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2 **Critical Factors Influencing Adoption of Blockchain-Enabled Smart Contracts in**
3 **Construction Projects**

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7

8 **ABSTRACT**

9 Construction projects are premised upon contractual arrangements, and contracts constitute the basis of
10 their success. A contract enables execution of work and transfer of payments, tracking of key
11 performance indicators and facilitation of collaboration between project stakeholders. Historically,
12 construction projects have faced critical challenges due to poor alignment between clients' expectations,
13 contract terms and contractor performance. The advent of advanced digital technologies under the
14 concept of Industry 4.0 has the potential to benefit construction projects through application of
15 blockchain-enabled smart contracts. However, the adoption of smart contracts in construction projects
16 is at its early stage and what factors will influence its adoption remain unclear. Therefore, this study
17 seeks to explore and establish the critical factors influencing adoption of smart contracts in construction
18 contractual arrangements. Drawing on an international questionnaire survey of experienced
19 construction practitioners with involvement in smart contract initiatives and activities, the results
20 obtained from descriptive statistics and fuzzy set-based analysis show that trialability, relative
21 advantage, competitive advantage and compatibility of smart contracts are the important predictors of
22 their adoption. The findings suggest that practitioners share a view that technological characteristics of
23 blockchain-enabled smart contracts are critical to its adoption, regarding the technology's perceived
24 practicality in improving effectiveness and efficiency of construction projects. This study contributes
25 to technology diffusion research in construction and highlights drivers that require practitioners' and

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26 industry leaders' attention in order to ensure successful adoption of smart contracts for cost-effective
27 delivery of construction projects.

28 **Keywords:** Smart contracts; Blockchain technology; Construction projects; Construction industry

29

30 INTRODUCTION

31 The construction industry is a primary driver of economic growth and social development, ensuring the
32 delivery of critical infrastructures for other sectors, creation of jobs and contribution to national gross
33 domestic product (GDP). For example, construction contributes about 6% and 8% to UK's and
34 Australia's GDP, respectively (Pervez 2021; Hook 2019). Globally, McKinsey (2017) estimated that
35 around US\$10 trillion is expended on construction products and services annually. However, the
36 construction industry has long been confronted with several challenges that hinder its effective
37 performance, including poor productivity (McKinsey 2017), poor payment practices and associated
38 cash flow difficulties and insolvencies (Peters et al. 2019; Collins 2012), contractual disputes and
39 litigations (Carmichael 2002), and lack of trust and transparency (Edwards and Bowen 2003).
40 Historically, productivity in construction has lagged behind the manufacturing, retail and agriculture
41 industries, with an estimated global construction productivity gap of US\$1.6 trillion (McKinsey 2017).
42 According to McKinsey Global Institute, traditional contracts remain detrimental to increased
43 productivity in construction; efficient contracting practices can reduce cost by 6–7% and raise
44 productivity by 8–10% (McKinsey 2017).

45 Uncertainty in payments represents another well documented major challenge facing construction
46 projects (Collins 2012; Peters et al. 2019; PwC 2019). Late or non-payments result from clients'
47 unwillingness or inability to pay, or disputes over amounts due (Li et al. 2019). This creates adverse
48 impacts on projects, including cost and time slippages, project failures, cash flow difficulties and
49 mistrust (Collins 2012; Manu et al. 2015; Duryez and Hosseini 2019). An inquiry into insolvencies in
50 New South Wales' (Australia) construction industry revealed non-payments or payments withheld as
51 the primary cause (Collins 2012). Also, PwC's (2019) survey of SMEs revealed that 77% of companies
52 had cash flow difficulties resulting from late payments and that required substantial investment of
53 resources and time to chase payments.

54 Construction disputes are widespread with dire consequences on projects and stakeholders. The industry
55 is highly fragmented and characterised by adversarial, rather than collaborative, relationships
56 (Carmichael 2002). A primary cause of construction disputes has been linked to poor payment practices
57 and the resultant cash flow problems (Collins 2012; Peters et al. 2019). In its '*Global Construction*
58 *Disputes*' report, Arcadis (2020) observed that the global average cost of disputes is estimated at
59 US\$30.7 million, and the average dispute resolution time is 15 months. The Middle East recorded the
60 highest average cost of disputes of US\$62 million and North America saw the highest average length
61 of disputes (17.6 months). The report highlights collaboration among project stakeholders as a strategy
62 for disputes avoidance, mitigation and resolution. Unfortunately, a collaborative culture is lacking in
63 the construction industry, which is a contributor to failed projects (De Schepper et al. 2014).

64 As an efficient way to address the above challenges and to deliver effective construction projects, digital
65 technologies are receiving attention from researchers, practitioners and industry leaders (Penzes et al.
66 2018; Li et al. 2019). Blockchain and its innovations, such as blockchain-based smart contracts (or
67 smart contracts), are seen as an innovative technology with a potential solution to the foregoing
68 challenges (Hamledari and Fischer 2021; Li et al. 2019; Yang et al. 2020), by making construction
69 projects transparent, accountable and collaborative (Penzes et al. 2018; EY 2018). Administration of
70 smart contracts can significantly benefit construction projects, and several opportunities exist to
71 leverage this technology in the construction industry. Based on its innate characteristics of *immutable*,
72 *secure and traceable*, smart contracts offer a collaborative working environment between clients,
73 contractors, subcontracts, suppliers, and consultants (EY 2018). Such collaborative working improves
74 trust, reduces disputes and provides alignment between contracting parties.

75 Smart contract technology challenges the contractual model of the highly fragmented construction
76 industry (Arup 2019). Construction projects are procured using traditional contracts which are
77 characterised by intensive documentation and information. This renders some of the contractual
78 processes, such as preparation of interim payment applications, time-consuming, unsecure and
79 frequently erroneous. Blockchain-based smart contracts could help to automate contractual transactions
80 and eliminate paper-based traditional contracts (Hamledari and Fischer 2021) which are easy to forge

81 and take longer to move between contracting parties, making the contractual processes efficient and
82 secure (Ream et al. 2016).

83 For construction projects, a key area of application of smart contracts is automation of transactions and
84 payments (Hamledari and Fischer 2021; Cardeira 2016). Blockchain-based smart contracts can be
85 designed to automate transactions between contracting parties and automatically effect partial or full
86 payments to contractors, subcontractors and suppliers upon completion of work. Here, contract
87 conditions and schedules of payment are coded into smart contracts upfront (Arup 2019), which execute
88 themselves without third-party intermediaries through automated protocols (Hargaden et al. 2019;
89 Nawari and Ravindran 2019). Automated payment transactions are critical to addressing the problems
90 of late or non-payments and negative cash flow.

91 Linked to payments automation is improved cash flow through execution of blockchain-enabled smart
92 contracts. This development is expected to be a significant step forward for the construction industry
93 which is frequently cash poor. Smart contracts can be designed to run on the blockchain to manage and
94 monitor construction progress with the advantage of managing cash flow (Hunhevicz 2019). The extent
95 and consequences of cash flow problems was perhaps exemplified by the failure of UK's Carillion Plc.
96 (second largest construction and facilities management company) in January 2018 and further highlights
97 the need for smart contract technology. Carillion suffered late payments and was in debt of £1.5 billion
98 (Thomas 2018). Given Carillion's extended 120-day payment period (Li et al. 2020), the effect of its
99 collapse was felt throughout its supply chains. Blockchain presents a promise to solve such supply chain
100 problems; funds are held centrally on a decentralised blockchain system and authorised following
101 completion and verification of work (Arup 2019). On a construction project, this would help to avoid
102 or reduce intermediaries but also prevent clients from withholding payments to contractors and
103 contractors holding back payments to subcontractors, with the benefit of improved cash flow (Arup
104 2019).

105 Despite the foregoing potential of and growing interest in blockchain-based smart contracts, there are
106 limited applications of the technology in administering construction projects. And due to the relative
107 immaturity of smart contracts in construction previous scholarly work that has investigated adoption

108 and implementation at project level remains scant. Specifically, what factors will influence smart
109 contract adoption in construction projects remain unclear. This gap in the current literature is a barrier
110 that further hampers a wider adoption of smart contracts in construction projects and the industry. Also,
111 given the construction industry's inability or reluctance to embrace innovative technologies (Nikas et
112 al. 2007; Merschbrock 2012) previous studies on other technologies (e.g., BIM) explore factors and
113 external pressures exerting influences on their adoption (Ahuja et al. 2009; Cao et al. 2014; Pan and
114 Pan 2021), as a means to incentivise industry stakeholders towards acceptance and adoption of
115 technological innovations. Against this backdrop, it is therefore valuable and timely to investigate the
116 critical factors exerting influences on adoption of smart contracts based on construction practitioners'
117 perceptions. According to Cao et al. (2014), a project constitutes the fundamental unit of construction
118 and the decision adopt a technology is made at the project level. Therefore, this study considers the
119 adoption of smart contracts at the construction project level.

120 This research draws on international construction professionals with experience and interests in smart
121 contracts initiatives to provide a global perspective on factors influencing their adoption. This study
122 extends the scholarly work on technology diffusion in construction and highlights the primary drivers
123 for greater adoption of blockchain-enabled smart contracts construction projects. It is the first empirical
124 work to explore smart contracts adoption at construction project-level.

125 126 **LITERATURE REVIEW**

127 ***Blockchain Technology***

128 In its report, Arup (2019) noted that stripping the hype around blockchain, the technology possesses
129 unique characteristics capable of solving many of the omnipresent challenges plaguing the construction
130 industry. Blockchain is a data storage method; it is a shared digital ledger that enables the recording of
131 several transactions as well as tracking of tangible, intangible and digital assets in a network. These
132 assets (e.g., land, house or copyrights) are tracked and traded on the blockchain network at low risk and
133 reduced transaction costs (Gupta 2020). Each data block stores a series of transactions together with a
134 cryptographic summary of the preceding block, making the data blocks chained together and
135 consequently the transactions (data) immutable (Hamledari and Fischer 2021).

136 Blockchain presents an architecture that enables *nodes* (users) in a network to share an updated ledger
137 via a peer-to-peer replication during a transaction, and consensus is therefore reached in peer-to-peer
138 blockchain networks (Narayanan 2016). A blockchain network introduces a censorship-resistant shared
139 ledger of transactions that are efficient and economical because it avoids or minimises the requirement
140 for intermediaries and duplication of effort, and it is less vulnerable as it adopts a decentralised
141 consensus protocol to verify data (Gupta 2020). Therefore, nodes can authenticate and validate
142 transactions. In the Fintech sector, a popular use case of blockchain technology is Bitcoin (Nakamoto
143 2008) where blockchain provides a platform to record and store Bitcoin transactions (Bart et al. 2017).
144 Ethereum’s blockchain (Buterin 2014) comes with a protocol and a built-in Turing-complete language
145 allowing any user to create decentralised applications (DApp) and smart contracts (Buterin 2014) which
146 can be executed on the Ethereum virtual machine (EVM). EVM is a decentralised world computer that
147 makes it impossible to tamper with smart contracts (Hamledari and Fischer 2021).

148 ***Blockchain-enabled Smart Contracts***

150 Smart contracts are among the highly disruptive and critical blockchain technology-enabled innovations
151 (Arup 2017). The notion of a smart contract was introduced in 1994 by a legal scholar and a computer
152 scientist, Nick Szabo (Szabo 1994). Szabo defines a smart contract as “a computerised transaction
153 protocol that executes the terms of a contract.” The automated transaction protocol seeks to achieve
154 three broad objectives: to satisfy terms of contractual agreements, reduce both malevolent and
155 accidental errors, and reduce the requirement for intermediaries in enforcing a contract. In other words,
156 a smart contract is a digital computer code (or a programmable contract) that eliminates trusted third
157 parties and self-executes its terms upon satisfaction of pre-set conditions; the code is linked to digital
158 currencies (e.g., ether, bitcoin) as the representation or payment of an asset(s) (Arup 2017; Yang et al.
159 2020). Szabo (1994) discussed some economic gains of automated contracts which include reduced
160 contractual arbitrations [through automation], low fraud loss, and reduced cost of enforcing contracts
161 and transactions.

162 Arup (2017) outlined three unique properties for smart contracts viz: first, a smart contract is only
163 recorded on or enabled by blockchain. This allows a smart contract to ‘inherit’ properties of the

164 blockchain technology, including censorship resistance, immutability, high security, *etc.* Second, the
165 recording and transfer of assets on a blockchain is controlled by a smart contract. Third, a smart contract
166 is executed by a blockchain, and this can only be changed through a consensus by users. These
167 properties differentiate smart contracts from other computerised systems / software. Today, the advent
168 of blockchain technology and Bitcoin (Nakamoto 2008; Arup 2017) are advancing the concept of smart
169 contracts in many industries including construction. Blockchain-based smart contracts can enable a
170 number of construction processes to be automated, improved and made more efficient (Penzes et al.
171 2018).

172 *Previous Studies on Smart Contracts in Construction*

174 There is a growing interest from industry and academia on blockchain and smart contracts in the
175 construction industry (Li et al. 2019; Arup 2019). However, there is scant scholarly work on the subject
176 due to the relative immaturity of the smart contract technology (Laulathi et al. 2017). Pertinent
177 literature within the small body of knowledge includes the work of Yang et al. (2020) who drew on two
178 cases to demonstrate practical applications of public and private blockchain technologies in construction
179 business processes. The authors (*ibid*) demonstrated how a smart contract was implemented for
180 procuring a high-priced equipment for an international construction project and highlighted the ability
181 of smart contracts to eliminate payment delays and disputes and enhance contract administration. Li et
182 al. (2019) provided a review of state of blockchain in the built environment and construction industry
183 and proposed a roadmap for adoption. In appraising use cases, Li et al. emphasised that *regulation and*
184 *compliance* and *project bank accounts* are potential areas for application of blockchain technology.
185 With its characteristics, a smart contract is capable of automating current manually administered
186 payment principles of a project bank account in public construction projects, thereby eliminating the
187 consequences of late payments, non-payment and insolvencies in the construction industry.

188 Mason (2017) described BIM as the forerunner of smart contracts where blockchain serves as the
189 platform for running smart contracts and that semi-automation, rather than full automation, of contracts
190 is the possible outcome. This assertion is informed by the current limitations of the technology,
191 complexity of projects with frequent variations and the need for human interventions in managing

192 construction contracts (Gabert and Grönlund 2018). Hence, smart contracts could be more suited for
193 simple transactional activities in construction (Mason 2017). Badi et al. (2021) applied the technology-
194 organisation-environment (TOE) model to examine and identify factors influencing adoption and use
195 intention of smart contracts in the UK construction sector. The TOE framework is useful at examining
196 the key influences for adopting technologies within firms, with a focus on technological, organisational,
197 and environmental considerations (Oliveira and Martins 2010). Badi et al.'s (2021) study contributes to
198 understanding of construction organisations' attitudes and perceptions toward smart contracts use; its
199 major limitation, however, is the focus on the UK's construction sector. Given the global interest in
200 smart contracts, it is imperative to explore what global influences are driving adoption and use of smart
201 contracts.

202 In another study, Hamledari and Fischer (2021) explored the use of blockchain-based smart contracts
203 in automation of interim payments in construction projects, as a means to resolve the inefficient
204 workflows and time-consuming document processing associated with traditional payment practices.
205 Their study presented a use case to illustrate smart contract-based payment processes with an unmanned
206 aerial vehicle-based progress monitoring. As noted earlier, blockchain-based automation of progress
207 payments will benefit project stakeholders through reduced inefficiencies, contractual disputes and
208 opportunity for fraud and corrupt transactions by providing a 'single source of truth for projects'
209 (Zhong-Brisbois 2019; Hamledari and Fischer 2021). Progress payments automation could also reduce
210 costs by minimising or avoiding multiple intermediaries.

211 The above literature review evidence that smart contract technology can mitigate some of the pertinent
212 problems plaguing construction projects such as inefficient payment practices, high incidence of
213 disputes, and poor contract administration. The literature review also shows that potential areas of
214 application of smart contracts include regulation and compliance, and project bank accounts. Also, it is
215 clear that smart contract has a significant role to play in payments processing and security in
216 construction projects. The current scholarly work is limited to possible use cases and benefits of the
217 smart contract technology.

218
219 ***Prior Studies on Adoption of Digital Technologies in Construction***

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221 Construction research continues to explore adoption of various digital technologies in its attempt to
222 address the challenges plaguing construction projects, organisations and the industry. Nikas et al. (2006)
223 examined the antecedents and drivers that influence adoption of collaborative information technologies
224 in the construction industry. The results showed that senior management's commitment to employees'
225 training and skills development and increasing size of an organisation are the primary factors affecting
226 intention to adopt collaborative technologies. In studying information, communication and technology
227 (ICT) adoption, Ahuja et al. (2009) reported that technical, managerial and people issues are the primary
228 factors driving adoption of ICTs in building project management in the construction industry. In a
229 related case study of three large construction organisations in Australia, Peansupap and Walker (2005)
230 reported that the important factors influencing adoption of ICT are related to management, individual,
231 technology and workplace environment issues.

232 Lee et al. (2013) proposed a BIM acceptance model from the perspectives of individuals and
233 organisations and reported that perceived usefulness of BIM technology and behavior control (internal
234 and external pressure) directly influence individual's intention to adopt and use BIM. Using the
235 institutional theory, Cao et al. (2014) investigated the effects of the coercive, mimetic and normative
236 isomorphic pressures on adoption of BIM in construction projects. Drawing on survey data from
237 construction projects in China, the study showed that mimetic and coercive pressures have a significant
238 effect on BIM adoption in construction projects while normative pressure indicated no influence. In a
239 similar study carried out in the UK, Howard et al. (2017) surveyed the perceptions of construction
240 practitioners working with BIM to determine the issues impeding proliferation of the technology at the
241 individual level. The authors (*ibid*) observed that performance expectancy does not impact behavioral
242 intention to use BIM, and that individuals using BIM may not necessarily anticipate job performance
243 rewards from using it. From the perspective of building contractors in Hong Kong, Pan and Pan (2021)
244 observed that top management support is the most influential determinant of construction robots
245 adoption. Other important determinants include relative advantage, organisational readiness,
246 competitive pressure, and high costs. Prior literature on technology adoption has focused on ICT, BIM

247 and/or other general digital technologies. Every technology is unique, and its adoption and use is
248 influenced by a different set of factors.

249 Smart contract is a new digital technology in the construction industry, understanding the important
250 factors that affect its successful adoption in construction projects will enhance its adoption rate and use.
251 However, existing literature has not fully attempted to understand the drivers for acceptance and
252 adoption of smart contracts at construction project level. The diffusion of the smart contract technology
253 will not grow in construction projects unless there exists a body of knowledge providing better
254 understanding among project stakeholders of the primary enablers of smart contracts. The construction
255 industry is a laggard in embracing and adopting innovative technologies (Merschbrock 2012), and
256 therefore, to advance adoption of new technologies has often required research to investigate and
257 establish the factors influencing their adoption (Cao et al. 2014; Hwang et al. 2022). This is also true
258 for smart contracts and a wider acceptance and adoption of the technology will depend on bottom-up
259 efforts from stakeholders at construction projects level. This is because technology adoption decision
260 is made at project level (Cao et al. 2014), thereby driving adoption. In addition, there is a global attention
261 on smart contracts, and therefore, awareness and understanding of the global influences affecting
262 adoption of the technology is imperative for advocates and the international construction industry. Yet,
263 very few studies have investigated what would influence smart contracts adoption in construction
264 projects from the perspective of construction practitioners. The current study contributes to filling this
265 knowledge gap by exploring the influences driving the adoption of smart contracts in construction
266 projects from the perspective of construction practitioners across countries. Specifically, this study
267 identifies and prioritises the critical factors exerting influence on adopting smart contracts.

268 269 ***Multi-Level Fuzzy Synthetic Evaluation (FSE) Method***

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271 The fuzzy set theory (Zadeh 1965) is a mathematical logic to represent and manipulate fuzzy terms,
272 such critical, very critical, and extremely critical, and uses grades of membership in sets as opposed to
273 the true or false membership in traditional sets. Fuzzy sets are capable of representing a varying degree
274 of truth values and includes any real number between 0 and 1, and therefore, the value of membership
275 function in a fuzzy set defines the degree to which an object belongs to the set (Tah and Carr 2000).

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The fuzzy synthetic evaluation (FSE) is a branch of the fuzzy set theory and uses fuzzy mathematics to model and quantify vague expressions that are present in natural language. These vague, fuzzy expressions are called linguistic variables in a fuzzy set environment (Wei et al. 2010; Xu et al. 2010). In practice, a set of factors are frequently evaluated based on expert judgement of decision-makers (such as survey participants) using linguistic variables such as disagree, agree, and strongly agree. The FSE method provides a mathematical way to define and quantify such fuzzy expressions (Thomas et al. 2006). Kuo and Chen (2006) noted that FSE has attributes for evaluating objects or factors. A comprehensive evaluation is performed on the relevant objects to generate the overall evaluation. In producing an overall evaluation, not only the main factors (or objects) are considered, but the sub-factors which define each principal factor are considered which leads to a multi-level problem which is solved by the multi-level FSE. The multi-level fuzzy model is most useful and suited method for calculating the membership values from the lowest level (sub-factors) to the top level (principal factors) (Wei et al. 2010; Hsiao 1998). For example, in this study, the multi-level fuzzy model is used to calculate the overall evaluation score of each critical factor group (CFG) by first determining the membership values of the sub-critical factors that define each CFG. Hence, the evaluation score of a CFG is obtained through deriving the membership values, and then de-fuzzifying the evaluation fuzzy vector, of the CFG. There are attempts to apply FSE method within construction to evaluate and prioritise factors or objects. Tran et al. (2011) proposed a fuzzy set-based methodology to rank the probability and consequences of manhole collapses. Liu et al. (2013) used the FSE method to assess and rank risks associated with construction drilling projects. Xu et al. (2010) used the FSE method to prioritise and rank-order the risks associated public-private partnership (PPP) projects.

RESEARCH METHODS

To explore the phenomena under investigation, this research largely employed an empirical epistemological lens (Merriam 2009) to analyse primary quantitative data collected from a structured questionnaire survey (Hoxley 2008). To explore and reveal factors that influence smart contracts adoption, an interpretivist philosophical stance (Leitch et al. 2010) was adopted in the literature review

305 sections. This enabled the factors identified from the literature (see below) to be refined and
306 reconstructed to suit the study's aim. A questionnaire survey instrument was then prepared premised
307 upon the factors obtained from the literature review – thus constituting a virtuous knowledge cycle on
308 existing theories contributing towards generating new insight. The research methods and approach are
309 described in the sections below. The overall research framework is presented in Fig. 1.

310 **Insert Fig. 1 around here**

311
312 ***Identifying Factors Influencing Smart Contracts Adoption***

313 The list of factors influencing adoption of smart contracts is constructed based on a review of: (a) related
314 academic studies on blockchain and smart technologies (Yang et al. 2020; Hamledari and Fischer 2021;
315 Badi et al. 2021). Given the limited scholarly work on smart contracts, relevant studies were purposively
316 searched on websites of top-ranked construction journals; (b) industry reports on blockchain/smart
317 contracts applications in the construction sector, including publications by construction professional
318 bodies and individuals (Penzes et al. 2018; Cardeira 2016; Ream et al. 2018) and consulting firms (Arup
319 2017, 2019; EY 2018); and (c) technology acceptance theories and technology diffusion studies in
320 construction (Lee et al. 2013; Cao et al. 2014). The outcome of the review exercise yielded 27 factors
321 that could potentially drive smart contracts adoption in construction projects. The factors were carefully
322 constructed to suit the context of the current study and presented in Table 1.

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

324
325 ***Questionnaire Survey***

326 The questionnaire was administered to construction practitioners with experience in and/or working on
327 smart contracts initiatives as well as construction academics and researchers focused on blockchain and
328 smart contract technology applications. The questionnaire was initially designed based on outcome of
329 literature review and subsequently, comments from experienced researchers currently working on this
330 subject. Specifically, these researchers provided comments on the data collection instrument's design,
331 structure, scope, appropriateness, wording and clarity of the constructs. The wording of the smart
332 contracts' adoption factors was informed by Badi et al. (2021), but with changes and refinement to suit

333 the context and purpose of the present study. This approach provides an inbuilt validity to the
334 questionnaire (Howard et al. 2017). A questionnaire survey was used as the primary data collection
335 method because it is anonymous, provides reliable data at minimal cost (Cohen et al. 2007), and captures
336 knowledge and experiences of respondents (Hoxley 2008). Also, the questionnaire survey method is
337 widely utilised by researchers to investigate factors influencing technology adoption in construction
338 (Howard et al. 2017; Lee et al. 2013; Cao et al. 2014). The questionnaire consisted of a five-point rating
339 scale (1 = strongly disagree and 5 = strongly agree) that were used to solicit knowledge and opinions of
340 the survey respondents.

341 Likert scales are widely used in the construction management and engineering research (e.g., Li et al.
342 2013; Ameyaw et al. 2017; Murphy et al. 2015; Howard et al. 2017; Cao et al. 2014; Lee et al. 2013;
343 Gunduz and Elsherbeny 2020). Construction researchers use Likert scales when conducting surveys of
344 attitudes and opinions in evaluating objects or factors. Likert scales frequently contain a midpoint word
345 such as 'neutral' (Allen and Seaman 2007; Tsang, 2012) as used in the questionnaire survey for this
346 study. The objective is to provide the respondents with a truly neutral opinion without missing their
347 opinions (Tsang, 2012). The presence of a neutral midpoint can also deter respondents from choosing
348 extreme points (responses) on the Likert scale which may not truly reflect their opinions. Thus, the
349 respondent is not compelled to commit to a particular position, thereby providing the benefit of
350 minimising response bias (Croasmum and Ostrom 2011; Tsang 2012). It is a common practice in the
351 construction management literature to treat ordinal variables in Likert scales as interval variables (Ho
352 et al. 2009; Li et al. 2013; Gunduz and Elsherbeny 2020) and can be analysed using descriptive statistics
353 and other analytical methods such as factor analysis and correlation analysis (Harpe 2015; Brown 2011;
354 Carifio and Perla 2008). In addition, the use of Likert scales involves a consideration of reliability,
355 which should be calculated using the Cronbach's alpha reliability test (Brown 2011). In this study, the
356 Cronbach's alpha value was calculated based on the survey data.

357 The Likert scale response format was developed with the intention to report means and standard
358 deviations of the adoption factors. Therefore, the basic item-writing considerations (Busch 1993) were
359 observed in developing the questionnaire survey instrument using Likert scales. The item stems used

360 statements on which the survey respondents expressed their agreement with each statement according
361 to their knowledge, understanding and experience of smart contracts. Numbered scales ranging from
362 one to five were used because people are comfortable with and think in terms of degrees (Brown 2011;
363 Carifio and Perla 2008; Hwang et al. 2022; Nunnally 1978). Following the above point, the scale
364 category labels (response choices) are presented to provide the survey respondents with the appearance
365 of equal intervals, using the numbered scales. This is to ensure that the response choices are uniformly
366 ranked, avoiding ambiguity and ensuring that the response choices are interpreted consistently and
367 meaningfully (Nunnally 1978; Busch 1993; Harpe 2015). Hence, Likert-type scales are suitable for this
368 study as they generate information (data) based on the survey respondents' expert opinions and
369 knowledge of the topic being investigated. The Likert scale is effective at ranking objects or factors,
370 given that item stems are clearly constructed, response choices are well labelled and uniformly ranked,
371 multiple response options including a neutral response to enable the survey respondents to judge each
372 item stem in terms of agreement. From the foregoing, the survey data allow for the use of means and
373 standard deviations in order to prioritise and determine factors exerting influence on smart contract
374 adoption. Finally, as recommended by Blaikie (2003), the percentages of the survey response for each
375 scale item are calculated.

376 *Questionnaire Administration and Survey Participants*

377 The questionnaire was distributed to professional construction managers, contract managers and
378 administrators, quantity surveyors, project managers and construction researchers working in public
379 and private sectors and universities/research agencies. A robust ethical protocol governed the
380 administration of this survey instrument, which included providing participants with assurances that all
381 personal details given would remain strictly confidential and would not be divulged nor disseminated
382 without prior written consent; guarantees that data protection policies would oversee the handling and
383 management of data security; and an offer that the results would be made freely available post
384 publication. Cumulatively, these ethical and legal measures enabled informed consent to be secured
385 from survey participants but also protect their data privacy. Because smart contract technology is new
386 and adoption is at its early stages (Lauslahti et al. 2017; Badi et al. 2021), the respondents were targeted
387 and purposively selected. The respondents were carefully and purposefully selected based on the

388 guidelines put forward in the literature (Okoli and Pawlowski 2004; Murphy et al. 2015). Selection
389 criteria were developed to identify relevant skills groups. In this study, the main skills groups targeted
390 were industry practitioners and academics/researchers. The individual participants were selected based
391 on the following selection criteria, with a survey respondent having: a) substantial working experience
392 in the construction industry with a direct involvement in projects, b) current and direct involvement or
393 experience in the adoption process of (new) digital technologies in construction, and c) sound
394 understanding and knowledge of blockchain-based smart contract technology and its applications.
395 These criteria include sub-criteria such as evidence of peer-reviewed publications in academic and
396 practitioner journals and membership of industry professional bodies (Murphy et al. 2015). To ensure
397 quality and reliable responses, persons who satisfied the above criteria were considered and invited to
398 participate in the survey. In addition, the respondents hold senior level positions and have between five
399 and over 20 years working experience in the construction industry and delivery of construction projects.
400 In order to provide a global perspective on the driving factors for smart contracts adoption, the survey
401 participants have industry background/experience from 20 countries (Table 2). The respondents were
402 selected through a combination of strategies; searching through LinkedIn profiles, websites of
403 construction organisations, and industry and academic research publications. A chain-referral
404 (snowball) technique (Parker et al. 2019) was also used to increase number of respondents; initially
405 contacted respondents were asked to share the survey with, or recommend, other knowledgeable
406 practitioners in smart contracts who may be willing to participate in the survey.

407 Survey responses were secured through a web-based survey system (SurveyMonkey®), with a web link
408 to the questionnaire emailed to the respondents. The survey was also shared on the Co-operative
409 Network for Building Researchers (CNBR) platform and the professional network of Project
410 Management Institute (PMI). Overall, 61 responses were received, but 41 were deemed valid for
411 analysis (Table 2). Obtaining a significant number of responses by e-mail contact is challenging (Stern
412 et al. 2014). Some of the invited respondents declined to participate due to lack of knowledge on smart
413 contracts while others failed to complete the survey. Some e-mails bounced because the individuals
414 have moved companies. Because of the strict participant selection criteria adopted and the fact that
415 smart contract is an emerging area, the number of responses achieved is sufficient for analysis.

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

417 The respondents indicate a mix of professional backgrounds and work in various roles within the
418 construction project management team (or as research consultants to such) viz.: 27%
419 contractors/subcontractors, 36% consulting firms, 27% universities and research institutions, 10% for
420 ‘other’ category. From Table 2, the respondents are senior construction professionals / practitioners
421 with knowledge of and involvement in blockchain and smart contract initiatives and developments in
422 the construction industry; 22% are quantity surveyors; 17% are project and construction managers; 24%
423 are commercial, contract and programme managers/directors; 24% are researchers; and 12% are ‘other’
424 category.

425
426 **ANALYSES AND RESULTS**

427 Statistical analyses were performed on the survey data using the IBM SPSS Statistics 20 and Microsoft
428 Excel Spreadsheet. The analyses include internal consistency reliability of the scale, descriptive mean
429 scoring, relative significance analysis, standard deviation, normalisation analysis and interrater
430 agreement analysis. Extended analysis was performed using fuzzy set theory, which is implemented to
431 evaluate and establish the most important factors influencing on smart contracts adoption.

432
433 ***Reliability Analysis***

434 The Cronbach’s alpha coefficient (α) was computed to determine the internal consistency of the adopted
435 scale. A scale’s internal consistency gauges the degree to which the scale’s items ‘hang together’ and
436 whether the scale items measure the same underlying construct (Pallant 2010). The α coefficient ranges
437 between 0 and 1, with a value above 0.7 deemed acceptable in exploratory studies (DeVellis 2003). In
438 this study, the calculated α coefficient is 0.945 which suggests an excellent internal consistency
439 reliability of the scale for the sample (Pallant 2010). In addition, the values in the *Inter-Item Correlation*
440 *Matrix* are all positive, suggesting that the scale’s items measured the same underlying constructs, and
441 therefore, the survey data are reliable for statistical analyses (Cohen et al. 2007).

442
443 ***Critical Driving Factors for Smart Contracts Adoption***

444 The mean scores, relative significance (importance) indices (RSI) and normalised values are calculated
445 to establish the important factors (Xu et al. 2010; Lee et al. 2010; Ameyaw et al. 2017) for smart
446 contracts adoption. This helps to ascertain the critical factors influencing adoption of smart contracts.
447 These statistics help to rank order the driving factors in order to extract the critical factors from the
448 general list of 27 used in the questionnaire survey.

449 The use of descriptive statistics (mean and standard deviation) for preliminary analysis of the survey
450 data is consistent with Harpe's (2015) recommendation that a numerical response format containing at
451 least five response options can be treated as continuous variables. It was argued that the use of numeric
452 presentation (in Likert-type scales) gives the responses interval characteristic, and therefore, means and
453 standard deviations can be calculated for each scale item. Second, Carifio and Perla (2008) concluded
454 that it is "perfectly appropriate to summarise the ratings generated from Likert scales using means and
455 standard deviations". The authors (*ibid*) considered that Likert scale data are similar to interval scale
456 data, with an insignificant degree of measurement error (Shields et al. 1987). For example, Gunduz and
457 Elsherbeny (2020) calculated the means and standard deviations of contract administration factors
458 affecting construction projects using summative ratings from a Likert scale. Hwang et al. (2022) used
459 means and standard deviations to prioritise and establish the important challenges in the, and effective
460 strategies for promoting, adoption of smart technologies in the construction industry. Third, as reported
461 in Table 3, the distribution of the participants' responses (survey data) show that the participants used
462 the full range of response categories of the response categories for each scale item. This means that (i)
463 the 'shorter' item problem is avoided and (ii) the descriptive analysis will produce meaningful results
464 without missing the true message from the data (Harpe, 2015; Carifio and Perla 2008). Based on the
465 five-point Likert scale, five mean ranges relating to different thresholds are used to capture and interpret
466 the level of agreement among the respondents as: ≥ 1.50 = "strongly disagree"; $1.51-2.50$ = "disagree";
467 $2.51-3.50$ = "neutral"; $3.51-4.50$ = "agree"; and ≤ 4.51 = "strongly agree". Therefore, a driving factor
468 with a mean score of ≤ 3.51 is considered '*critical*' in this study. The mean scores range between 2.29
469 and 4.41, with 16 (59%) factors ranging between 3.54 and 4.41. The mean ranges and cut-off criterion
470 have been used by previous studies (Li et al. 2013; Ameyaw et al. 2017; Gunduz and Elsherbeny 2020)
471 to prioritise important factors from a list. The mean scores, standard deviations and rankings of the

472 factors are reported in Table 3. In case of equal mean score, the factor with the lowest standard deviation
473 is ranked higher. In addition to the mean values, the percentages of response in each category of the
474 statements are calculated (Blaikie, 2003) and summarised into disagree, neutral and agree in Table 3.
475 These percentage responses provide the basis for building membership functions using the fuzzy set
476 theory (Table 5) for modeling and ranking the critical factor groups influencing smart contracts
477 adoption.

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

479 The RSI is an alternative method for extracting important factors from a list (Kometa et al. 1995). The
480 method transforms the survey respondents' (numerical) ratings of the factors influencing smart
481 contracts adoption to importance indices to establish the relative ranking of the factors. Kometa et al.
482 (1995) used the RSI technique to determine the relative ranking of the attributes of project delivery
483 success. In this study, a factor prioritisation scale is adopted based on the five-point rating scale as:
484 $0.00 \leq \text{index} < 0.43$ ("low significance"); $0.43 \leq \text{index} < 0.57$ ("moderate significance"); $0.57 \leq \text{index} < 0.71$
485 ("significant"); $0.71 \leq \text{index} < 0.86$ ("very significant"); and $0.86 \leq \text{index} < 1.00$ ("extremely significant").

486 The use of the factor prioritisation scale is based on Ameyaw et al. (2017). A driving factor with an
487 index ≥ 0.71 is regarded as significant (important); this approach also yields 16 critical factors
488 influencing smart contracts adoption (Table 3). The last method for establishing the critical driving
489 factors is the normalisation technique (Xu et al. 2010). The calculated normalised values are based on
490 the mean scores and are scaled between 0 and 1. Factors with a value ≥ 0.50 (Xu et al. 2010) are regarded
491 as critical factors (Table 3).

492 Overall, the results of the statistical analysis yielded 16 driving factors that are perceived by the expert
493 respondents to influence the decision to adopt smart contracts in construction projects. Among the 16
494 driving factors, the top five critical factors have mean scores and significance indices ranging between
495 4.00 and 4.41 and 0.80 and 0.88, respectively. These factors include f-13 ($\bar{x} = 4.41$), f-11 ($\bar{x} = 4.17$), f-
496 08 ($\bar{x} = 4.12$), f-01 ($\bar{x} = 4.00$) and f-04 ($\bar{x} = 4.00$). The first two factors (f-13 and f-11) relate to ability
497 and opportunity to try-out smart contracts prior to their adoption by stakeholders in construction
498 projects. This is important, given that every new technology has risks that may not be well understood

499 at early stages of implementation. Blockchain and smart contracts are no exception. Smart contract is a
500 new technology-enabled contracting practice (Lauslahti et al. 2017) and the construction industry is
501 trying to understand the extent of their full potential and how they can be leveraged in construction
502 projects (Penzes et al. 2018). A trial period will provide opportunity to carefully analyse the match
503 between practical industry problems and smart contracts' characteristics (Hamledari and Fischer 2021).
504 This is a prerequisite for successful adoption. The third driver is about boosting transparency in
505 construction projects regarding cost, time and score. Transparency is possible because all transactions,
506 payments and information resources are recorded and automatically shared on the blockchain network.
507 This allows each stakeholder to follow the process and authenticate their records.

508
509 ***Agreement Analysis of the Critical Factors***

510 The inter-rater agreement (IRA) method was used to measure the amount of consensus by the
511 respondents on the ratings of the 16 critical factors influencing smart contracts adoption established
512 above. The IRA method is an alternative and a popular technique for assessing the strength of agreement
513 among group respondents (Brown and Hauenstein 2005). In this study, Brown and Hauenstein's (2005)
514 IRA estimate, a_{WG} , is used to assess the absolute consensus in ratings provided by the survey
515 respondents for each factor (Eq. 1). The a_{WG} estimate has been used in construction studies to measure
516 consensus among survey respondents. For example, Ameyaw et al. (2017) used the a_{WG} estimate to
517 ascertain the level of agreement among practitioners on significance of critical success factors water-
518 based PPP projects. Gunduz and Elsherbeny (2020) applied the a_{WG} estimate to evaluate the strength of
519 agreement construction contract administration factors on project performance. The IRA statistic ranges
520 between -1 and +1 and captures the amount of agreement to the highest possible disagreement. An
521 estimate of 1 represents a perfect agreement among the respondents and vice versa and is interpreted
522 as: 0.00–0.30 = “*lack of agreement;*” 0.31–0.50 = “*weak agreement;*” 0.51–0.70 = “*moderate*
523 *agreement;*” 0.71–0.90 = “*strong agreement;*” and 0.91–1.00 = “*very strong agreement.*” An estimate
524 of 0.71 and above suggests a high degree of consensus.

525
$$a_{WG(1)} = 1 - \frac{2*s_x^2}{[(H+L)M - M^2 - (H*L)]*[k/(k-1)]} \quad [1]$$

526 where M denotes the observed mean score based on respondents' ratings for a given factor, H and L
527 represents the maximum and minimum values of the Likert scale (5 and 1) respectively, k indicates the
528 number of survey respondents, and S_X^2 denotes observed variance on M . The IRA results are reported in
529 Table 4, ranging from 0.69 to 0.83 with fifteen factors rated as '*strong agreement*' and one factor rated
530 as '*moderate agreement*.' The results indicate that the respondents' assessment of the factors are not
531 random responses (Ameyaw et al. 2017).

532
533 ***Grouping the Critical Factors***

534 After establishing the 16 critical factors (CFs) from the statistical analyses (see Table 3), they were
535 subject to further analysis using the fuzzy set theory. However, before applying the fuzzy set theory,
536 the 16 CFs are classified into four critical factor groups (CFGs), namely: 1) compatibility; 2)
537 competitive advantage; 3) triability; and 4) relative advantage (see Table 5). This categorisation is based
538 on the attributes (characteristics) of innovations by Rogers (2003) and technology, organisation and
539 environment (TOE) framework by DePietro et al. (1990). For example, compatibility, trialability, and
540 relative advantage are among the five general attributes of innovations Rogers (2003) identified to
541 consistently influence technological innovations adoption. The innovation attributes explain 49% to
542 87% of the variance in the adoption rate of innovations (Rogers 2003). Similarly, competitive advantage
543 is an environmental factor of the TOE framework that influences successful adoption of technological
544 innovations (Pan and Pan 2021; Lee et al. 2013; Chatterjee et al. 2021). Innovation adoption research
545 has shown that attributes of innovation and the TOE concept influence technological innovation
546 adoption and have been applied to investigate technology adoptions in different disciplines, including
547 construction (e.g., Pan and Pan 2021; Lee et al. 2013). Grouping the 16 CFs into four CFGs based on
548 well-established technology adoption theories/frameworks provides inbuilt reliability to the
549 classification without the need for a statistical classification. As shown in Table 5, each CFG is
550 measured and defined by a number of CFs which together provide a measure of that factor group.
551 Overall, the 16 critical factors capture and explain some of the most important factors facilitating
552 adoption of technology. It is worth noting that adoption of a technology will be driven by a set of factors
553 influenced by characteristics of the technology, industry conditions (Lee et al. 2013). In this study, the

554 ‘relative advantage’ group has the highest numbers of factors (Table 5), suggesting that adoption of a
 555 new technology in construction is significantly influenced the potential benefits it can offer to adopters.
 556 The next stage of the analysis involves combing the scores of the CFs of each CFG into one score using
 557 the fuzzy set theory in order to rank the CFGs.

558
 559 *Evaluating the Critical Factors and Critical Factor Groups using Fuzzy Set Theory*

560 Having categorised the critical factors into categories into four factor groups (Table 5), the fuzzy set
 561 theory (FST) (Zadeh 1965; Hsiao 1998) is used to employed to evaluate and rank the factor groups. The
 562 objective is to establish the most important factor groups exerting influence on adoption of smart
 563 contracts. The FST is practical at dealing with and overcoming vagueness and subjectivity that
 564 characterise traditional questionnaire survey responses using linguistic variables (Ameyaw et al. 2015).
 565 The FST has been used in construction research to address practical problems, including risk allocation
 566 decision-making (Ameyaw and Chan 2015) and risk assessment and ranking (Ameyaw et al. 2017).
 567 Readers may refer to these studies for applications of the FST. Hence, this section presents the relevant
 568 definitions and theoretic operations that are used to develop the analysis and ranking methodology
 569 outlined below.

570 The first step in the FST is the representation of fuzzy sets to derive the membership functions. \mathbf{U}
 571 constitutes a universal set and represents a set of objects represented generically by x , then a fuzzy set
 572 A in \mathbf{U} can be generated as follows:

573
$$\mathbf{A} = \frac{\mu_A(x_1)}{x_1} + \frac{\mu_A(x_2)}{x_2} + \dots + \frac{\mu_A(x_n)}{x_n} \quad [2]$$

574 where $\mu_A(x)$ is the grade membership (or membership function), the expressions $\frac{\mu_A(x_i)}{x_i}$ are not fractions
 575 but represent the relation between x_i and its grade membership $\mu_A(x_i)$, which ranges from [0,1]. Hence,
 576 grade membership of a specific critical factor for smart contract adoption is expressed as:

577
$$\mathbf{A} = \frac{\mu_A(x_1)}{\text{strongly disagree}} + \frac{\mu_A(x_2)}{\text{disagree}} + \dots + \frac{\mu_A(x_n)}{\text{strongly agree}} \quad [3]$$

578 And the grade membership of a critical factor A_i based on above expression is written as:

579
$$\mathbf{A}_i = (\mu_A(x_1), \mu_A(x_2), \dots, \mu_A(x_i)), \text{ and } \sum_{i=1}^n \mu_A(x_i) = 1 \quad [4]$$

580 For example, the membership function of critical factor *f-15* is derived using Eq. [3] and expressed
 581 using Eq. [4]:

582
$$\mathbf{A}_{d15} = (0.000 \quad 0.122 \quad 0.293 \quad 0.390 \quad 0.195)$$

583 Having established the grade membership for each critical factor, the fuzzy relational matrices can be
 584 derived. Say \mathbf{R} denotes a fuzzy relation on $\mathbf{X} \times \mathbf{Y}$, where \mathbf{X} and \mathbf{Y} have m and n elements, respectively.
 585 Then following from Eq. [4], \mathbf{R} is defined by the relational matrix as follows:

586
$$\mathbf{R} = (x_{ij})_{mn} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \dots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \quad [5]$$

587 Thus, \mathbf{R} is called fuzzy relational matrix and its elements of are given by $x_{ij} = \mu_R(x_i, y_i)$ whose
 588 memberships range from [0,1]. Using Eq. [5], the fuzzy relational matrix for '*Competitive advantage*
 589 (*CA*)' is derived:

590
$$\mathbf{R}_{\text{Competitive advantage}} = \begin{bmatrix} 0.000 & 0.122 & 0.293 & 0.390 & 0.195 \\ 0.049 & 0.049 & 0.366 & 0.366 & 0.171 \\ 0.000 & 0.073 & 0.293 & 0.439 & 0.195 \end{bmatrix}$$

591 The values of the fuzzy relational matrices of all the critical factor groups are presented in Table 5.

592
 593 The next step is to establish the weightings of the critical factors and consequently the weighting
 594 function set of each critical factor group. Using the mean scores, the weightings of the individual critical
 595 factors and the critical factor group through the following equation and reported in Table 5:

596
$$w_i = \frac{M_i}{\sum_{i=1}^n M_i} \quad [6]$$

597 where w_i is the weighting of a driving factor i or factor group i ; M_i is the means score of driving factor
 598 i ; $\sum_{i=1}^n M_i$ is sum of all mean values of the driving factors of factor groups. The weighting of a factor
 599 reflects its importance regarding influencing smart contract adoption and ranges between 0 and 1, with

600 the sum of a weighting function set equals to 1, i.e., $\sum_{i=1}^m W_i = 1$ (Hsiao 1998). Hence, the weighting
 601 function set of 'Competitive advantage' factor is given by:

$$602 \quad \mathbf{W}_{\text{Competitive advantage}} = \{w_{d3}, w_{d15}, w_{d23}\} = \{0.342, 0.333, 0.324\} = \sum W = 1$$

603
 604 Having established the fuzzy relational matrices and the weighting function sets of the factor groups,
 605 then the fuzzy synthetic evaluation set, \mathbf{Z} , of a given factor group is given by:

$$606 \quad \mathbf{Z} = \mathbf{W} \circ \mathbf{R} = \{z_1, z_2, \dots, z_m\} \quad [7]$$

607 where \mathbf{Z} gives grades of membership of a critical factor group; and " \circ " denotes composite operation
 608 processed by various fuzzy mathematical functions (Hsiao 1998). Here, the generalised weighted mean
 609 method $M(*, +, \beta)$ is used to perform the composite operation in Eq. [7]. The characteristic of this
 610 method is that it takes into consideration and preserves the effects of all the individual critical factors,
 611 and so, the value of $\beta = 1$ (Hsiao 1998). Also, in this study the weightings are normalised ($\sum_{i=1}^m W_i = 1$),
 612 and therefore the model regresses to addition of real numbers. The $M(*, +, \beta)$ method (Hsiao, 1998) is
 613 defined as

$$614 \quad z_j = \left(\sum_{i=1}^m W_i * x_{ij}^\beta \right)^{1/\beta}, j = 1, 2, \dots, n \quad [8]$$

615 Using 'Competitive advantage' as an example, the member functions are obtained as follows:

$$616 \quad \mathbf{Z}_{\text{Competitive advantage}} = \begin{bmatrix} 0.342 \\ 0.333 \\ 0.324 \end{bmatrix} * \begin{bmatrix} 0.000 & 0.122 & 0.293 & 0.390 & 0.195 \\ 0.049 & 0.049 & 0.366 & 0.366 & 0.171 \\ 0.000 & 0.073 & 0.293 & 0.439 & 0.195 \end{bmatrix}$$

$$617 \quad = (0.016 \quad 0.082 \quad 0.316 \quad 0.399 \quad 0.187)$$

618 Now, the critical values of each factor group are computed through Eq. (8) using the grade
 619 memberships. This process is called defuzzification, which transforms fuzzy memberships into crisp
 620 values (Ameyaw and Chan 2015) to ascertain their degree of influence in adopting smart contracts. The
 621 criticality values are presented in column 5 of Table 5.

$$622 \quad \text{Index}_{[\text{factor group } i]} = \mathbf{Z}_i * \mathbf{E} \quad [9]$$

623 where E denotes scale options to measure criticality of the factors or groups. In this study, five scale
624 options are used and interpreted as $e_1 =$ not critical [1], $e_2 =$ slightly critical [2], $e_3 =$
625 moderately critical [3], $e_4 =$ critical [4], and $e_5 =$ very critical [5]. For example, the index of
626 ‘*competitive advantage*’ is obtained as follows:

$$627 \quad \text{Index}_{[\text{Competitive advantage}]} = (0.016, 0.082, 0.316, 0.399, 0.187) * (1,2,3,4,5) = 3.660$$

628 The relative indexes of all the CFGs are above 3.51, ranging between 3.54 and 4.30 (Table 5),
629 suggesting that they positively impact decision to adopt smart contracts in construction projects.

630

631

632 **DISCUSSION**

633 This study sought to establish the critical factors influencing adoption of blockchain-based smart
634 contracts in construction projects, drawing on the views of construction experts and practitioners. The
635 descriptive analyses yielded 16 critical factors believed to influence smart contracts adoption, which
636 are further grouped into four critical factor groups as: 1) trialability; 2) relative advantage; 3)
637 competitive advantage; and 4) compatibility.

638

639 ***Trialability***

640 Trialability is the first factor group lending support to adoption of smart contracts and comprises of two
641 factors (f-11 and f-13) with a relative criticality index of 4.30 (Table 5). It refers to the extent to which
642 a technological innovation may be experimented with on a limited basis before adoption (Rogers and
643 Shoemaker, 1971). This finding finds support for previous studies that highlight the significant
644 influence of trialability in successful adoption of innovative technologies (Lin and Chen 2012; Rogers
645 2003; Kendall et al. 2001). Technological innovations that can be tried are adopted more frequently and
646 quickly compared to less trialable ones (Kendall et al. 2001; Tornatzky and Klein 1982). In this study,
647 trialability is highly advocated by the survey respondents, with 98% voting that they would experiment
648 with smart contracts before adoption in practice and 83% in favour of a trial period prior to adoption.
649 In other words, trialability is characterized by *ability to try out* (f-13), and *opportunity to experiment*

650 with (f-11) smart contracts on real projects before adoption. Both factors have been reported to enhance
651 the prospect of successful adoption of innovations (Lin and Chen 2012). Unsurprisingly, both factors
652 were rated highly by the survey respondents, with mean values > 4.00 (Table 3). Indeed, this finding
653 suggests the necessity for a trial period to experiment with smart contracts before practical
654 implementation; the testing period is valuable to identifying potential risks, bugs and failures and
655 addressing them in a safe and secure manner before application in practice. Blockchain applications
656 and smart contract systems are new technologies that will require trial to build trust, collaboration and
657 confidence of project stakeholders (Mason and Escott 2018; Badi et al. 2021). Although numerous
658 studies including this study have observed that trialability characteristic positively influences
659 technology adoption, Badi et al. (2021) found no positive correlation between trialability and smart
660 contracts adoption in the UK construction sector. A possible reason could be that their respondents were
661 not engaged in smart contract activities and had little or no knowledge and understanding of smart
662 contracts, unlike in this study where the respondents are involved in smart contract initiatives.

663
664 ***Relative Advantage***

665 The second factor group influencing smart contracts adoption in construction projects is relative
666 advantage which is measured by nine critical factors (see Table 5). According to Moore and Benbasat
667 (1991), relative advantage refers to the extent to which a technological innovation is perceived as being
668 better than its predecessor. Relative advantage is akin to Davis' (1989) *perceived usefulness*
669 characteristic and is strongly espoused as a fundamental predictor of innovation adoptions (Pan and Pan
670 2021; Rogers 2003; Lee 2004). Thus, this finding is in parity with previous studies that highlight relative
671 advantage as a key driver of adoption of other technologies (Lee et al. 2015; Chatterjee et al. 2021). For
672 example, Lee et al. (2015) observed that relative advantage significantly affects individual's intention
673 to accept BIM while Chatterjee et al. (2021) reports that relative advantage is positively associated with
674 adoption of artificial intelligence (AI) in the manufacturing industry. The criticality index of 3.88 (Table
675 5) suggests that practitioners regard blockchain-enabled smart contract technology as an instrument to
676 enhance job performance and that smart contracts are perceived to impact on and enhance efficient
677 delivery of construction projects. From Table 3, the respondents perceive smart contracts to have

678 potential benefits, including maximises transparency in cost, time and scope (78%, $\bar{x} = 4.12$), facilitates
679 progress payments (76%, $\bar{x} = 4.00$), provides secured payment transactions (68%, $\bar{x} = 4.00$) and reduces
680 ambiguities in project scope (78%, $\bar{x} = 3.95$). In related studies, researchers highlighted potential
681 benefits of smart contracts adoption in construction, including security of payments, automatised
682 payments, reduced disputes, and automated contract formation (Mason and Escott 2018), cultivation of
683 trust and collaboration *by design* and risk mitigation (Hamledari and Fischer 2021). Overall, this finding
684 suggests that working with smart contracts is a rewarding task for practitioners and that smart contract
685 technology is capable of creating benefits in projects – crucial to facilitating smart contracts adoption.

686

687 *Competitive Advantage*

688 The third factor group influencing adoption of smart contracts in construction projects is competitive
689 advantage, with an adoption index of 3.66. Competitive advantage of a technological innovation is the
690 extent to which the technology provides gains or benefits to (project) organisations (Rogers 2003) and
691 is reported to strongly influence technology adoption across sectors (Pan and Pan 2021; Chatterjee et
692 al. 2021; Badi et al. 2021). As organisations compete to become pioneers in the use of emerging (often
693 digitalised) technologies (such as those inextricably linked to the rapidly expanding Industry 4.0
694 concept viz: virtual reality, cloud computing, artificial intelligence, *etc.*) to beat the competition, the
695 more the need to adopt new technologies by rival competitors intensifies. In this study, the respondents
696 agree that smart contracts will increase profit levels of organisations on construction projects ($\bar{x} = 3.76$),
697 provide adopters with a strong competitive advantage ($\bar{x} = 3.66$), and enables adopters to beat the
698 competition ($\bar{x} = 3.56$). This finding aligns with Tornatzky and Klein (1982) who provides an argument
699 for a strong positive correlation between an innovative technology's profitability and its adoption in
700 other industries. Comparatively, smart contracts offer advantages over traditional contracts which have
701 been criticised for being time-consuming to prepare, susceptible to forgery and errors and consequently,
702 responsible for late- or non-payment problems in the construction industry (Ream et al. 2016;
703 Hamledari and Fischer 2021). The construction business environment is fiercely competitive,
704 characterised by low margins; for example, the average margin of contractors in the UK is around 1.5%
705 (The Construction Index 2017). Therefore, this finding emphasises smart contracts' capability to

706 enhance effectiveness and efficiency of projects and to automate transactions and payments, resulting
707 in time and cost effectiveness and reduction in payment times with direct benefits to construction supply
708 chains (Hamledari and Fischer 2021). These advantages will considerably influence decisions to adopt
709 smart contracts in construction projects as adopters will have an edge over their competitors in winning
710 work.

711
712 ***Compatibility***

713 Compatibility emerged as the fourth factor group driving smart contracts adoption in construction
714 projects with an index of 3.54. Rogers and Shoemaker (1971) broadly defined compatibility as the
715 extent to which an “innovation is perceived as being consistent with the existing values, past
716 experiences, and needs of [potential adopters].” Technology’s compatibility to potential adopters’ needs
717 and experiences is found to be positively correlated to technology (Lee et al. 2015; Moore and Benbasat
718 1991). Compatibility is represented by two important variables in this study: i) compatibility with *values*
719 and *beliefs* of construction practitioners/organisations; and ii) compatibility with current contract
720 management *needs* and *practices* of practitioners/organisations and projects. The first aspect of
721 compatibility of smart contracts suggests a cognitive or normative compatibility (Moore and Benbasat
722 1991), which means compatibility with what practitioners think about smart contracts. Thus, smart
723 contracts are highly likely to be adopted and implemented if the project stakeholders perceive smart
724 contracts to be compatible with their value and belief systems. This finding is consistent with previous
725 studies on other technologies such as AI and tourism mobile payment (Chatterjee et al. 2021; Peng et
726 al. 2012). The second aspect implies practical compatibility (Moore and Benbasat 1991) of smart
727 contracts, which refers to compatibility with practitioners’ job functions and contract management
728 needs. This finding suggests that the survey respondents believe that smart contracts: 1) hold the
729 potential to support job performance of practitioners; 2) are compatible with *values* and *beliefs* of
730 construction practitioners/projects; 3) are congruent with existing contract practices and management
731 systems; and 4) are able to address construction projects’ needs. Advocates argue that smart contracts
732 are key to enhancing efficiency of project management and project governance, project collaboration

733 and transparency, accurate execution and monitoring of contract conditions, and solving late- or non-
734 payment issues (Penzes et al. 2018; Cardeira 2016; Arup 2017; Li et al. 2020).

735
736 **IMPLICATIONS**

737 The findings hold useful implications for construction practitioners and industry leaders interested in
738 the application of blockchain-based smart contracts in projects and the future of contractual practices.
739 This study contributes to the existing body of knowledge on digitalisation/digital technologies under
740 the concept of Industry 4.0 by providing understanding of the critical issues that require consideration
741 during the adoption process of blockchain-based smart contracts. A better understanding of the primary
742 drivers will guide decision-makers to identify appropriate areas of focus when developing industry and
743 policy strategies to promote wider adoption of blockchain-based smart contracts across the construction
744 industry. This has the potential to contribute toward the digitalisation and transformation of the
745 construction industry and its supply chains. Also, the findings reflect the attitude of practitioners in the
746 construction industry where practitioners are reluctant to adopt new/emerging technologies unless they
747 are convinced of the advantages such technologies bring to their business operations and practices. The
748 findings show that *trialability* and *usefulness* of smart contracts are perceived to be the top-rated driving
749 forces for adoption. This provides opportunity to smart contracts proponents to ensure that there are
750 real-world applications of smart contracts in case projects, in order to raise awareness of the real benefits
751 provided by smart contract technology and encourage wider uptake of the technology among
752 construction practitioners and stakeholders. Trials of smart contracts through case projects is also key
753 to identifying and resolving potential problems that may arise during real implementation and even to
754 build trust and confidence in smart contract technology. Further, the findings are valuable to smart
755 contracts advocates, particularly smart contract designers, contract administrators, and project
756 management and legal consultancies that will be interested in providing professional services to
757 construction clients. The *relative advantage* of smart contracts as a determinant for their adoption
758 suggests that smart contracts designers should be able to design contracts that are practical, able to
759 satisfy the business needs of clients and projects, and compatible with existing contract management
760 systems.

761

762 CONCLUSIONS

763 Blockchain-based smart contracts is attracting a growing interest among construction industry leaders
764 and practitioners. Smart contract is an innovative technology to automate construction contract
765 processes and is showing the potential to enhance the performance and efficiency of construction
766 projects by ensuring transparency, accountability and collaborative working. However, given its nature,
767 the construction industry is a laggard in adopting innovative technologies, facing challenges including
768 resistance to change and fragmentation of the industry. This research study explored and established
769 the critical factors exerting influences on construction project-level adoption of smart contracts using
770 international questionnaire survey of construction practitioners. The findings revealed 16 important
771 factors that are perceived to drive smart contracts adoption and the top five critical factors are ability to
772 try out a smart contract, a trial period before smart contract adoption, maximising transparency in
773 project delivery, facilitating payments and reduced payout time, and security of payment in projects.
774 Agreement analysis shows strong consensus among the survey respondents regarding the importance
775 of the critical factors. In descending order of influence based on computed criticality index values, the
776 four critical factor groups driving smart contracts adoption are trialability, relative advantage,
777 competitive advantage, and compatibility. The respondents share a view that relative advantage and
778 trialability characteristics of smart contracts are crucial *vis-à-vis* the technology's perceived practicality
779 in improving effectiveness and efficiency of construction projects and providing opportunity to
780 experiment with smart contracts prior to implementation. Also, the respondents perceive that smart
781 contract technology is compatible with existing contracting practices / systems and therefore has a
782 potential to solve most challenges confronting construction projects. This has the potential to enhance
783 adoptability of smart contracts, as practitioners may not be required to significantly adjust existing
784 contract management systems and practices.

785 The results should be interpreted with consideration of some limitations. First, the data for the study are
786 based on a relatively small sample size, although this does not invalidate the significance and reliability
787 of the results. Given the immaturity of smart contract technology and with adoption at early stages
788 across the world, this sample comprising of experienced construction practitioners directly involved in

789 smart contract initiatives and research is deemed adequate to provide useful and reliable results. Second,
790 because of the immaturity of smart contracts, the current study provides an assessment of the generic
791 factors based on technology acceptance theories and models considered to influence adoption of smart
792 contract technology in construction projects. Third, the study's results were based on expert responses
793 of construction practitioners from across the world; hence, the current results may vary from those of
794 country-specific studies as a result of social, cultural, legal and political considerations. Despite this
795 limitation, the results provide a universal set of important factors that may be applicable in many
796 countries given the diverse backgrounds of the respondents. This may necessitate future research studies
797 as noted below.

798 To further understand and promote adoption of smart contracts in the construction industry will warrant
799 future scholarly works. First, future research studies should be undertaken in other countries to establish
800 specific factors influencing smart contracts adoption. Such studies may apply and evaluate the factors
801 established by the current study. Next, future studies may be conducted to identify specific applications
802 of blockchain-based smart contracts for various project stakeholders, and to propose a framework to
803 promote the adoption and implementation of the technology in construction projects. Finally, future
804 studies may explore influences of institutional isomorphism and support of project owners/clients on
805 smart contract adoption. Clients are the sponsors of projects and therefore bring profound influences on
806 project design, construction and technology adoptions (Cao et al. 2014). Future study could incorporate
807 other important influences for smart contract adoption. Results of such studies have the potential to
808 assist in refining strategies for smart contracts adoption.

809

810 **DATA AVAILABILITY STATEMENT**

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

813

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817

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Table 1 Potential factors influencing smart contracts adoption

Factor ID	Factor	Statement	Reference
f-01	Facilitation of payments and reduction of payout time	A smart contract facilitates (progress) payments and reduces payout time by reducing delays in invoice verification process	Cardeira (2016), EY (2018), Hamledari and Fischer (2020), Mason and Escott (2018)
f-02	Ease of understanding	A smart contract is easy to understand	Chatterjee et al. (2021)
f-03	Generation of increased profits to adopters	The use of smart contracts will allow the generation of higher profits to organisations	Nikas et al. 2007
f-04	Security of payments in projects	A smart contract provides secured payments in construction projects	Hamledari and Fischer (2020)
f-05	Competitive pressure to adopt smart contracts	The organisation has experienced competitive pressure to adopt smart contracts	Nikas et al. (2007)
f-06	Available technological support adoptions	Existing technologies in the organisation support smart contract adoption	Badi et al. (2021), Lee et al. (2015)
f-07	Minimises intermediaries and overall project costs	A smart contract reduces intermediary and overall project costs by highlighting inefficiencies	EY (2018)
f-08	Maximises transparency in project delivery	A smart contract maximises transparency of project cost, time and scope	EY (2018)
f-09	Consistency with the existing values and beliefs of the organisation	A smart contract is consistent with the existing values and beliefs of the organisation	Chatterjee et al. (2021), Badi et al. (2021), Lee et al. (2013)
f-10	Intention to try out a smart contract in a limited scope prior to adoption	The organisation intends to try out a smart contract in a limited scope in its projects, before deciding whether to adopt it in practice	Badi et a. (2021), Moore and Benbasat (1991)
f-11	A trial period before smart contract adoption	A trial period before adopting a smart contract in practice will reduce perceived risks	Badi et al. (2021), Moore and Benbasat (1991)
f-12	Protection of contracting parties from late payments and insolvencies	A smart contract protects contracting parties from late (progress) payments and potential insolvencies	Arup (2019), Arup (2017)
f-13	Ability to try out a smart contract	Ability to try out a smart contract is important in the organisation's decision to adopt it in future projects	Badi et al. (2021), Moore and Benbasat (1991)
f-14	Compatibility with the existing contract management systems and/or contractual processes	A smart contract is easy to integrate with existing contractual processes and/or compatible with the existing contract management systems in the organisation	Lee et al. (2015), Moore and Benbasat (1991)
f-15	A stronger competitive advantage	The use of smart contracts would offer the organisation a stronger competitive advantage	Nikas et al. (2007), Chatterjee et al. (2021)
f-16	Ease of use and manageable	A smart contract is easy to use and is manageable	Lee et al. (2015), Chatterjee et al. (2021), Mason and Escott (2018), Badi et al. (2021)
f-17	Compatibility with the contract management needs of the organisation/projects	A smart contract is compatible with the contract management needs of the organisation/projects	Lee et al. (2015), Badi et al. (2021)
f-18	Transparent and favourable government legislation	Government legislation about smart contracts is transparent and supports / favours the adoption of smart contracts	EY (2018), Neuburger (2017)
f-19	Availability of resources and experienced and skilled IT personnel	The organisation has adequate resources and experienced and skilled IT personnel to support smart contract adoption	Chatterjee et al. (2021)
f-20	Improved trust among contracting parties	A smart contract improves trust among contracting parties via automatic sharing of corrections to time and material databases	Hamledari and Fischer (2021)
f-21	Minimizing ambiguities in the scope of work	A well-designed and implemented smart contract minimizes ambiguities in the scope of work which would help in quick resolution of change orders and claims	EY (2018)
f-22	Understanding of positive effects of smart contracts	The organisation has a clear understanding of the positive effects of smart contracts in construction projects	Moore and Benbasat (1991), Badi et al. (2021)
f-23	Increased ability to outperform the competition	The use of smart contracts would increase the ability of the organisation to outperform the competition	Chatterjee et al. (2021), Badi et al. (2021), Lee et al. (2015)
f-24	Minimising complexity resulting in informed decision-making	A smart contract minimises complexity thereby facilitating informed decision-making in projects	EY (2018)
f-25	Reduced occurrence, and efficient resolution, of disputes	A smart contract reduces the occurrence, and ensures efficient resolution, of disputes among contracting parties	Hamledari and Fischer (2020)
f-26	Provision of legal protection	Organisations or firms are legally protected through smart contracts	Ferreira (2021), Badi et al. (2021),
f-27	Pressured to adopt smart contracts	The organisation's business partners recommend or push for (i.e., pressure) the adoption of smart contracts	Nikas et al. (2007)

Table 2 Profile of survey respondents

Background	Experience	Count	%
Years of industry experience	3–5	13	31.71
	6–10	5	12.20
	11–19	11	26.83
	20+	12	29.27
Professional category	Quantity surveyor	9	21.95
	Proj. / Construction manager	7	17.07
	Commercial, Contract & Programme manager / director	10	24.39
	Academic / researcher	10	24.39
	Other*	5	12.20
Professional membership	RICS	10	24.39
	CIOB & RICS	6	14.63
	ICE	5	12.20
	ASCE	4	9.76
	RIBA	1	2.44
	Other**	15	36.59
	Core business of your organisation	Main/sub-contractor	11
Professional consultancy		15	36.59
University / research institution		11	26.83
Other***		4	9.76
Construction projects involved in	General construction projects	24	58.54
	PFI / PPP projects	10	24.39
	Mix of above	7	17.07
Countries in which respondents practice(d):	Continent	Country/territory	
	Africa	South Africa, Nigeria, Somalia, Ghana, Angola	
	Asia	China, Hong Kong, Cambodia, Indonesia, India, Malaysia, UAE, Jordan	
	Europe	United Kingdom, Spain, Greece, Turkey	
	North America	United States	
	Oceania	Australia, New Zealand	
	Global	Respondents with work experience across multiple (>3) countries	

*Concession analyst, technology consultant, lawyer, PPP consultant.

**Law Society (NSW, Australia), Technical Chamber of Greece, Assoc. of Consulting Engineers (India), WAPPP.

***Development institution, public institution, manufacturer/supplier; No. of countries: 20 + Global

Table 3 Results of factors influencing smart contracts adoption

Factor ID	*Summary of percentage of participants' responses			Weighted	Relative significance index	Mean score	Standard deviation	Normalised value	Rank
	Disagreement (%) (<i>strongly disagree + disagree</i>)	Neutral (%) (<i>neither agree nor disagree</i>)	Agreement (%) (<i>agree + strongly agree</i>)						
f-13	2.44	0.00	97.56	181	0.88	4.41	0.63	1.00	1
f-11	2.44	14.63	82.93	171	0.83	4.17	0.77	0.87	2
f-08	2.44	19.51	78.05	169	0.82	4.12	0.81	0.84	3
f-01	7.32	17.07	75.61	164	0.80	4.00	0.97	0.77	4
f-04	4.88	26.83	68.29	164	0.80	4.00	0.92	0.77	4
f-21	7.32	14.63	78.05	162	0.79	3.95	0.92	0.75	6
f-07	7.32	24.39	68.29	158	0.77	3.85	0.88	0.69	7
f-20	7.32	24.39	68.29	157	0.77	3.83	0.86	0.68	8
f-12	12.20	24.39	63.41	156	0.76	3.80	1.01	0.67	9
f-03	7.32	29.27	63.41	154	0.75	3.76	0.86	0.64	10
f-25	14.63	24.39	60.98	153	0.75	3.73	1.03	0.63	11
f-15	12.20	29.27	58.54	150	0.73	3.66	0.94	0.59	12
f-23	9.76	36.59	53.66	146	0.71	3.56	1.00	0.53	13
f-24	14.63	34.15	51.22	146	0.71	3.56	0.98	0.53	13
f-09	9.76	36.59	53.66	145	0.71	3.54	0.81	0.52	15
f-17	9.76	34.15	56.10	145	0.71	3.54	0.87	0.52	15
f-10	19.51	26.83	53.66	139	0.68	3.39	1.09	0.44	17
f-26	19.51	39.02	41.46	139	0.68	3.39	1.00	0.44	17
f-02	21.95	34.15	43.90	137	0.67	3.34	1.04	0.41	19
f-22	24.39	26.83	48.78	136	0.66	3.32	1.21	0.40	20
f-16	24.39	43.90	31.71	132	0.64	3.22	0.99	0.35	21
f-18	26.83	43.90	29.27	127	0.62	3.10	1.04	0.28	22
f-14	36.59	34.15	29.27	121	0.59	2.95	1.09	0.20	23
f-19	46.34	19.51	34.15	118	0.58	2.88	1.19	0.16	24
f-06	43.90	24.39	31.71	116	0.57	2.83	1.22	0.13	25
f-27	43.90	29.27	26.83	114	0.56	2.78	1.13	0.10	26
f-05	48.78	29.27	21.95	106	0.52	2.59	1.26	0.00	27

*Participant opinions are measured using a five-point scale: 1 = Strongly Disagree; 2 = Disagree; 3 = Neither Agree nor Disagree; 4 = Agree; 5 = Strongly Agree. The percentage in agreement is the sum of "Strongly agree" and "Agree" responses. The percentage in disagreement is the sum of "Strongly disagree" and "disagree" responses.

Table 4 Agreement analysis of factors

Factor ID	<i>a_{WG}</i> estimate	Level of consensus
f-13	0.81	Strong agreement
f-11	0.78	Strong agreement
f-08	0.77	Strong agreement
f-01	0.69	Moderate agreement
f-04	0.72	Strong agreement
f-21	0.73	Strong agreement
f-07	0.77	Strong agreement
f-20	0.78	Strong agreement
f-12	0.71	Strong agreement
f-03	0.79	Strong agreement
f-25	0.70	Strong agreement
f-15	0.76	Strong agreement
f-23	0.73	Strong agreement
f-24	0.75	Strong agreement
f-09	0.83	Strong agreement
f-17	0.80	Strong agreement

Table 5 Weightings and membership functions of critical factors (CFs) and critical factor groups (CFGs)

CFG/CF	Mean score		Weighting		Measurement of membership functions (MFs)					Criticality index					
	CF	CFG	CF	CFG	MFs of CFs			MFs of CFGs		Index	Weight	Rank			
Compatibility		7.073		0.115				0.012	0.085	0.354	0.451	0.098	3.54	0.23	4
f-09	3.537		0.500		0.000	0.098	0.366	0.439	0.098						
f-17	3.537		0.500		0.024	0.073	0.341	0.463	0.098						
Competitive Advantage		10.976		0.179				0.016	0.082	0.316	0.399	0.187	3.66	0.24	3
f-15	3.659		0.333		0.000	0.122	0.293	0.390	0.195						
f-23	3.561		0.324		0.049	0.049	0.366	0.366	0.171						
f-03	3.756		0.342		0.000	0.073	0.293	0.439	0.195						
Trialability		8.585		0.140				0.000	0.024	0.071	0.488	0.416	4.30	0.28	1
f-13	4.415		0.514		0.000	0.024	0.000	0.512	0.463						
f-11	4.171		0.486		0.000	0.024	0.146	0.463	0.366						
Relative advantage		34.854		0.567				0.006	0.080	0.231	0.397	0.287	3.88	0.25	2
f-08	4.122		0.118		0.000	0.024	0.195	0.415	0.366						
f-01	4.000		0.115		0.024	0.049	0.171	0.415	0.341						
f-04	4.000		0.115		0.000	0.049	0.268	0.317	0.366						
f-21	3.951		0.113		0.024	0.049	0.146	0.512	0.268						
f-07	3.854		0.111		0.000	0.073	0.244	0.439	0.244						
f-20	3.829		0.110		0.000	0.073	0.244	0.463	0.220						
f-12	3.805		0.109		0.000	0.122	0.244	0.341	0.293						
f-24	3.561		0.102		0.000	0.146	0.341	0.317	0.195						
f-25	3.732		0.107		0.000	0.146	0.244	0.341	0.268						