivity. Quality, client satisfaction, and productivity are key issues that can directly affect the overall project success (Lam et al., 2008). Furthermore, future AHP applications could focus on developing quality performance measurement models to help assess and measure the quality performance of different stakeholders within the construction industry. As Lam et al. (2008) mentioned, their developed self-assessment quality management system is a "tailor-made" system for Hong Kong contractors to assess and improve their quality performance. Hence, there is scope to develop AHP-based quality measurement models/systems for international contractors and other construction stakeholders to improve their quality performance.

Knowledge management represents another promising direction for future AHP applications in CM. Knowledge management is about creating value from the intangible assets of an organization and facilitating knowledge sharing and integration (Alavi and Leidner, 1999). Over the last two decades, knowledge management has received increasing attention from practitioners; consequently, many organizations and individuals have developed multiple frameworks for knowledge management in different industries (Rubenstein-Montano et al., 2001). Undoubtedly, many construction organizations lack such frameworks. Accordingly, future AHP applications could focus on developing knowledge management frameworks for identifying the processes, mechanisms, cultures, and technologies essential for implementing knowledge strategies in construction organizations. Such frameworks can assist construction organizations leverage knowledge both inside their organizations and externally among their shareholders and customers (Rubenstein-Montano et al., 2001). Although future AHP applications are needed in many other areas of CM (Table 3), the above discussion is limited to quality management and knowledge management because of brevity.

LIMITATIONS OF THIS STUDY

This study forms the initial phase of a literature study that has been initiated to fully review the AHP application in CM from different perspectives. This research identifies the AHP application areas in CM, but does not present application examples to illustrate how AHP can be used 'step-by-step' to address specific problems within the identified areas. However, the papers reviewed provide a useful reference point to understand how AHP was used to tackle specific problems. In addition, future review will include papers published beyond 2014 and use software tools such as *VOSviewer* (Centre for Science and Technology Studies, 2018) to construct bibliometric networks to better understand the literature. Moreover, although it was relatively straightforward to use the topic coverage of the reviewed papers to identify and categorize AHP application areas in CM, the process was largely dependent on the authors' subjective judgments. Finally, research is needed to differentiate between AHP and other MCDM methods through comparing their merits and demerits to determine which methods are superior to the others in various CM circumstances (c.f. Arroyo et al., 2014).

CONCLUSIONS

AHP has become a popular method for organizing, analyzing, and modeling complex decisions within the CM field. This paper attempted to review AHP application in CM so as to improve understanding of the decision areas and decision problems that AHP could efficiently resovle. The paper's objectives were to: summarize existing literature related to AHP applications in CM; identify the popular AHP application areas and problems; and provide directions for future AHP application. To achieve these objectives, 77 relevant AHP-based papers published in eight selected peer-reviewed CM journals from 2004 to 2014 were identified through a systematic desktop search and reviewed.

The findings revealed that risk management and sustainable construction were the most popular AHP application areas in CM. In addition, it was identified that AHP is flexible and can be used as a stand-alone tool or in conjunction with other tools to rigorously tackle construction-related decision-making problems. Moreover, a descriptive analysis of the reviewed papers showed a wide application of AHP in Asia. Reasons behind the wide adoption of AHP are that it does not require large sample size, it can achieve a high level of consistency, and it is easy to implement. Based upon the findings presented, directions for future AHP applications were proposed. To summarize, the findings suggested that AHP (whether stand-alone or integrated) can help researchers and practitioners address a variety of decision-making problems that matter. As such, construction researchers, practitioners, and institutions are advised to consider AHP applications when the need to analyze multicriteria decisions in wide-ranging areas of CM arises.

This paper could be useful for researchers and practitioners interested in the application of AHP to analyze and model construction decisions. For researchers, this paper provides a comprehensive review of past AHP-based studies in CM, which is necessary for conducting future studies. In addition, this paper could help practitioners better understand and judge the usefulness of AHP in tackling specific decision-making problems in CM, which could encourage its wider use in CM. Notably, decision support systems and models developed for the construction industry are myriad as a result of AHP usage. However, practitioners may not find it easy to locate these systems and models, as they are scattered throughout the extant literature. With the help of this review paper, practitioners could readily become familiar with the potentially useful decision support systems and models, which in turn might trigger attempts to use them in practice.

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Tables

Table 1. AHP pairwise comparison scale.

Weight	Definition
1	Equal importance
3	Weak importance of one over other
5	Essential or strong importance
7	Very strong importance
9	Absolute importance
2,4,6,8	Intermediate values between the two adjacent judgments
Reciprocals of previous values	If factor *"i"* has one of the previously mentioned numbers assigned to it when compared to factor *"j"*, then *j* has the reciprocal value when compared to *i*.

Table 2. Number of papers from selected journals.

No.	Name of Journal	Number of papers	Percentage
1	ASCE Journal of Construction Engineering and Management (JCEM)	25	32
2	Automation in Construction (AIC)	13	17
3	Building and Environment (BE)	10	13
4	Construction Management and Economics (CME)	9	12
5	ASCE Journal of Management in Engineering (JME)	8	11
6	International Journal of Project Management (IJPM)	5	6
7	Engineering, Construction and Architectural Management (ECAM)	5	6
8	Building Research and Information (BRI)	2	3
Total		77	100

Table 3. Summary of applications of AHP in construction management.

Decision areas	Decision problems	Author(s)	Year	Other methods
Risk management (9 papers, 11.69%)	Decision making for balanced risk allocation selection	Khazaeni, G., Khanzadi, M., and Afshar, A.	2012	Fuzzy sets theory; Delphi
	Assessment of the risk condition in the construction industry	Subramanyan, H., Sawant, P.H., and Bhatt, V.	2012	Fuzzy sets theory
	Improving risk assessment accuracy in PPP projects	Li, J., and Zou, P.X.W.	2011	Fuzzy sets theory
	Exploring a knowledge extraction method through the establishment of project risk ontology	Tserng, H.P., Yin, S.Y.L., Dzeng, R.J., Wou, B., Tsai, M.D., and Chen, W.Y.	2009	Ontology
	Appraising risk environment of joint venture (JV) projects to support rational decision-making	Zhang, G., and Zou, P.X.W.	2007	Fuzzy sets theory
	Decreasing the risk of JVs in China for global contractors	Hsueh, S.L., Perng, Y.H., Yan, M.R., and Lee, J.R.	2007	Utility Theory
	Improving project risk assessment for coping with risks in complicated construction situations	Zeng, J., An, M., and Smith, N.J.	2007	Fuzzy reasoning techniques
	Enhancing risk management through effective decisions and proactive corrective actions	Abdelgawad, M., and Fayek, A.R.	2010	Fuzzy logic; FMEA
	Facilitating the identification and assessment of risk at the initial stage of subway projects	Zou, P.X.W., and Li, J.	2010	Fuzzy sets theory
Sustainable or green construction (9 papers, 11.69%)	Lifecycle assessment of economic and environmental sustainability of highway designs	Lee, J., Edil, T.B., Benson, C.H., and Tinjum, J.M.	2013	LCA; LCCA
	Sustainable building materials selection	Akadiri, P.O, Olomolaiye, P.O., and Chinyio, E.A.	2013	Fuzzy sets theory
	Achieving more informed corporate decisions regarding the management of sustainable technologies	Pan, W., Dainty, A.R.J., and Gibb, A.G.F.	2012	TDR; BDR; PA method
	Analysis of influential location factors of sustainable industrial areas	Ruiz, M.C., Romero, E., Pérez, M.A., and Fernández, I.	2012	GIS software; NetWeaver
	Sustainability enhancement of integrated housing recovery efforts after natural disasters	El-Anwar, O., El-Rayes, K., and Elnashai, A.S.	2010	Mixed functional (mathematical) equations
	Exploring and prioritizing key performance indicators (KPIs) for assessing sustainable intelligent buildings	ALwaer, H., and Clements-Croome, D.J.	2010	-
	Maximizing infrastructure system decision-making to maximize economic, social, and environmental benefits to stakeholders	Mostafa, M.A., and El-Gohary, N.M.	2014	Social welfare function
	A green building assessment tool development	Ali, H.H., and Al Nsairat, S.F.	2009	-

	Improving the performance of indoor environmental quality of residential buildings	Lai, J.H.K., and Yik, F.W.H.	2009	-
Transportation (5 papers, 6.49%)	Developing a bridge health index (BH) for optimum allocation of resources for maintenance actions	Wakchaure, S.S., and Jha, K.N.	2012	-
	Evaluating the efficiency of and improving fund allocation for bridge maintenance	Wakchaure, S.S., and Jha, K.N.	2011	DEA
	Appropriate bridge construction method selection	Pan, N.F.	2008	Fuzzy sets theory
	Prioritizing rural roads for funds allocation	Dalal, J., Mohapatra, P.K.J., and Mitra, G.C.	2010	-
	To develop an effective and practical quality index for highway construction	Minchin, R.E., Hammons, M.I., and Ahn, J.	2008	MCS
Housing (4 papers, 5.19%)	Helping developers to select appropriate sites for residential housing development	Ahmad, I., Azhar, S., and Lukauskis, P.	2004	OLAP; GIS; Utility Theory
	Exploring mass housing and its conflicts during the production process	Mahdi, I.M., Al-Reshaid, K., and Fereig, S.M.	2006	SA
	Design performance level evaluation for quantitative evaluation of quality performance in housing projects	Hyun, C., Cho, K., Koo, K., Hong, T., and Moon, H.	2008	Delphi; ANOVA
	Optimization in temporary housing projects	El-Anwar, O., and Chen, L.	2013	Haversine formula
Contractor prequalification and selection (4 papers, 5.19%)	An advanced model for contractor prequalification and selection	El-Sawalhi, N., Eaton, D., and Rustom, R.	2007	NN; GA; Delphi
	Facilitating effective decision-making in selecting highway construction contractors	Abudayyeh, O., Zidan, S.J., Yehia, S., and Randolph, D.	2007	-
	Assisting owners' decisions in selecting contractors for construction management at risk projects	El-Sayegh, S.M.	2009	SA
	A decision support system for contractor selection in Turkey	Topcu, Y.I.	2004	-
Competitive advantage/competitiveness assessment (4 papers, 5.19%)	Measuring the competitiveness of construction enterprises	Sha, K., Yang, J., and Song, R.	2008	-
	Key competitiveness indicators (KCIs) for evaluating contractor competitiveness	Shen, L.Y., Lu, W.S., and Yam, M.C.H.	2006	Cluster analysis
	Increasing the competitive advantage of hospitals through optimal location selection	Wu, C.R., Lin, C.T., and Chen, H.C.	2007	SA; Delphi
	Increasing the competitive advantage of enterprises in senior citizen housing industry	Hsu, P.F., Wu, C.R., and Li, Z.R.	2008	Delphi
Plant and equipment management (3 papers, 3.90%)	Enhancing equipment selection decisions	Goldenberg, M., and Shapira, A.	2007	-
	Enhancing equipment selection decisions	Shapira, A., and Goldenberg, M.	2005	-

	Evaluation and selection of concrete pumps for a project	Tam, C.M., Tong, T.K.L., and Wong, Y.W.	2004	SIR method
Building design (3 papers, 3.90%)	Improving decision-making at the early stage of the design process	Schade, J., Olofsson, T., and Schreyer, M.	2011	MAUT
	Provision of a decision support environment for evaluating and selecting design alternatives	Cariaga, I., El-Diraby, T., and Osman, H.	2007	FAST; QFD; DEA
	Improving design decisions to affect building performance	Hopfe, C.J., Augenbroe, G.L.M., and Hensen, J.L.M.	2013	Simulation
Dispute resolution (3 papers, 3.90%)	Exploring key features of alternative dispute resolution (ADR) for effective implementation	Cheung S.O., Suen, H.C.H., Ng, S.T., and Leung, M.Y.	2004	-
	Helping parties to significantly analyze issues in a conflict more logically	Al-Tabtabai, H.M., and Thomas, V.P.	2004	-
	Selection of dispute resolution methods for international construction projects	Chan, E.H.W., Suen, H.C.H., and Chan, C.K.L.	2006	MAUT
Health and safety management (2 papers, 2.60%)	Measurement and evaluation of crane-related safety hazards on construction sites	Shapira, A., and Simcha, M.	2009	Probabilities
	Computation of overall index for realistic reflection of site safety levels due to tower crane operations	Shapira, A., Simcha, M., and Goldenberg, M.	2012	-
Construction productivity (2 papers, 2.60%)	Predicting the impact of a technology on productivity	Goodrum, P.M., Haas, C.T., Caldas, C., Zhai, D., Yeiser, J., and Homm, D.	2011	Historical analysis
	Exploring and assessing factors that have impact on workers' productivity improvement	Doloi, H.	2008	SA
Project delivery systems selection (for projects in general) (2 papers, 2.60%)	Assisting owners to make effective decisions in the selection of optimal project delivery systems	Mafakheri, F., Dai, L., Slezak, D., and Nasiri, F.	2007	Linear programming
	Assisting decision makers to select the most suitable delivery method for their projects	Mahdi, I.M., and Alreshaid, K.	2005	SA
Office projects delivery (2 papers, 2.60%)	Classifying offices for reliable practitioners' assessment	Daud, M.N., Adnan, Y.M., Mohd, I., and Aziz, A.A.	2011	-
	Selection of planning and design alternatives for public office projects	Hsieh, T.Y., Lu, S.T., and Tzeng, G.H.	2004	Fuzzy sets theory
Facilities management (2 papers, 2.60%)	Evaluation of facility management services buildings	Lai, J.H.K., and Yik, F.W.H.	2011	-
	Assisting complex decision-making in building maintainability (BM).	Das, S., Chew, M.Y.L., and Poh, K.L.	2010	-
Fire safety management (2 papers, 2.60%)	Optimal selection of fire origin room (FOR)	Tavares, R.M., Tavares, J.M.L., and Parry-Jones, S.L.	2008	-
	Fire safety evaluation of existing hotel buildings	Chen, Y.Y., Chuang, Y.J., Huang, C.H., Lin, C.Y., and Chien, S.W.	2012	-

Contractor performance evaluation (at company level) (2 papers, 2.60%)	Classifying contractors and assessing their performance using proper measures	Nassar, K., and Hosny, O.	2013	Fuzzy clustering
	Assessing and comparing the performance of construction companies	Yu, I., Kim, K., Jung, Y., and Chin, S.	2007	Performance scores; coefficient of variance
Procurement/purchasing[a]	Enhancing purchasing strategies in construction companies	Arantes, A., Ferreira, L.M.D.F., and Kharlamov, A.A.	2014	KPM; MDS; linear transformation
Bidding[a]	Improving bidding strategies of construction firms and supporting bid or no bid decisions	Chou, J.S., Pham, A.D., and Wang, H.	2013	Fuzzy sets theory; MCS
Planning and scheduling[a]	Scheduling multiple projects with competing priorities in the face of organizational constraints	Goedert, J.D., and Sekpe, V.D.	2013	-
Information management[a]	Knowledge sharing and supporting decisions relating to route selection for buried urban utilities	Osman, H.M., and El-Diraby, T.E.	2011	Ontology modelling approach; fuzzy inference system
Earned value management[a]	Providing project managers with a system to assess project performance and monitor progress	Chou, J.S., Chen, H.M., Hou, C.C., Lin, C.W.	2010	MCS
Benchmarking[a]	How to determine the most suitable process to benchmarked company	Cheng, M.Y., Tsai, M.H., and Sutan, W.	2009	Semantic similarity analysis; trend model method
Quality management[a]	Helping contractors to solve quality problems	Lam, K.C., Lam, M.C.K., and Wang, D.	2008	Fuzzy sets theory
Knowledge management[a]	Assisting organizations in determining their achievement levels towards a learning culture	Chinowsky, P.S., Molenaar, K., and Bastias, A.	2007	-
International expansion[a]	Company executives' decisions to enter into international markets or not; evaluation of key decision factors	Gunhan, S., and Arditi, D.	2005	-
Contractors' self-performance measurement (at project level)[a]	Assisting contractors to measure their performance in relation to critical project objectives during the construction phase	Nassar, N., and AbouRizk, S.	2014	-
Earthmoving projects delivery[a]	Determination of optimal layout of a haul route for large-scale earthmoving projects	Kang, S., and Seo, J.	2013	Least-cost path analysis; Linear interpolations; Linguistic evaluations
High-rise building[a]	Improving the set-based design (SBD) procedure for high-rise building construction through effective selection of alternatives	Lee, S.I., Bae, J.S., and Cho, Y.S.	2012	S-BIM
Pricing[a]	Supporting decisions for the selection of appropriate pricing system for a project	Kaka, A., Wong, C., and Fortune, C., and Langford, D.	2008	-
Public projects delivery[a]	Procedural determination of budgets for government projects	Lai, Y.T., Wang, W.C., and Wang, H.H.	2008	Simulation
Build-operate-transfer (BOT) infrastructure projects[a]	Evaluation of critical decision/success factors of BOT projects	Salman, A.F.M., Skibniewski, M.J., and Basha, I.	2007	-

Value engineering[a]	Identification of the most leveraging features of a project	Cha, H.S., and O'Connor, J.T.	2006	Fuzzy sets theory; mathematical equations
Value enhancement in crucial decisions[a]	Analysis and evaluation of various aspects of decision making in subway construction in Barcelona	Ormazabal, G., Viñolas, B., and Aguado, A.	2008	Value functions
Design of ETO (Engineer-To-Tender) products[a]	Exploring approaches to better support ETO product design process	Pandit, A., and Zhu, Y.	2007	Ontology approach; process models
Drilling; differential settlement[a]	Understanding the effects of construction factors on the development of surface heave during installation of horizontal directional drilling (HDD)	Lueke, J.S., and Ariaratnam, S.T.	2005	Factorial experiment

Note: [a] Decision areas with one paper on AHP application, representing 1.30% of the total sample; S-BIM = Structural building information modelling; MAUT = Multi-attribute utility theory; SA = Sensitivity analysis; ANOVA = Analysis of variance; FAST = Functional analysis system technique; QFD = Quality function deployment; DEA = Data envelopment analysis; SIR = Superiority and inferiority ranking; OLAP = Online analytical processing; GIS = Geographical information system; LCA = Life-cycle assessment; LCCA = Life-cycle cost analysis; TDR = Top-down direct rating; BDR = Bottom-up direct rating; PA = Point allocation; FMEA = Failure mode and effect analysis; KPM = Kraljic purchasing portfolio matrix; MDS = multidimensional scaling; MCS = Monte Carlo simulation; NN = Neural Network; and GA = Genetic Algorithm.

Table 4. Country-wise application of AHP.

No.	Country	Number of papers
1	US	11
2	Taiwan	10
3	UK	8
4	Hong Kong	6
5	Korea	6
6	China	6
7	Canada	5
8	India	4
9	Israel	4
10	Kuwait	3
11	Spain	2
12	United Arab Emirates	2
13	Egypt	1
14	Saudi Arabia	1
15	Portugal	1
16	Singapore	1
17	Sweden	1
18	Australia	1
19	Malaysia	1
20	Iran	1
21	Jordan	1
22	Turkey	1

Figures

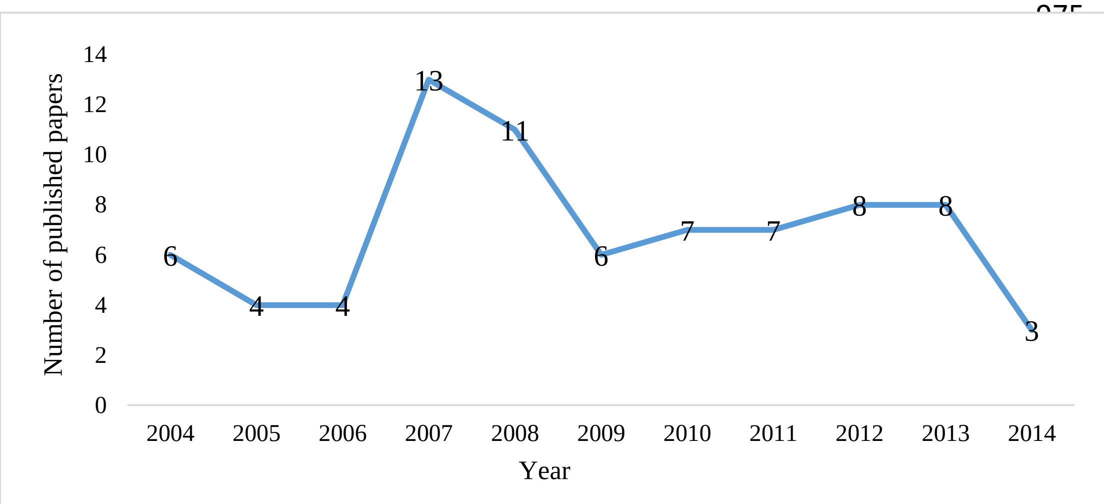

Fig. 1. Year-wise distribution of the reviewed AHP-based papers.

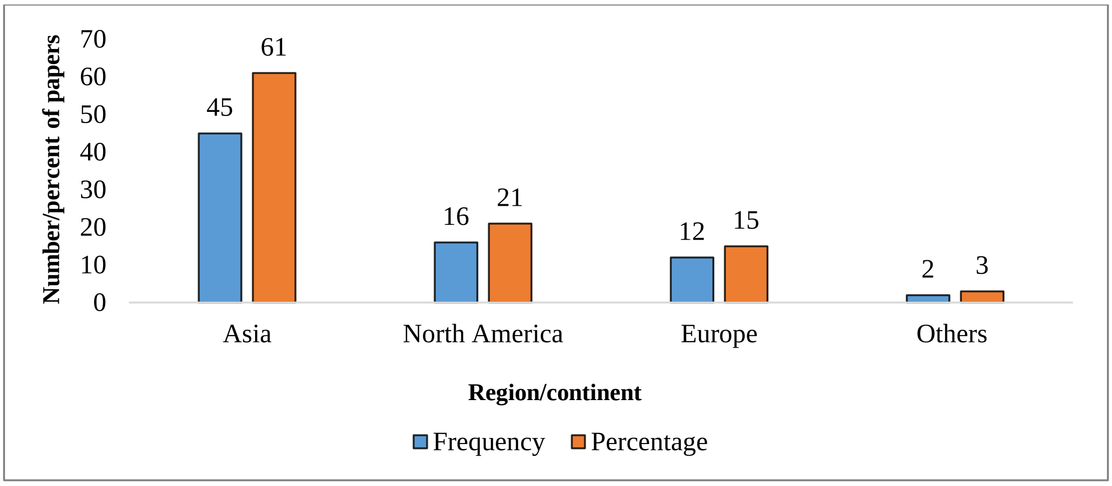

Fig. 2. Region-wise application of AHP.

REVIEW OF APPLICATION OF ANALYTIC HIERARCHY PROCESS (AHP) IN CONSTRUCTION

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