

26 INTRODUCTION

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

40

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

51

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

71

72 **AHP DECISION-MAKING METHOD**

73 AHP was created by Saaty (1980) to deal with decision-making problems in complex and
74 multicriteria situations (c.f. Dyer and Forman, 1992; Saaty, 1990). Therefore, this research is
75 not concerned with explicating specific details about the method but rather the basic concepts

76 of it. AHP assists in making decisions that are characterized by several interrelated and often
77 competing criteria, and it establishes priorities amongst decision criteria when set within the
78 context of the decision goal (Shapira and Goldenberg, 2005). A key aspect is that decision
79 criteria are assessed with respect to their relative importance in order to allow trade-offs
80 between them.

81

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

100 also been found to be less than 0.1, the judgments can then be synthesized to prioritize the
101 decision criteria together with their corresponding sub-criteria.

102

103 **[Insert Table 1 about here]**

104

105 **RESEARCH METHODOLOGY**

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

124 from BE and nine were from CME, in total representing 74% of the sample. The remaining
125 papers were distributed across the other four journals.

126

127 **[Insert Table 2 about here]**

128

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

138

139 **REVIEW OF AHP APPLICATIONS IN CM**

140 **Identification of Decision Areas and Decision Problems**

141 As the most commonly used MCDM method, AHP attracts the most attention from decision
142 makers because of the availability of extensive literature on its application (Jato-Espino et al.,
143 2014). It is thus essential to better understand the specific decision problems that AHP can
144 resolve. Such an understanding would greatly stimulate interest in AHP applications within the
145 wider areas of CM.

146

147 Table 3 presents all of the 77 identified papers and provides a quick reference guide and
148 meaningful information about the applications of AHP in CM. The table was developed based

149 on information extracted from the reviewed papers. First, the papers' research interests/ topics
150 aided the identification of the decision areas. Based upon this, AHP has been found to be
151 applicable to many different areas of CM. Second, the papers' research aims/ objectives
152 presented the decision problems that AHP was used to address. This showed that AHP has been
153 applied to numerous construction-related decision-making problems. These findings suggest
154 that AHP is useful in enabling strategic and sound decision-making in a wide range of CM
155 areas, which is consistent with the viewpoint of Jato-Espino et al. (2014). Following the
156 identification of the decision areas and problems, the reviewed papers were then grouped,
157 based upon the decision problems, under the decision areas. Each paper was assigned to only
158 one decision area, thus if a paper appears to have multiple research interests [e.g., Lai and Yik's
159 (2009) paper addressed both sustainability and housing/residential building issues], it was
160 assigned to the best-fit decision area, as suggested by Hong et al. (2012). Although deciding
161 on the best-fit decision area for a paper may seem subjective and associated with some level of
162 uncertainty, it is believed that variations were minimized. Lastly, the authors and years of
163 publication of the reviewed papers, and other methods combined with AHP in some of the
164 papers are also presented in the table.

165

166 **[Insert Table 3 about here]**

167

168 **Descriptive Analysis**

169 A descriptive analysis of the papers was also undertaken to illustrate insightful trends in the
170 application of AHP in CM. Of the 77 papers, 14 papers were published in the years before 2007
171 and during 2007, a peak of 13 papers was evident (Fig. 1) which appears to be a purely random
172 occurrence given a lack of any 'special issue' that could easily explain it. In recent years (2009
173 to 2013), relatively stable trend was observed with an average of seven papers published every

174 year – however, in 2014 this trend significantly reduced. This outcome might be because many
175 more MCDM methods have emerged in recent years, giving the AHP tight competition in terms
176 of MCDM methods application.

177

178 **[Insert Fig. 1 about here]**

179

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

186

187 **[Insert Table 4 about here]**

188

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

195

196 **[Insert Fig. 2 about here]**

197

198

199 **AHP APPLICATIONS IN IDENTIFIED CM AREAS**

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

204

205 **Risk Management**

206 Risk management is a major CM area comprising defects, misalignments, and crises that can
207 lead to inflated risks, project conflicts, and other negative performance outcomes (Zheng et al.,
208 2016). Risk management decisions are often made using multiple criteria. Interestingly, all the
209 AHP applications within the risk management area involved integrated approaches to combine
210 AHP with other techniques.

211

212 ***AHP Combined with Fuzzy Sets Theory***

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

224

225 ***AHP Combined with Fuzzy Sets Theory and Delphi***

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

233

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

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

242

243 ***AHP Combined with Utility Theory***

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

248

249 ***AHP Combined with Ontology***

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

256

257 **Sustainable Construction**

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

260

261 ***Stand-alone AHP Studies***

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

273

274 ***Integrated Approaches***

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

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

282

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

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

292

293 ***AHP Combined with Geographic Information System and Netweaver***

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

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

301

302 *AHP Combined with Mathematical Models*

303 El-Anwar et al. (2010) suggested a combination of AHP and mathematical functions (such as
304 sustainability index and environmental performance index) to tackle the issue of maximizing
305 the sustainability of post-disaster housing recovery and construction. To help decision makers
306 quantify and maximize the sustainability of post-natural disaster integrated housing recovery
307 efforts, sustainability metrics were computed and incorporated into an optimization model.
308 AHP was used to identify the relative importance of different sustainability metrics. Mostafa
309 (2014) also presented a stakeholder-sensitive, social welfare-oriented sustainability benefit
310 analysis model to evaluate infrastructure project alternatives. A key component of the model
311 is AHP that was used to compute stakeholder benefit preference weights.

312

313 **Transportation**

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

316

317 *Stand-alone AHP Studies*

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

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

325

326 *Integrated Approaches*

327 *AHP Combined with Data Envelopment Analysis*

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

333

334 *AHP Combined with FSs and Delphi*

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

340

341 *AHP Combined with Monte Carlo Simulation*

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

348

349 **Housing**

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

352

353 *AHP Combined with Delphi and Analysis of Variance*

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

361

362 *AHP Combined with Sensitivity Analysis*

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

369

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

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

380

381 *AHP Combined with Mathematical Models*

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

386

387 **Contractor Prequalification and Selection**

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

392

393 *Stand-alone AHP Studies*

394 Abudayyeh et al. (2007) employed AHP to develop a decision-making tool for contractor
395 prequalification. Specifically, the technique was used to find the relative weights of various
396 prequalification criteria, which were subsequently used to rank contractors to select the top-

397 ranked contractor for the project. Similarly, Topcu (2004) proposed an AHP-based decision
398 model to prequalify and select contractors based on preference ranking.

399

400 *Integrated Approaches*

401 *AHP Combined with Neural Network, Genetic Algorithm, and Delphi*

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

407

408 *AHP Combined with Sensitivity Analysis*

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

414

415 **Competitive Advantage**

416 *Stand-alone AHP Studies*

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

421

422 *Integrated Approaches*

423 *AHP Combined with Cluster Analysis*

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

428

429 *AHP Combined with Sensitivity Analysis and Delphi*

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

440

441 **DISCUSSION**

442 This review illustrates that risk management and sustainable construction are the two most
443 popular AHP application areas in CM. As Table 3 shows, risk management and sustainable
444 construction had the highest number of papers on AHP applications (9 papers, 11.69%). While
445 the risk management issues were primarily concerned with the effective identification,
446 assessment, and allocation of risks, the sustainable construction issues focused on improving

447 sustainable development decisions within the construction industry. It is not a surprise to find
448 that risk management and sustainable construction problems attracted the greatest attention in
449 AHP application within CM. Risk management and sustainable construction are probably the
450 most delicate areas of CM, as their activities are likely to affect the well-being of humans, the
451 environment, and the construction industry as a whole. The presence of risk events within the
452 construction industry could impede the success of construction operations. Conversely, sound
453 sustainable construction decisions could help enhance human health and the environment.
454 Thus, the widespread application of AHP for integrated and holistic assessments toward risk
455 management- and sustainable construction-related decisions is crucial.

456

457 AHP applications were also found in other important areas of CM, such as transportation (5
458 papers, 6.49%), housing (4 papers, 5.19%), contractor prequalification and selection (4 papers,
459 5.19%), competitive advantage (4 papers, 5.19%), plant and equipment management (3 papers,
460 3.90), building design (3 papers, 3.90) and dispute resolution (3 papers, 3.90). This suggests
461 that AHP is practically applicable to decision-making problems in a broad range of CM areas.
462 Generally, decision-making in the identified CM areas requires thorough analysis of multiple
463 economic, social, environmental, and technical factors whose knowledge could be arduous to
464 quantify and process. Moreover, a lack of objectivity is almost inevitable in these construction-
465 related decision-making problems due to the need to consider subjective criteria. These may
466 explain the reason why AHP has become popular and successful in CM. AHP can be used to
467 validate subjective judgments and provide a high level of consistency.

468

469 This review not only demonstrates the usefulness and versatility of AHP and how it fits well
470 into the nature of dealing with various construction-related decision-making problems, but it
471 also demonstrates AHP's flexibility and simplicity of application. The review results suggest

472 that AHP is useful and allows construction decision makers to implement it either as a stand-
473 alone tool or integrate it with other advanced decision-making methods to ensure a more
474 reliable decision-making process. Also, AHP (stand-alone and integrated) has frequently been
475 used as a method to easily identify the most important aspects of construction-related decision
476 problems, affirming its appropriateness for such problems. Other decision-making methods
477 (e.g., the analytic network process (ANP) and DEA) might be useful for similar purposes,
478 however, they are more stringent and time-consuming, giving AHP a significant advantage
479 (Jato-Espino et al., 2014). For example, although ANP is considered a general form of AHP
480 (Saaty, 1996), its ability to allow interdependencies among decision criteria makes it time-
481 consuming and hence difficult to apply amongst busy practitioners or decision makers.

482

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

494

495 **When and Why to Use AHP**

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

502

503 *Small Sample Size*

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

516

517 The extant literature on AHP applications in CM indicates that there is no strict requirement
518 on the minimum sample size for AHP analysis. Some studies used sample sizes ranging from
519 four to nine (Akadiri et al., 2013; Chou et al., 2013; Pan et al., 2012; Li and Zou, 2011; Dalal
520 et al., 2010; Zou and Li, 2010; Pan, 2008; Lam et al., 2008; Hyun et al., 2008; Zhang and Zou,

521 2007). Only a few studies used sample sizes greater than 30 (El-Sayegh, 2009; Ali and Al
522 Nsairat, 2009). These findings suggest that AHP can be performed with small sample size to
523 achieve useful decision results and models, which often makes it a more preferred method in
524 CM research than other MCDM methods. However, it is still imperative for researchers to treat
525 the choice of AHP sample size with special attention, because the possible impact of an
526 optimally selected sample size on the decision outcomes cannot be undermined.

527

528 *High Level of Consistency*

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

542

543 *Simplicity and User-Friendly Software*

544 Other prominent reasons stated for using AHP relate to its simplicity of implementation and
545 the availability of user-friendly software, Expert Choice, for analyzing AHP data (El-Anwar

546 and Chen, 2013; Hsu et al., 2008; El-Sawalhi et al., 2007; Ahmad et al., 2004; Topcu, 2004;
547 Cheung et al., 2004). These aforementioned researchers argue that AHP helps to easily and
548 effectively break down a complex construction decision problem into a hierarchy that provides
549 a deeper understanding of all the criteria involved. Using this hierarchy, decision makers are
550 able to pairwise compare the criteria, rather than assess the relative importance of the large
551 number of tangible and intangible criteria simultaneously. This provides a structured and
552 analytic, yet simple approach that does not require any special skills from the decision makers
553 to determine the best solution.

554

555 **FUTURE AHP APPLICATIONS IN CM**

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

565

566 In the area of quality management, for example, only one related AHP study was found (Lam
567 et al., 2008). Yet, quality is a critical issue for almost all construction stakeholders and one of
568 the key criteria for measuring project success in construction. Thus, more AHP applications in
569 analyzing quality management decisions are needed. Future research could expand on the work
570 of Lam et al. (2008) in order to develop more decision support systems to help solve quality

571 problems in construction projects. The development of such decision support systems should
572 focus on incorporating and assessing not only criteria that can help achieve better quality, but
573 also those that can help attain higher client satisfaction and higher productivity. Quality, client
574 satisfaction, and productivity are key issues that can directly affect the overall project success
575 (Lam et al., 2008). Furthermore, future AHP applications could focus on developing quality
576 performance measurement models to help assess and measure the quality performance of
577 different stakeholders within the construction industry. As Lam et al. (2008) mentioned, their
578 developed self-assessment quality management system is a “tailor-made” system for Hong
579 Kong contractors to assess and improve their quality performance. Hence, there is scope to
580 develop AHP-based quality measurement models/systems for international contractors and
581 other construction stakeholders to improve their quality performance.

582

583 Knowledge management represents another promising direction for future AHP applications
584 in CM. Knowledge management is about creating value from the intangible assets of an
585 organization and facilitating knowledge sharing and integration (Alavi and Leidner, 1999).
586 Over the last two decades, knowledge management has received increasing attention from
587 practitioners; consequently, many organizations and individuals have developed multiple
588 frameworks for knowledge management in different industries (Rubenstein-Montano et al.,
589 2001). Undoubtedly, many construction organizations lack such frameworks. Accordingly,
590 future AHP applications could focus on developing knowledge management frameworks for
591 identifying the processes, mechanisms, cultures, and technologies essential for implementing
592 knowledge strategies in construction organizations. Such frameworks can assist construction
593 organizations leverage knowledge both inside their organizations and externally among their
594 shareholders and customers (Rubenstein-Montano et al., 2001). Although future AHP

595 applications are needed in many other areas of CM (Table 3), the above discussion is limited
596 to quality management and knowledge management because of brevity.

597

598 **LIMITATIONS OF THIS STUDY**

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

612

613 **CONCLUSIONS**

614 AHP has become a popular method for organizing, analyzing, and modeling complex decisions
615 within the CM field. This paper attempted to review AHP application in CM so as to improve
616 understanding of the decision areas and decision problems that AHP could efficiently resolve.
617 The paper’s objectives were to: summarize existing literature related to AHP applications in
618 CM; identify the popular AHP application areas and problems; and provide directions for
619 future AHP application. To achieve these objectives, 77 relevant AHP-based papers published

620 in eight selected peer-reviewed CM journals from 2004 to 2014 were identified through a
621 systematic desktop search and reviewed.

622

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

635

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

645 the potentially useful decision support systems and models, which in turn might trigger
646 attempts to use them in practice.

647

648 **DISCLOSURE STATEMENT**

649 The authors report no potential conflict of interest.

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949 **Tables**

950

951 **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>i</i> " has one of the previously mentioned numbers assigned to it when compared to factor " <i>j</i> ", then <i>j</i> has the reciprocal value when compared to <i>i</i> . |

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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 |

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955 **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., Dzung, 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 |
| 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 | - |

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|-----------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|------|---------------------------|
| Transportation (5 papers, 6.49%) | Improving the performance of indoor environmental quality of residential buildings | Lai, J.H.K., and Yik, F.W.H. | 2009 | - |
| | 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 | - |
| Housing (4 papers, 5.19%) | To develop an effective and practical quality index for highway construction | Minchin, R.E., Hammons, M.I., and Ahn, J. | 2008 | MCS |
| | 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 |
| Contractor prequalification and selection (4 papers, 5.19%) | Optimization in temporary housing projects | El-Anwar, O., and Chen, L. | 2013 | Haversine formula |
| | 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 |
| Competitive advantage/competitiveness assessment (4 papers, 5.19%) | A decision support system for contractor selection in Turkey | Topcu, Y.I. | 2004 | - |
| | 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 | - |

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|--------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|------|---------------------|
| Building design (3 papers, 3.90%) | Evaluation and selection of concrete pumps for a project | Tam, C.M., Tong, T.K.L., and Wong, Y.W. | 2004 | SIR method |
| | 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 |
| Dispute resolution (3 papers, 3.90%) | Improving design decisions to affect building performance | Hopfe, C.J., Augenbroe, G.L.M., and Hensen, J.L.M. | 2013 | Simulation |
| | 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 | - |
| Health and safety management (2 papers, 2.60%) | Selection of dispute resolution methods for international construction projects | Chan, E.H.W., Suen, H.C.H., and Chan, C.K.L. | 2006 | MAUT |
| | 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 | - |

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|---------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|------|-------------------------------------------------------------------------|
| 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 | - |

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|----------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|------|-------------------------------------------|
| 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 |

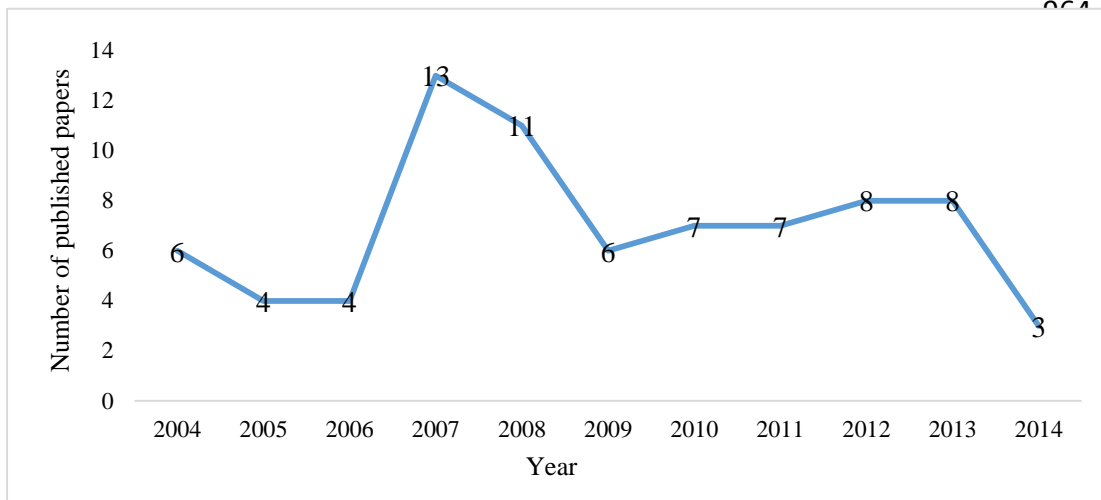
956 Note: ^a Decision areas with one paper on AHP application, representing 1.30% of the total sample; S-BIM = Structural building information modelling; MAUT = Multi-attribute
957 utility theory; SA = Sensitivity analysis; ANOVA = Analysis of variance; FAST = Functional analysis system technique; QFD = Quality function deployment; DEA = Data
958 envelopment analysis; SIR = Superiority and inferiority ranking; OLAP = Online analytical processing; GIS = Geographical information system; LCA = Life-cycle assessment;
959 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 =
960 Kraljic purchasing portfolio matrix; MDS = multidimensional scaling; MCS = Monte Carlo simulation; NN = Neural Network; and GA = Genetic Algorithm.

961 **Table 4.** Country-wise application of AHP.

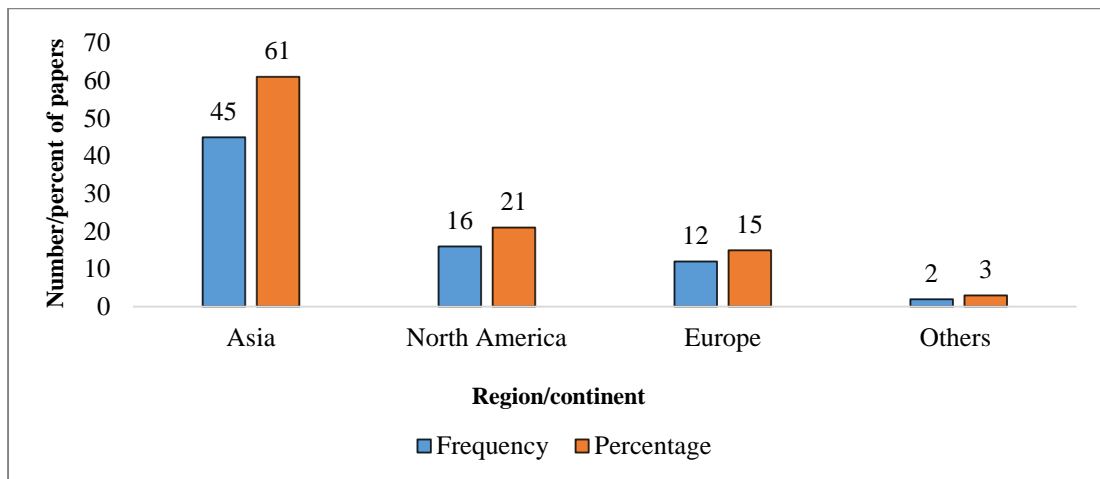
| No. | Country | Number of papers |
|-----|----------------------|------------------|
| 1 | US | 11 |
| 2 | Taiwan | 10 |
| 3 | UK | 8 |
| 4 | Hong Kong | 6 |
| 5 | Korea | 6 |
| 6 | China | 6 |
| 7 | Canada | 5 |
| 8 | India | 4 |
| 9 | Israel | 4 |
| 10 | Kuwait | 3 |
| 11 | Spain | 2 |
| 12 | United 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 |

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963 **Figures**



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



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974 **Fig. 2.** Region-wise application of AHP.

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

27

28 **KEYWORDS**

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

31

32 **INTRODUCTION**

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

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47 Saaty's (1980) AHP represents a popular MCDM method that has attracted considerable
48 attention throughout industry, including construction, over the past two decades. Construction
49 decision-making problems in particular, have been characterized as being complex, ill-defined

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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

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75 clear signposting to potentially useful decision support systems and models, which in turn may
76 trigger greater usage in practice.

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78 **AHP DECISION-MAKING METHOD**

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

87

88 The AHP consists of three steps: (1) *hierarchy formation* – the first level of the hierarchy
89 contains the decision goal, whereas the subsequent lower levels represent the progressive
90 breakdown of the decision criteria, sub-criteria, and the alternatives for reaching the decision
91 goal; (2) *pairwise comparisons* – decision makers (who are often domain experts) are asked to
92 complete pairwise comparisons of the elements at each level of the hierarchy, assuming the
93 elements are independent of each other. In this regard and considering the decision goal,
94 comparisons are made between the relative importance of every two criteria at the second level
95 of the hierarchy. Every two sub-criteria under the same criterion (at level two) are also
96 compared, and so on and so forth. These pairwise comparisons are often based on a nine-point
97 scale, as shown in Table 1 (Saaty, 1980); and (3) *verification of consistency* – expert judgments
98 are necessary for determining the relative importance of each criterion and any alternative to
99 achieving the decision goal. Because AHP allows subjective judgments by decision makers,

100 consistency of the judgments is not automatically guaranteed. Therefore, consistency
101 verification is essential to ensuring optimized outcome. Saaty (2000) mentioned that to control
102 the consistency of pairwise comparisons, a computation of consistency ratio should be
103 performed. At this stage, decision makers are required to revise their initial judgments if the
104 computed consistency ratio exceeds the threshold of 0.1 (Saaty, 2000). After all of the
105 necessary pairwise comparisons, and revisions have been made, and the consistency ratio has
106 also been found to be less than 0.1, the judgments can then be synthesized to prioritize the
107 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

125 or secondary decision-making tool as some simply mentioned AHP in the literature review
126 and/or recommended its application for future research. A review of each paper's contents was
127 then undertaken to filter out unrelated papers; 77 papers were eventually considered valid for
128 further analysis. Table 2 shows the number of relevant papers collected from each of the
129 selected journals. It reveals that 25 of the papers were from JCEM, 13 were from AIC, 10 were
130 from BE and nine were from CME, in total representing 74% of the sample. The remaining
131 papers were distributed across the other four journals.

132
133 **[Insert Table 2 about here]**
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135 The next sections offer an overview of the benefits of applying AHP to construction-related
136 decision-making problems, identifying the specific decision areas and decision problems to
137 which AHP could be applicable or useful. Moreover, a concise review of the literature (based
138 on the top six identified decision areas) is provided to demonstrate the versatility and worth of
139 AHP in diverse construction situations. Where applicable, the application cases reviewed in a
140 certain decision area are divided into stand-alone and integrated approaches – depending upon
141 whether the AHP was used in a particular case as a sole method or in combination with other
142 notable methods. This approach will help to elucidate upon the inherent flexibility of AHP in
143 terms of combining it with other methods to analyze and model construction-related decisions.

144 145 **REVIEW OF AHP APPLICATIONS IN CM**

146 **Identification of Decision Areas and Decision Problems**

147 As the most commonly used MCDM method, AHP attracts the most attention from decision
148 makers because of the availability of extensive literature on its application (Jato-Espino et al.,
149 2014). It is thus essential to better understand the specific decision problems that AHP can

150 resolve. Such an understanding would greatly stimulate interest in AHP applications within the
1
2 151 wider areas of CM.

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6
7 153 Table 3 presents all of the 77 identified papers and provides a quick reference guide and
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9
10 154 meaningful information about the applications of AHP in CM. The table was developed based
11
12 155 on information extracted from the reviewed papers. First, the papers' research interests/ topics
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14 156 aided the identification of the decision areas. Based upon this, AHP has been found to be
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17 157 applicable to many different areas of CM. Second, the papers' research aims/ objectives
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19 158 presented the decision problems that AHP was used to address. This showed that AHP has been
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22 159 applied to numerous construction-related decision-making problems. These findings suggest
23
24 160 that AHP is useful in enabling strategic and sound decision-making in a wide range of CM
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26 161 areas, which is consistent with the viewpoint of Jato-Espino et al. (2014). Following the
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29 162 identification of the decision areas and problems, the reviewed papers were then grouped,
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32 163 based upon the decision problems, under the decision areas. Each paper was assigned to only
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34 164 one decision area, thus if a paper appears to have multiple research interests [e.g., Lai and Yik's
35
36 165 (2009) paper addressed both sustainability and housing/residential building issues], it was
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39 166 assigned to the best-fit decision area, as suggested by Hong et al. (2012). Although deciding
40
41 167 on the best-fit decision area for a paper may seem subjective and associated with some level of
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44 168 uncertainty, it is believed that variations were minimized. Lastly, the authors and years of
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46 169 publication of the reviewed papers, and other methods combined with AHP in some of the
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49 170 papers are also presented in the table.

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53 172 **[Insert Table 3 about here]**

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58 174 **Descriptive Analysis**

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

[Insert Fig. 1 about here]

185
186 With regard to geographical origins, the US and Taiwan accounted for the highest number of
187 AHP-based papers published with 11 and 10 papers, respectively, as shown in Table 4. This
188 finding suggests that the application of AHP in CM within these two developed countries is
189 relatively more mature than that in other countries. Although some developing countries, such
190 as China (6 papers) and India (4 papers), have made good progress in the application of AHP
191 in CM, there are still opportunities to conduct more studies.

[Insert Table 4 about here]

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195 Finally, the papers were also viewed from a regional perspective. Fig. 2 shows that there is a
196 relatively large number of AHP applications in Asia (45 papers, 61%) – a finding that concurs
197 with the earlier research of Jato-Espino et al. (2014). In light of the extent of construction
198 development in many Asian countries, it could be that the wide application of AHP in

199 enhancing construction decisions has been significantly helpful. This wide usage of AHP in
200 Asia should encourage other regions outside Asia to pursue AHP application in CM.

201

202 **[Insert Fig. 2 about here]**

203

204 **AHP APPLICATIONS IN IDENTIFIED CM AREAS**

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

209

210 **Risk Management**

211 Risk management is a major CM area comprising defects, misalignments, and crises that can
212 lead to inflated risks, project conflicts, and other negative performance outcomes (Zheng et al.,
213 2016). Risk management decisions are often made using multiple criteria. Interestingly, all the
214 AHP applications within the risk management area involved integrated approaches to combine
215 AHP with other techniques.

216

217 ***AHP Combined with Fuzzy Sets Theory***

218 Subramanyan et al. (2012) designed a model for construction project risk assessment by using
219 a combination of fuzzy sets theory (FSs) and AHP. During the process of designing the model,
220 FSs was used to capture both subjectivity and linguistic terms, while AHP was applied to
221 weight and prioritize various risk factors. Li and Zou (2011) also developed a FSs-AHP-based
222 risk assessment method for improving the accuracy of project risk assessment. FSs-AHP was
223 used to pairwise compare between different risk criteria – after which the pairwise comparisons

224 were synthesized to obtain risk priorities. Li and Zou (2011) proved the validity of this FSs-
225 AHP-based method to assess risks in public-private partnership (PPP) projects, by exhibiting
226 its applicability in an actual PPP expressway project. Other applications of FSs-AHP in the
227 area of risk management were presented by Zhang and Zou (2007), Zeng et al. (2007), and Zou
228 and Li (2010).

230 *AHP Combined with Fuzzy Sets Theory and Delphi*

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

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

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

248 *AHP Combined with Utility Theory*

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

253

254 ***AHP Combined with Ontology***

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

261

262 **Sustainable Construction**

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

265

266 ***Stand-alone AHP Studies***

267 Ali and Al Nsairat (2009) used AHP to develop a green building rating tool. After identifying
268 the green building assessment criteria, the criteria were weighted and prioritized using AHP.
269 Similarly, Lai and Yik (2009) applied AHP to identify the significant indoor environmental
270 quality areas in high-rise residential buildings. Specifically, AHP was used to derive
271 importance weights for various indoor environmental quality attributes. The researchers (*ibid*)
272 claimed that the results can assist facility managers in managing buildings within constrained
273 budgets. Likewise, Alwaer et al. (2010) developed a sustainability assessment model to assess

1 274 the performance of intelligent building systems in the construction industry. The assessment of
2 275 the model was based upon the use of AHP to assign relative importance weights to different
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4 276 sustainability issues; the research sought to help stakeholders choose the most suitable
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7 277 indicators for intelligent buildings.
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10 11 279 ***Integrated Approaches***

12 280 ***AHP Combined with Life-Cycle Assessment and Life-Cycle Cost Analysis***

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15 281 Lee et al. (2013) developed a rating system for assessing the economic and environmental
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17 282 sustainability of highways using life-cycle assessment (LCA) and life-cycle cost analysis
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19 283 (LCCA) as measurement methods for quantifying environmental impact and economic impact,
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21 284 respectively. AHP was used to weight different sustainability indexes as a means of
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24 285 encouraging recycling of materials, which is a vital component of a holistic sustainable
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27 286 development (*ibid*).
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31 288 ***AHP Combined with Top-Down Direct Rating, Bottom-Up Direct Rating, and Point***

32 289 ***Allocation***

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34 290 Pan et al. (2012) presented construction firms with value-based decision criteria and quantified
35
36 291 the relative importance of these for the purpose of assessing sustainable building technologies.
37
38 292 Different combinations of AHP, top-down direct rating (TDR), bottom-up direct rating (BDR),
39
40 293 and point allocation (PA) were used in different cases to weight various decision criteria by
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43 294 pairwise comparisons. Case studies involving six UK construction firms sought to examine
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46 295 decision criteria for the selection of sustainable building technologies and verified the
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49 296 effectiveness of the method developed.
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54 298 ***AHP Combined with Geographic Information System and Netweaver***

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

307 *AHP Combined with Mathematical Models*

308 El-Anwar et al. (2010) suggested a combination of AHP and mathematical functions (such as
309 sustainability index and environmental performance index) to tackle the issue of maximizing
310 the sustainability of post-disaster housing recovery and construction. To help decision makers
311 quantify and maximize the sustainability of post-natural disaster integrated housing recovery
312 efforts, sustainability metrics were computed and incorporated into an optimization model.
313 AHP was used to identify the relative importance of different sustainability metrics. Mostafa
314 (2014) also presented a stakeholder-sensitive, social welfare-oriented sustainability benefit
315 analysis model to evaluate infrastructure project alternatives. A key component of the model
316 is AHP that was used to compute stakeholder benefit preference weights.

318 **Transportation**

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

322 *Stand-alone AHP Studies*

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

330

331 *Integrated Approaches*

332 *AHP Combined with Data Envelopment Analysis*

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

338

339 *AHP Combined with FSs and Delphi*

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

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346 *AHP Combined with Monte Carlo Simulation*

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

353

354 **Housing**

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

357

358 *AHP Combined with Delphi and Analysis of Variance*

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

366

367 *AHP Combined with Sensitivity Analysis*

368 Mahdi et al. (2006) used AHP to design a decision model for reducing the construction cost
369 and waiting time caused by conflict encountered when economic versus quality decisions have
370 to be made in selecting delivery alternatives for housing projects. The effects of different
371 criteria on the selection of proper housing delivery alternatives were analyzed using AHP, after

372 which sensitivity analysis (SA) was performed to investigate the sensitivity of the final decision
373 to possible changes in judgments.

374

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

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

385

386 ***AHP Combined with Mathematical Models***

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

391

392 ***Contractor Prequalification and Selection***

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

397

398 ***Stand-alone AHP Studies***

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

405 ***Integrated Approaches***

406 ***AHP Combined with Neural Network, Genetic Algorithm, and Delphi***

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

413 ***AHP Combined with Sensitivity Analysis***

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

420 ***Competitive Advantage***

421 ***Stand-alone AHP Studies***

1 422 Sha et al. (2008) used AHP within a bespoke system to define and measure competitiveness in
2 423 the construction industry. The system can help construction enterprises better evaluate their
3
4 424 overall performance and improve their competence. The indicators at the different levels of the
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6
7 425 system were weighted using AHP.
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11 427 *Integrated Approaches*

13 428 *AHP Combined with Cluster Analysis*

16 429 Shen et al. (2006) established key competitiveness indicators for assessing contractor
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18 430 competitiveness. After formulating a list of contractor competitiveness indicators, a
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21 431 combination of AHP and cluster analysis (CA) was applied to determine the weights of project
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24 432 success criteria.
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28 434 *AHP Combined with Sensitivity Analysis and Delphi*

31 435 Wu et al. (2007) adopted the modified Delphi method, AHP, and SA to present an AHP-based
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33 436 evaluation model for selecting the optimal location of hospitals. The modified Delphi method
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36 437 was applied to define the evaluation criteria and sub-criteria that were used to construct a
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39 438 hierarchy based upon which pairwise comparison matrices were established using AHP. SA
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41 439 was performed to examine the model's response to changes in the importance of the criteria.
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43 440 Hsu et al. (2008) also presented an optimal model to evaluate the resource-based allocation for
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46 441 enterprises who sought competitive advantage in the senior citizen housing sector. The
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48 442 modified Delphi method was adopted to accumulate and integrate expert opinions to devise the
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51 443 competitive advantage criteria before AHP was applied to determine the importance weight of
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53 444 each competitive advantage criterion.
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57 446 **DISCUSSION**

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

461
462 AHP applications were also found in other important areas of CM, such as transportation (5
463 papers, 6.49%), housing (4 papers, 5.19%), contractor prequalification and selection (4 papers,
464 5.19%), competitive advantage (4 papers, 5.19%), plant and equipment management (3 papers,
465 3.90), building design (3 papers, 3.90) and dispute resolution (3 papers, 3.90). This suggests
466 that AHP is practically applicable to decision-making problems in a broad range of CM areas.
467 Generally, decision-making in the identified CM areas requires thorough analysis of multiple
468 economic, social, environmental, and technical factors whose knowledge could be arduous to
469 quantify and process. Moreover, a lack of objectivity is almost inevitable in these construction-
470 related decision-making problems due to the need to consider subjective criteria. These may

1 471 explain the reason why AHP has become popular and successful in CM. AHP can be used to
2 472 validate subjective judgments and provide a high level of consistency.

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7 474 This review not only demonstrates the usefulness and versatility of AHP and how it fits well
8
9 475 into the nature of dealing with various construction-related decision-making problems, but it
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11 476 also demonstrates AHP's flexibility and simplicity of application. The review results suggest
12
13 477 that AHP is useful and allows construction decision makers to implement it either as a stand-
14
15 478 alone tool or integrate it with other advanced decision-making methods to ensure a more
16
17 479 reliable decision-making process. Also, AHP (stand-alone and integrated) has frequently been
18
19 480 used as a method to easily identify the most important aspects of construction-related decision
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21 481 problems, affirming its appropriateness for such problems. Other decision-making methods
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23 482 (e.g., the analytic network process (ANP) and DEA) might be useful for similar purposes,
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25 483 however, they are more stringent and time-consuming, giving AHP a significant advantage
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27 484 (Jato-Espino et al., 2014). For example, although ANP is considered a general form of AHP
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29 485 (Saaty, 1996), its ability to allow interdependencies among decision criteria makes it time-
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31 486 consuming and hence difficult to apply amongst busy practitioners or decision makers.
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41 488 Regarding the nature of application, Table 3 shows that AHP was mainly applied in
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43 489 combination with other methods, with FSs being the most common method in the integrated
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45 490 AHP approaches. This could be attributed to the popular belief that AHP is incapable of
46
47 491 handling the imprecision and uncertainty involved in construction decisions and hence
48
49 492 combining it with FSs enhances its capability (Zadeh, 1965). The presence of many other
50
51 493 methods (e.g., DEA, MCS, UT, LCCA, and MAUT) in the integrated AHP approaches further
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53 494 indicates that the integration of AHP with other methods can be implemented in many diverse
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55 495 ways to conform to the nature and environment of the construction decision problem.
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496 Consequently, it would be useful if researchers and practitioners continue to apply AHP to
497 organize, analyze, and model complex construction decisions to develop more useful models
498 to support decision-making in wide-ranging areas of CM.

499

500 **When and Why to Use AHP**

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

507

508 *Small Sample Size*

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

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2 522 The extant literature on AHP applications in CM indicates that there is no strict requirement
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5 523 on the minimum sample size for AHP analysis. Some studies used sample sizes ranging from
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7 524 four to nine (Akadiri et al., 2013; Chou et al., 2013; Pan et al., 2012; Li and Zou, 2011; Dalal
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10 525 et al., 2010; Zou and Li, 2010; Pan, 2008; Lam et al., 2008; Hyun et al., 2008; Zhang and Zou,
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12 526 2007). Only a few studies used sample sizes greater than 30 (El-Sayegh, 2009; Ali and Al
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15 527 Nsairat, 2009). These findings suggest that AHP can be performed with small sample size to
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17 528 achieve useful decision results and models, which often makes it a more preferred method in
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19 529 CM research than other MCDM methods. However, it is still imperative for researchers to treat
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22 530 the choice of AHP sample size with special attention, because the possible impact of an
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24 531 optimally selected sample size on the decision outcomes cannot be undermined.

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29 533 *High Level of Consistency*

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32 534 Although AHP has been criticized for incorporating subjective judgments into the decision-
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34 535 making process, it has been proved of decreasing bias and ensuring that subjective judgments
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36 536 are validated using consistency analysis (Saaty, 1980; Saaty and Vargas, 1991). Analysis of
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39 537 the reviewed papers showed that this is one of the most prominent reasons why researchers
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41 538 selected AHP (Hsu et al., 2008; Abudayyeh et al., 2007; Shapira and Goldenberg, 2005;
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44 539 Cheung et al., 2004). AHP is capable of using both subjective and objective data for proper
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46 540 decision-making. This capability makes AHP important for construction-related decision-
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49 541 making, as subjective judgments from different experts form a crucial part of construction
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51 542 decision-making (Hsu et al., 2008). This review suggests that in construction-related decision-
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54 543 making, AHP can help ensure a high level of consistency among the judgements obtained from
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56 544 multiple experts who might have different perceptions, experiences, and understanding of the

1 545 decision criteria. This paper argues that if the reliability of decision results matters, then the
2 546 consistency of expert judgments also matters.
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6 7 548 *Simplicity and User-Friendly Software*

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9 549 Other prominent reasons stated for using AHP relate to its simplicity of implementation and
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11 550 the availability of user-friendly software, Expert Choice, for analyzing AHP data (El-Anwar
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13 551 and Chen, 2013; Hsu et al., 2008; El-Sawalhi et al., 2007; Ahmad et al., 2004; Topcu, 2004;
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15 552 Cheung et al., 2004). These aforementioned researchers argue that AHP helps to easily and
16
17 553 effectively break down a complex construction decision problem into a hierarchy that provides
18
19 554 a deeper understanding of all the criteria involved. Using this hierarchy, decision makers are
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21 555 able to pairwise compare the criteria, rather than assess the relative importance of the large
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23 556 number of tangible and intangible criteria simultaneously. This provides a structured and
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25 557 analytic, yet simple approach that does not require any special skills from the decision makers
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27 558 to determine the best solution.
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35 36 560 **FUTURE AHP APPLICATIONS IN CM**

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38 561 Reviewing the literature revealed that AHP has not been extensively applied in certain areas of
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40 562 CM and hence warrants future research attention. In this study, any CM area where only one
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42 563 paper on AHP application was found is considered as an area requiring additional attention in
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44 564 the future AHP applications; albeit areas with more than one paper may also require additional
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46 565 investigation. As shown in Table 3, CM decision areas where only one paper applying AHP
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48 566 was found include, but not limited to, quality management, knowledge management, planning
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50 567 and scheduling, pricing, and bidding of construction operations. This implies that more AHP
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52 568 applications in modeling and improving different types of decisions in these areas of CM are
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54 569 required.
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2 571 In the area of quality management, for example, only one related AHP study was found (Lam
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5 572 et al., 2008). Yet, quality is a critical issue for almost all construction stakeholders and one of
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7 573 the key criteria for measuring project success in construction. Thus, more AHP applications in
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10 574 analyzing quality management decisions are needed. Future research could expand on the work
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12 575 of Lam et al. (2008) in order to develop more decision support systems to help solve quality
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14 576 problems in construction projects. The development of such decision support systems should
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17 577 focus on incorporating and assessing not only criteria that can help achieve better quality, but
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19 578 also those that can help attain higher client satisfaction and higher productivity. Quality, client
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22 579 satisfaction, and productivity are key issues that can directly affect the overall project success
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24 580 (Lam et al., 2008). Furthermore, future AHP applications could focus on developing quality
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26 581 performance measurement models to help assess and measure the quality performance of
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29 582 different stakeholders within the construction industry. As Lam et al. (2008) mentioned, their
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32 583 developed self-assessment quality management system is a “tailor-made” system for Hong
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34 584 Kong contractors to assess and improve their quality performance. Hence, there is scope to
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36 585 develop AHP-based quality measurement models/systems for international contractors and
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39 586 other construction stakeholders to improve their quality performance.

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43 588 Knowledge management represents another promising direction for future AHP applications
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46 589 in CM. Knowledge management is about creating value from the intangible assets of an
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49 590 organization and facilitating knowledge sharing and integration (Alavi and Leidner, 1999).
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51 591 Over the last two decades, knowledge management has received increasing attention from
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54 592 practitioners; consequently, many organizations and individuals have developed multiple
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56 593 frameworks for knowledge management in different industries (Rubenstein-Montano et al.,
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58 594 2001). Undoubtedly, many construction organizations lack such frameworks. Accordingly,
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595 future AHP applications could focus on developing knowledge management frameworks for
596 identifying the processes, mechanisms, cultures, and technologies essential for implementing
597 knowledge strategies in construction organizations. Such frameworks can assist construction
598 organizations leverage knowledge both inside their organizations and externally among their
599 shareholders and customers (Rubenstein-Montano et al., 2001). Although future AHP
600 applications are needed in many other areas of CM (Table 3), the above discussion is limited
601 to quality management and knowledge management because of brevity.

603 **LIMITATIONS OF THIS STUDY**

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

618 **CONCLUSIONS**

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

627
628 The findings revealed that risk management and sustainable construction were the most popular
629 AHP application areas in CM. In addition, it was identified that AHP is flexible and can be
630 used as a stand-alone tool or in conjunction with other tools to rigorously tackle construction-
631 related decision-making problems. Moreover, a descriptive analysis of the reviewed papers
632 showed a wide application of AHP in Asia. Reasons behind the wide adoption of AHP are that
633 it does not require large sample size, it can achieve a high level of consistency, and it is easy
634 to implement. Based upon the findings presented, directions for future AHP applications were
635 proposed. To summarize, the findings suggested that AHP (whether stand-alone or integrated)
636 can help researchers and practitioners address a variety of decision-making problems that
637 matter. As such, construction researchers, practitioners, and institutions are advised to consider
638 AHP applications when the need to analyze multicriteria decisions in wide-ranging areas of
639 CM arises.

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641 This paper could be useful for researchers and practitioners interested in the application of
642 AHP to analyze and model construction decisions. For researchers, this paper provides a
643 comprehensive review of past AHP-based studies in CM, which is necessary for conducting

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644 future studies. In addition, this paper could help practitioners better understand and judge the
645 usefulness of AHP in tackling specific decision-making problems in CM, which could
646 encourage its wider use in CM. Notably, decision support systems and models developed for
647 the construction industry are myriad as a result of AHP usage. However, practitioners may not
648 find it easy to locate these systems and models, as they are scattered throughout the extant
649 literature. With the help of this review paper, practitioners could readily become familiar with
650 the potentially useful decision support systems and models, which in turn might trigger
651 attempts to use them in practice.

652

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658

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 48 958 study of Nanjing Subway Line 2. *Construction Management and Economics*, 28(12),
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960 **Tables**

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2 962 **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>i</i> ” has one of the previously mentioned numbers assigned to it when compared to factor “ <i>j</i> ”, then <i>j</i> has the reciprocal value when compared to <i>i</i> . |

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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 |
| 9 | Total | 77 | 100 |

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966 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., Dzung, 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 |
| 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 | - |

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|-----------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|------|---------------------------|
| | 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 |
| Contractor prequalification and selection (4 papers, 5.19%) | Optimization in temporary housing projects | El-Anwar, O., and Chen, L. | 2013 | Haversine formula |
| | 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 | - |

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|--------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|------|---------------------|
| | 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 | - |

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| 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 | - |

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| 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.

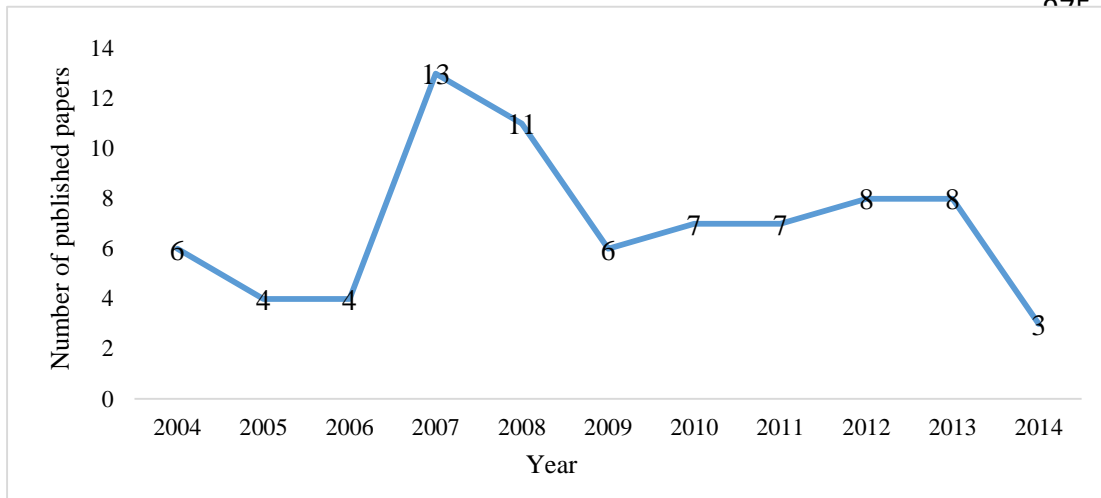
972 **Table 4.** Country-wise application of AHP.

| 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 |

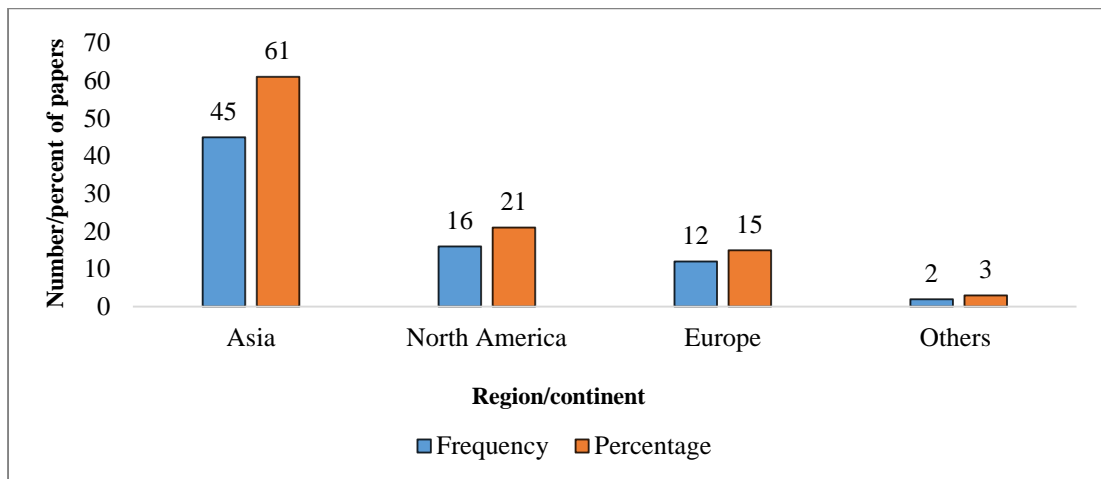
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974 **Figures**



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



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985 **Fig. 2.** Region-wise application of AHP.

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

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