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RESEARCH ARTICLE

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Attitudes towards offsite prefabrication: a fuzzy approach to examining uncertainty within U.K. industry perception

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ABSTRACT

Offsite prefabrication (OP) is an important approach in overcoming some inefficiencies in the U.K. construction sector. Whilst growth in OP can be demonstrated, its uptake is limited in relation to the expected benefit of its application. Perception, in part due to historical application, has been highlighted as a significant contributing factor in its limited uptake. However, despite recognition that the uncertainties associated with perception on OP are important to technological innovation adoption, these uncertainties were not explored in the previous studies. We adopt fuzzy-set theory, in combination with a survey from 76 organisations in the U.K., to explore these uncertainties in perception for a broad range of OP applications. Through fuzzy-set analysis, the study presents insight into some of the uncertainties related to the perception of OP through three themes: Uptake, Impression, and Strategy. This study proposes that the uncertainty in the perception of OP value, within specific and across all applications, needs to be explicitly considered to understand how perception is informing uptake. This research also suggests that negative perception is one of the key constraints to uptake and it is in fact the overall culture of the U.K. construction sector that is limiting the uptake of OP.

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Offsite prefabrication; perception; fuzzy-set theory; uncertainty; construction methods

1. Introduction

Despite the benefits of Offsite prefabrication (OP) being well-documented and widely recognised, uptake has been underwhelming and it is yet to embed itself into the sector (Goodier and Gibb 2007). Much research has purported causes of such limited uptake, with the foremost being negative industry perception toward OP that stems from ideas of post-war prefabrication, 1960s–1970s social housing, and 1980s 'scares' about timber-frame construction (Mao et al. 2015). Concerns around OP's cost, range, and quality are also understood to be a cause of negative views (Nadim and Goulding 2011). Although many studies on industry perception of OP have been conducted, many focus on the use of quantitative survey without the consideration of uncertainty in the interpretation of questions and response (Gibb and Isack 2003; Blismas, Pasquire, and Gibb 2006; Goodier and Gibb 2007; Pan, Gibb, and Dainty 2007; Nadim and Goulding 2010; Nadim and Goulding 2011; Mao et al. 2015). Although the use of psychometric scales (i.e. Likert) is well-known and widely practiced, a typical ordinal scale fails to capture any information about the intervals between responses and interpretation of question and response – so distorts information (Li 2013). Typical closed-response quantitative scaling in survey limits respondent choice, forcing choice between given options that might not reflect their view and fail to appreciate potential nuances in response (Hodge and Gillespie 2003).

The application of fuzzy-set theory enables imprecision and uncertainty in the linguistic interpretation of information (as presented in surveys) to be taken into account. Despite its limited use in a qualitative study (Ragin 2000; Smithson and Verkuilen 2006; Li 2013), the application to industry perception of OP can offer

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value in terms of highlighting the uncertainty as ambiguity in knowledge and equivocality within organisational decision making (Lipshitz and Strauss 1997).

Using fuzzy-set theory, the aim of the paper is to explicitly address the representation of uncertainty held within industry perceptions on the use of OP methods and demonstrate how these uncertainties inform existing commentary on the perceived points of influence on attitudes towards OP and associated uptake.

2. Current trend of offsite prefabrication uptake

Table 1 demonstrates the sub-sector variations in OP use within the U.K., highlighting low market share in the infrastructure and residential sub-sectors, but comparatively high market share in the commercial sub-

Table 1. Market share of offsite prefabrication in the sectors and sub-sectors of various economically similar countries.

	Market share of offsite prefabrication			
	Across the construction sector	Infrastructure sub-sector (including civil engineering)	Residential sub-sector	Commercial sub-sector
UK	'Limited use'[6] 1.7%[8] 2%[7] 2.1%[1] 6.28%[3] 7.02%[3] 7.01%*[3] 6-7%[11] 'Rather low'[10] 'Relatively low [adoption]'[13]	0.5%[1]	'Very low'[7] 1%[5] 3%[6] ≤5%[9]	'Widely accepted'[4]
Austria	-	-	33%[2]	>33%[2]
Germany	'Widely adopted'[4] 'Widely used'[6]	-	9%[9] 13%[4] 15%[2]	>15%[2]
Spain	-	-	5%[2]	>5%[2]
France	-	-	5%[2]	>5%[2]
Netherlands	-	-	20%[9]	-
Sweden	'Widely used'[6]	-	5-33%[2] '84% of detached houses'[9]	>5-33%[2]
Denmark	'Widely used'[6]	-	5-33%[2]	>5-33%[2]
Norway	'Widely used'[6]	-	5-33%[2]	>5-33%[2]
USA	'Not been utilized widely'[4] 'Widely used'[6] 7%[10] 'Relatively low [adoption]'[13]	-	≤5%[9] 20%[4]	>20%[4]
Japan	'Widely adopted'[4] 'Widely used'[6]	-	10%[4] 14%[5] 15%[2] 15%[9] 'Almost 100%'[6]	>13-15%[2]
Australia	'Limited use'[6] 'Limited use'[7] 'Rather low'[10] 'Relatively low [adoption]'[13]	-	≤5%[9]	-
China	'Lags behind'[12] 'Developing at a steady rate'[10]	-	-	-
Malaysia	'Rather low'[10] 'Relatively low [adoption]'[13]	-	-	-

References: [1]Goodier and Gibb (2004); [2]Linner and Bock (2012); [3]Taylor (2010); [4]Lu (2007); [5]Johnson (2007); [6]Zhao and Riffat (2007); [7]Blismas and Wakefield (2009); [8]Samuelsson-Brown, Parry, and Howlett (2003); [9]Sweet (2015); [10]Goulding et al. (2017); [11]KPMG (2016); [12]Hong et al. (2018); [13]Oakley (2017).

sector. In the residential sub-sector, where more specific data is provided, it shows limited growth in the contribution of OP from 3% in 2005 to ≤5% in 2015 (Zhao and Riffat 2007). Goodier and Gibb (2004) also provide a low market share of 0.5% for OP in new infrastructure work in the U.K.

Using the audited financial accounts of U.K. registered companies from the Financial Analysis Made Easy (FAME) database (FAME 2019) the Gross Output (GO) of, and Gross Value Added (GVA) by, the OP sector was estimated (see Table 2). Data from the Office for National Statistics (ONS) (ONS 2019) were used to identify historic sector output between 2007 and 2018, and the Construction Products Association's (CPA) industry forecast was utilised to indicate future sector output between 2019 and 2021 (CPA 2018). Expanding on Taylor's (2010) methodology in the forecasting element of the review, Figure 1 was developed by plotting the GO and GVA percentage share of OP from 2007 to 2017 and using linear regression to forecast its share between 2018 and 2021. Regression was used in recognition that the trend in growth is supported by the government and so is assumed to continue in the future. The output data for OP had to be a forecast from 2019 onwards due to the FAME (2019) database using audited financial information as the information for any given year will only be available in the subsequent year, after all, audited data has been received and collated. The forecast percentages for OP GO and GVA were then used to establish their monetary value by calculating the amount each percentage represented of actual sector GO and GVA in 2019, and of the CPA (2018) forecast GO and GVA for the sector from 2019 to 2021 (CPA 2018; ONS 2019). This data is captured in Table 2.

2.1 Attitudes toward offsite prefabrication

To further embed OP into the construction sector, the needs and perceptions of stakeholders must be adequately studied (Dave, Watson, and Prasad 2017). Several high-profile reports have also been produced by professional bodies such as the Construction Leadership Council (Farmer 2016), Construction Excellence (Wolstenholme 2009), and the Royal Institution of Chartered Surveyors (RICS 2018). Despite such developments in knowledge and understanding of OP, OP adoption has remained modest (Gan, Chang, and Wen 2018). There is, therefore, a current inconsistency between the positive perception of OP within industry leadership and industry uptake.

Nadim and Goulding (2011), who conducted a content analysis of transcripts from 54 questionnaires carried out under the ManuBuild EU research project which explored the perception of OP amongst construction industry practitioners, suggest that negative perceptions, in particular its cost, range, and quality, still exist in the U.K. Such sentiments have led to client scepticism and resistance, and so it remains a significant factor in limiting uptake (Mao et al. 2015). For Nadim and Goulding (2011) such sentiments are the result of OP's historic failure to deliver improved performance in post-war and 1960s–1970s social housing, as well as 'scares' about 1980s timber-frame housing. Such perceptions, however, conflict with research that has sought industry perspective on OP directly (Gibb and Isack 2003; Blismas, Pasquire, and Gibb 2006; Goodier and Gibb 2007; Pan, Gibb, and Dainty 2007; Nadim and Goulding 2010; Nadim and Goulding

Table 2. Gross output and gross value added by offsite prefabrication to UK construction sector from 2007-2021(* = forecast).

Year	UK construction gross output (£ million)	OP gross output (£ million)	OP % share of gross output	UK construction gross value added	OP gross value added (£ million)	OP % share of gross value added
2007	127,064	9072	7.14%	98,000	2013	2.05%
2008	128,644	8920	6.93%	95,000	2036	2.14%
2009	111,083	7413	6.67%	83,000	1684	2.03%
2010	117,385	8509	7.25%	90,000	1899	2.11%
2011	121,737	8776	7.21%	92,000	1998	2.17%
2012	116,837	8859	7.58%	85,000	2044	2.40%
2013	122,403	9290	7.59%	86,000	2111	2.45%
2014	135,950	10,398	7.65%	94,000	2315	2.46%
2015	143,118	11,067	7.73%	97,572	2449	2.51%
2016	151,771	11,879	7.83%	100,499	2583	2.57%
2017	165,917	13,079	7.88%	104,117	2749	2.64%
2018	171,150	13,654	7.98%	108,594	2892	2.66%
2019	*179,342	*14,791	*8.25%	*113,066	*3166	*2.80%
2020	*187,521	*15,587	*8.31%	*117,277	*3359	*2.86%
2021	*195,701	*16,354	*8.36%	*121,490	*3565	*2.93%

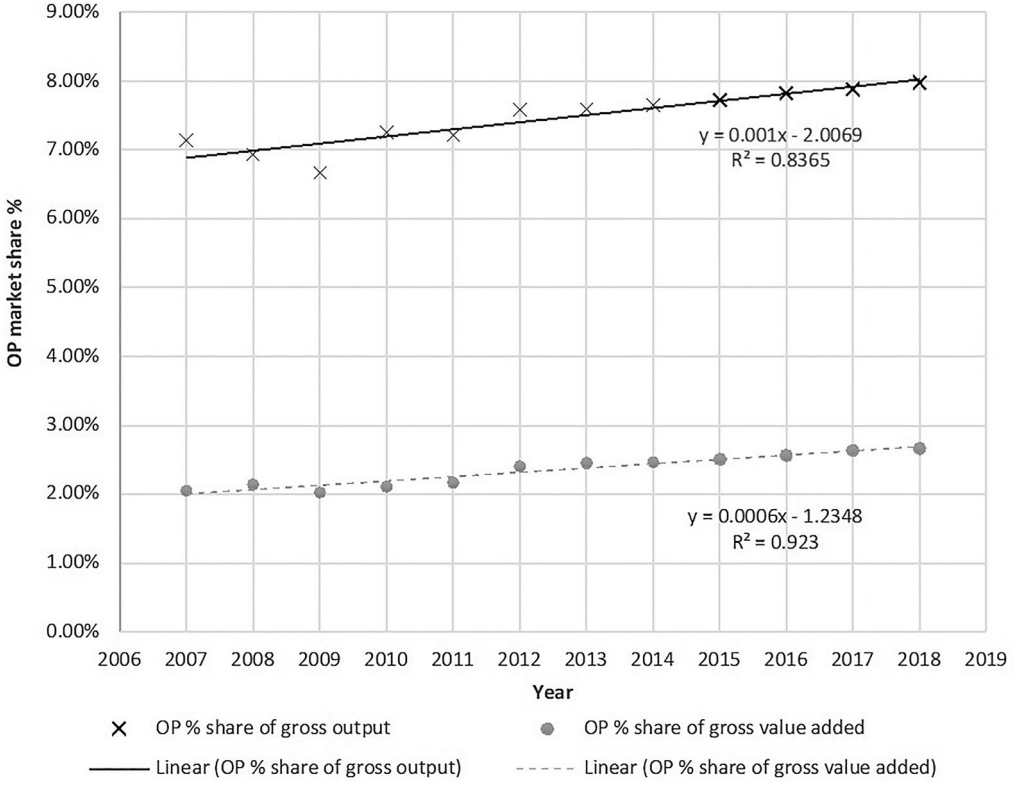

Figure 1. OP percentage share of U.K. construction gross output and gross value added from 2007 to 2018.

2011; Mao et al. 2015). For example, in Goodier and Gibb's (2007) questionnaire survey of over 75 suppliers/manufacturers, contractors, and designers/clients, the respondents recognised OP's quality, value, cost (both initial and whole life), and flexibility as drivers of the method. Not only does this contradict accounts that indicate negative industry perception towards OP's cost and quality, but it further highlights the void between the perception of OP and uptake.

For the top 100 U.K. housebuilders by unit completion in the survey of Pan et al.'s (2007), government promotion of OP is its largest driver. Based on the findings in a survey of 83 Chinese developers, Mao et al. (2015) also acknowledge the significance of government influence in driving uptake of OP. Government commissioned reports advocating the use of modern methods of construction (including OP) to improve performance across the sector, such as those produced by Latham (1994), Egan (1998), Wolstenholme (2009), and Farmer (2016) are viewed as critical drivers of uptake (Pan, Dainty, and Gibb 2004). Despite this, however, and despite the U.K. government stating that preferential treatment will be given to OP, there is yet to be overwhelming industry-wide adoption (Science & Technology Select Committee 2018). A possible explanation for the contradictory accounts of industry perception toward OP and uptake rate could be found in the methodology used by previous research, which has commonly engaged practitioners with a Likert-scale based survey (Nadim and Goulding 2010). Action to increase uptake might also be being dominated by more extreme, less representative, and thus polarising viewpoints. There could, equally, be uncertainty associated with positive perceptions that could be hindering uptake. Whether one factor or a combination of a few, understanding the reason behind this inconsistency is key if OP is to be embedded into the sector.

While Likert-scale surveys are a useful means to sample perception in terms of administration and data coding, information can be lost as language is imprecise (Symeonaki, Michalopoulou, and Kazani 2015). To tackle such imprecision, fuzzy set theory was developed and introduced to the social science community following its conception by Lotfi Zadeh (1965) for applications in engineering. Li (2013), who developed a novel fuzzy Likert scale system, states that fuzzy sets offer a model that improves precision and captures uncertainty in ordinary sets of information. The application of fuzzy sets could, therefore, provide some

insight into the observed inconsistency in perception versus uptake as it provides a more robust methodology that mitigates information loss and distortion (Vonglao 2017). Table 3 provides a summary of the previous research on OP which used discrete choice survey and is referenced in this study.

3. Research method

As noted, the aim of the paper is to explicitly address the representation of uncertainty held within industry perceptions on the use of OP methods and demonstrate how these uncertainties inform existing commentary on the perceived points of influence on attitudes towards OP and associated uptake. The data in this study was obtained through a questionnaire survey of 76 U.K. construction professionals across 22 organisations – including 28 clients and consultants, 18 designers, and 30 contractors. Of the responses, 72 were completed in line with the instructions provided. Based upon a calculated combined turnover of approximately £50.6billion, they represent over 30% of the U.K. construction sector's £163.5 billion output (Office for National Statistics 2019). The resultant findings, therefore, provide a crucial insight into the views and perceptions of some of the sector's major contributors.

A questionnaire survey was developed and distributed online through the Bristol Online Survey platform (Bristol Online Survey 2018). Homogenous, purposive sampling was used to derive the target sample of U.K. construction practitioners to reduce variation in response resulting from heterogeneity in the background of respondents. The questionnaire was separated into three themes with seven identified sub-themes (see Table 4). The questions within each theme were comprised of a statement and respondents were asked to identify their level of agreement to each.

The first theme, which explores current levels of OP uptake, establishes present trends in adoption and inter-sector variances in its use. The second theme, which examines industry practitioners' perception of OP, outlines the current impression of OP and the attitudes of different construction stakeholders towards it. The final theme, which evaluates strategies to increase uptake, asserts a range of approaches considered to be the most effective by industry practitioners to increase OP adoption, from full-scale sector reform to addressing on-site technical constraints.

Each statement in the questionnaire had two different response formats:

- Use of a five-point discrete choice scale with options ranging from strong disagreement to strong agreement scaled numerically from 1 to 20.

Table 3. Previous research on OP which used discrete choice survey and are referenced in this study.

Research reference	Aim of study	Research method	Sample size
Gibb and Isack (2003)	Understand major client expectations from and drivers for use of pre-assembly on their projects	Interview survey	59 senior from UK construction client organisations
Blismas, Pasquire, and Gibb (2006)	Create a benefit evaluation for off-site production in construction	Benefit evaluation using findings from Gibb and Isack (2003) interview survey	59 senior from UK construction client organisations
Goodier and Gibb (2007)	Identify the variances in opinion regarding OP across the sector (including between clients, designers, contractors and offsite suppliers) and indicate future growth opportunities for OP in the UK construction industry	Literature review & questionnaire survey	75 (39 clients, 13 contractors, 23 offsite suppliers) suppliers/ manufacturers, contractors, and designers/client
Pan, Gibb, and Dainty (2007)	Understand the perspective of UK housebuilders on the use of OP as a method of construction	Interviews & questionnaire survey	The top 100 UK housebuilders by unit completion
Nadim and Goulding (2010)	Understand the UK construction industry's perception regarding OP adoption/uptake	Questionnaire survey	36 large construction organisations
Nadim and Goulding (2011)	Explore the dominant concerns of the European Union (EU) construction industry regarding OP	Content analysis of a questionnaire survey conducted by the ManuBuild EU research project	54 construction organisations
Mao et al. (2015)	Identify the major barriers to Op in China	Questionnaire survey	83 Chinese construction sector developers

Table 4. Statements presented to participants for fuzzy interpretation of level of agreement. Seven themes identified in review used to group statements for analysis.

Theme	Sub-Theme	Statement
Level of Uptake	Culture	1. The use of offsite prefabrication is widespread across the UK construction sector.
		2. UK design culture is preventing greater uptake of offsite prefabrication in the UK construction sector.
	Where Applied	3. The infrastructure sub-sector is very likely to use offsite prefabrication.
		4. The commercial sub-sector is very likely to use offsite prefabrication.
		5. The residential sub-sector is very likely to use offsite prefabrication.
Impression of OP	Current	6. Greater uptake of offsite prefabrication would be beneficial to the UK construction sector.
		7. Offsite prefabrication has more benefits to the UK construction sector than drawbacks.
		8. There are more drivers than barriers to greater uptake of offsite prefabrication in the UK construction sector.
	Actor Barriers	9. Clients generally oppose the use of offsite prefabrication.
		10. Consultants generally oppose the use of offsite prefabrication.
		11. Designers generally oppose the use of offsite prefabrication.
		12. Contractors generally oppose the use of offsite prefabrication.
Strategies to increase uptake	Increasing trust & changing perception (*by transparency/visibility of process)	13. More easily accessible information on offsite prefabrication, to improve sector knowledge, will improve uptake.
		14. Greater and clearer government endorsement of offsite prefabrication, including endorsement of offsite prefabrication associations, will improve uptake.
		15. Enhancing OP design processes and technologies to enable greater client involvement will lead to increased uptake of offsite prefabrication.*
		16. Warranties and guarantees of product quality from offsite prefabrication manufacturers will increase uptake.
		17. Wider accreditation of offsite prefabrication manufacturers will increase uptake.
		18. Greater marketing of offsite prefabrication is needed to improve industry awareness and to address negative perceptions about it.
	Upskilling	19. Developing offsite manufacturing processes and technologies to enable 'mass customisation' to be integrated will improve uptake of prefabrication. (Flexibility)
		20. Improving logistical and on-site fixing issues through targeted training of manufacturers will increase uptake of offsite prefabrication.
		21. Improving offsite integration into the construction process through targeted training of construction personnel will increase uptake of offsite prefabrication.
	Business practice and incentives	22. Developing new business and procurement models for companies in the construction sector will enable them to integrate offsite prefabrication more easily.
		23. More government incentives, such as grants, to increase investment in offsite prefabrication will lead to greater uptake.
		24. Altering construction and procurement processes to encourage greater supply chain integration will overcome drawbacks in offsite prefabrication.

- Fuzzy rating scale, with a scale of 1–20 (with 1 representing the strongest level of disagreement, 10 a neutral response, and 20 the strongest level of agreement). Under this response format, participants were asked to identify two points on the scale which, between them, represented their level of agreement.

A common psychometric scale typically used in construction-related research seeking to engage the perspective of industry practitioners, the Likert scale is widely recognised and easy to code due to single numbers representing specific responses. More recently, however, the fuzzy set theory was introduced to social science applications that could address issues of imprecision and uncertainty in ordinary sets of information

and thus represent a more considered and robust approach for the survey. Using fuzzy set theory to capture distribution in the perceived understanding of industry perception regarding OP enables evaluation to move from deterministic towards something that accounts for imprecision in the meaning of the devised statements, as well as uncertainty in forced-commitment (i.e. membership) to take a position on a changing and immature construction approach.

A numeric scale of 1–20 was used in the survey, with 1 representing strong disagreement; 5 somewhat disagreement; 10 neutral; 15 somewhat agreement; and 20 strong agreement.

The isosceles triangulated method of fuzzification was used in data analysis (Li 2013). Analysis of each statement broadly followed the same process. Each participant's two-point agreement level was plotted on the input continuum. To produce a triangulated fuzzy number, a membership degree of a chosen agreement level between 0 and 1 was required. The membership function indicates how strongly a participant complies with their level of agreement and where their strongest compliance lies between their two-point agreement level. To find this, and avoid making the questionnaire survey excessively long, five equidistant middle values equal to 0%, 25%, 50%, 75%, and 100% of the triangulated fuzzy number band were considered in the data analysis.

The data is analysed to show the spread and likelihood associated with individual statement response across all respondents as well as spread and likelihood within themes. Linguistic responses are represented in both fuzzy and discrete choice scales along with the average for (a) each statement and (b) for each theme (set of statements).

The above groupings were selected as they would allow participants' fuzzy and discrete linguistic responses to each question and theme to be compared. This, in turn, enables analysis of the impact that a fuzzy (uncertainty) interpretation has on understanding industry perception towards OP.

4. Results

The survey was distributed to a range of industry practitioners from companies with turnovers ranging from £15 m to over £8bn (in 2018) and received 76 complete responses, of which 72 were useable.

The survey was separated into the themes identified in the research method section of the paper, namely: (i) Current level of uptake, (ii) Impression of OP, and (iii) Strategies to increase uptake. Table 5 compares participants' discrete and fuzzy responses in numerical and linguistic terms. The level of information attained from the fuzzy responses was far greater than that for the discrete response option (taken as the mid-point of the fuzzy scale in our analysis). It also shows that in many cases participants' fuzzy responses, when reviewed in linguistic terms, do not align with their discrete response. This was the case in over 70% of questions. Comparative to the discrete response choice, the fuzzy responses show a greater degree of uncertainty amongst respondents as fewer occupy either extreme of the scale (i.e. strongly agree/strongly disagree) and more align with a neutral response.

Table 5 shows that in their discrete response the largest section of participants strongly agreed that greater uptake of OP would be beneficial to the sector, that OP has more benefits than drawbacks, and that there are more drivers than barriers to uptake. A higher proportion (over 60%) of respondents, however, strongly agreed with the first two statements than the last and the fuzzy responses to all differ entirely. When translated to a linguistic label, the average fuzzy response shows that participants only somewhat agreed that greater uptake would be beneficial to the sector and that OP has more benefits than drawbacks but had a neutral stance on there being more drivers than barriers to uptake. There was, however, less certainty and/or consensus amongst participants about whether there are more drivers than barriers to OP uptake as there is a notably larger delta between the lower and higher point in the average fuzzy response.

Although 42% of participants 'strongly disagreed' that the use of OP is widespread across the U.K., the average fuzzy response equated to a less committed 'somewhat disagreement'. The discrete and fuzzy level of 'somewhat agreement' that designers and design culture are a barrier suggests that culture (49%) is the more influential factor (designers at 45%). As with the question on designer opposition to OP use, the linguistic translation of the average fuzzy response to the same question regarding consultants ('neutral') matched the most popular discrete response – though it occupied a larger section of the disagreement end of the scale. In relation to client and contractor opposition to OP use, the average fuzzy response to both equated to a 'neutral' perception, despite a discrete response of 'disagreement' to contractor opposition. Both, nevertheless, did not align with the most popular discrete responses – 'somewhat disagreement' (34%) to the statement on client opposition to OP use and 'strong disagreement' (46%) to the statement on contractor opposition.

Table 5. Discrete vs fuzzy responses to each question.

Statement		Most popular discrete linguistic response	% of respondents who chose it	Average fuzzy response	Fuzzy response in linguistic terms
Current level of uptake					
Culture	Table 3, Statement 1	Strongly disagree	42%	4.6, 7.3	Somewhat disagree
	Table 3, Statement 2	Somewhat agree	49%	13.9, 15.6	Somewhat agree
Where Applied	Table 3, Statement 3	Somewhat agree / Neutral	38% (selected each)	10.4, 12.4	Neutral
	Table 3, Statement 4	Somewhat agree	55%	12.9, 15.7	Somewhat agree
	Table 3, Statement 5	Strongly disagree	29%	5.8, 7	Somewhat disagree
Impression of OP					
Current	Table 3, Statement 6	Strongly agree	61%	14.4, 16.8	Somewhat agree
	Table 3, Statement 7	Strongly agree	63%	12.5, 14.8	Somewhat agree
	Table 3, Statement 8	Strongly agree	42%	9.1, 12.7	Neutral
Actor Barriers	Table 3, Statement 9	Somewhat disagree	34%	9,4, 11.5	Neutral
	Table 3, Statement 10	Neutral	36%	8.3, 10.1	Neutral
	Table 3, Statement 11	Somewhat agree	45%	11.9, 14.8	Somewhat agree
	Table 3, Statement 12	Strongly disagree	46%	6.4, 10.2	Neutral
Strategies to increase uptake					
Increasing trust & changing perception (*by transparency /visibility of process)	Table 3, Statement 13	Somewhat Agree	57%	11.9, 14.3	Somewhat agree
	Table 3, Statement 14	Strongly agree / Somewhat agree	47% (selected each)	12.6, 14.8	Somewhat agree
	Table 3, Statement 15	Somewhat agree	54%	12.5, 14.3	Somewhat agree
	Table 3, Statement 16	Somewhat agree	45%	9.7, 11.5	Neutral
	Table 3, Statement 17	Somewhat agree	47%	10.3, 11.4	Neutral
	Table 3, Statement 18	Somewhat agree	50%	18, 19.6	Strongly agree
Upskilling	Table 3, Statement 19	Somewhat agree	57%	18.1, 19.5	Strongly agree
	Table 3, Statement 20	Strongly agree	43%	12.4, 14.3	Somewhat agree
	Table 3, Statement 21	Somewhat agree	40%	10.3, 13.1	Neutral
Business practice and incentives	Table 3, Statement 22	Somewhat agree	29%	18.1, 19.5	Strongly agree
	Table 3, Statement 23	Strongly agree	70%	18.2, 19.7	Strongly agree
	Table 3, Statement 24	Somewhat agree	37%	18.2, 19.5	Strongly agree

When asked how likely each of the major industry sub-sectors are to use OP, in terms of their discrete response, Table 6 indicates that most participants (55%) somewhat agreed that the commercial sector is very likely to use the methods, the largest section (29%) of participants strongly disagreed that the residential sector is very likely, and an equal proportion (38%) somewhat agreed or had a neutral feeling that the infrastructure sector is very likely. For the commercial sector, as per the discrete response, the average fuzzy response also equated to somewhat agree with the statement that the sector is very likely to use OP. Participants' fuzzy responses regarding the infrastructure and residential sectors differed, however, to their discrete response. The average fuzzy response to the question on the infrastructure sector being very likely to use OP translates to a neutral linguistic response, though the fuzzy response itself occupied more of the agreement section of the scale. The average fuzzy response to the same question on the residential sector being very likely to use OP equates to somewhat disagreement in linguistic terms.

4.1 Spread in response

The x-axes of Figures 2–4 represent the scale of agreement to the statements in both fuzzy and implied discrete terms. The *y*-axes identify the membership function of each participant's response, with the red y-axis corresponding with participants' discrete response and the blue *y*-axis corresponding with participants' fuzzy response. The membership function is a scale from 0 to 1 that rates the accuracy of a participant's response. 0 = full non-membership (i.e. the response is an absolute false). 1 = full membership (i.e. the response is absolute truth). As the discrete scale represents a crisp boundary, a member either does or does not belong to a set. With participants' fuzzy responses, however, their membership can operate across a range.

Table 6. Most effective ways to increase OP uptake (average discrete vs. average fuzzy response).

Rank (Fuzzy vs Discrete)	Statement	Fuzzy response	Fuzzy response in linguistic terms	Implied discrete response	% of respondents who chose it
1–1	More government incentives, such as grants, to increase investment in offsite prefabrication will lead to greater uptake.	18.2, 19.7	Strongly agree	Strongly agree	70%
2–7	Greater marketing of offsite prefabrication is needed to improve industry awareness and to address negative perceptions about it.	18, 19.6	Strongly agree	Somewhat agree	50%
3–11	Altering construction and procurement processes to encourage greater supply chain integration will overcome drawbacks in offsite prefabrication.	18.2, 19.5	Strongly agree	Somewhat agree	37%
4–5	Developing offsite manufacturing processes and technologies to enable 'mass customisation' to be integrated will improve uptake of prefabrication.	18.1, 19.5	Strongly agree	Somewhat agree	57%
4–12	Developing new business and procurement models for companies in the construction sector will enable them to integrate offsite prefabrication more easily.	18.1, 19.5	Strongly agree	Somewhat agree	29%
6–2	Greater and clearer government endorsement of offsite prefabrication, including endorsement of offsite prefabrication associations, will improve uptake.	12.6, 14.8	Somewhat agree	Strongly agree / Somewhat agree	47% (selected each)
7–6	Enhancing OP design processes and technologies to enable greater client involvement will lead to increased uptake of offsite prefabrication.	12.5, 14.3	Somewhat agree	Somewhat agree	54%
8–3	Improving logistical and on-site fixing of issues through targeted training of manufacturers will increase uptake of offsite prefabrication.	12.4, 14.3	Somewhat agree	Strongly agree	43%
9–4	More easily accessible information on offsite prefabrication, to improve sector knowledge, will improve uptake.	11.9, 14.3	Somewhat agree	Somewhat Agree	57%
10–10	Improving offsite integration into the construction process through targeted training of construction personnel will increase uptake of offsite prefabrication.	10.3, 13.1	Neutral	Somewhat agree	40%
11–9	Warranties and guarantees of product quality from offsite prefabrication manufacturers will increase uptake.	9.7, 11.5	Neutral	Somewhat agree	45%
12–8	Wider accreditation of offsite prefabrication manufacturers will increase uptake.	10.3, 11.4	Neutral	Somewhat agree	47%

The fuzzy responses are given on a scale of 0–20 (strong disagreement to strong agreement). As participants were asked for the upper and lower bounds of their confidence in agreement with the proposed states. Different mid-points of membership are applied to give different weighting to the response ranges given. Off-site prefabrication uptake is presented in Figure 2, industry impression (Figure 3), and strategies for uptake (Figure 4). The discrete responses in the survey indicate differences in perception under each theme. The weighted distributions, however, generally have a wider spread and demonstrate non-uniform and sometimes multi-modal functionality in perception (modal points in the fuzzy distributions align to high-frequency discrete responses).

The multimodal nature of some distributions highlights opposing perceptions of certain barriers/drivers to greater OP uptake. Skewed distributions (e.g. Statement 23, Figure 4(b)) indicate stronger alignment in the industry view. As in Statement 8 (Figure 3(a)), the spread in response can be across most (if not all) of the response range that hints towards there being no clear industry viewpoint, whilst peaks in response by the sample from industry can give confidence in the majority perception. The influence of these distributions in perception cannot be evaluated for the weight of influence on the level of uptake.

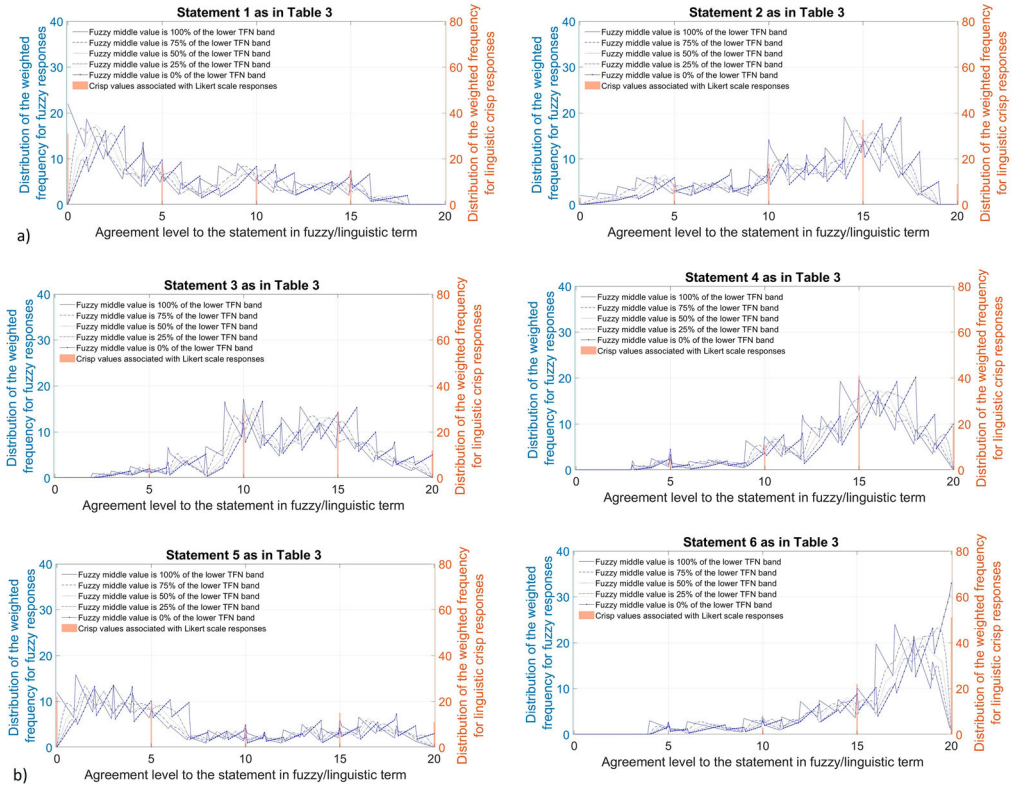

Figure 2. Weighted frequency of responses to the questions regarding the current level of offsite prefabrication uptake for sub-themes (a) Culture and (b) Where Applied. Distributions for all assumed mid-point values are given, as well as frequency of linguistic values as presented on the numerate scale.

4.2 Increasing uptake

Statements 13–24 focus on ways in which uptake of OP might be increased in the U.K. Table 6 was produced to provide a ranked comparison of the ways considered best by participants, both by most popular implied discrete response and by the average fuzzy response.

Table 6 shows that participants, in both their discrete and fuzzy responses, consider increased government incentives in OP, such as grants, the most effective way to increase uptake. This is, however, the only consensus in the discrete and fuzzy responses in terms of the top 6 rankings. As discrete responses, just under half of the participants (47%) strongly agreed that greater and clearer government endorsement of OP will increase uptake, although the same percentage of participants only somewhat agreed with this statement. A similar percentage of participants (43%) in their discrete response, strongly agreed that improving logistical and on-site fixing of issues through training of OP manufacturers will increase uptake. The majority of participants (57%) in their discrete response, somewhat agreed that more easily accessible information on OP to improve sector knowledge, and the development of OP manufacturing processes and technologies to enable 'mass customisation' to be integrated will encourage greater uptake. A similar percentage of participants (54%) in their discrete response 'somewhat agreed' that enhancing OP design processes and technologies to enable greater client involvement will lead to increased uptake.

Table 6 also shows that the average fuzzy response regarding ways to increase OP uptake does not fully align with their implied discrete response. Behind more government incentives, there was strong agreement that greater marketing of OP is needed to improve industry awareness, address negative perception, and increase uptake. Altering construction and procurement processes to encourage greater supply chain integration are highlighted in the analysis as perceived to assist in overcoming OP's drawbacks and increase uptake.

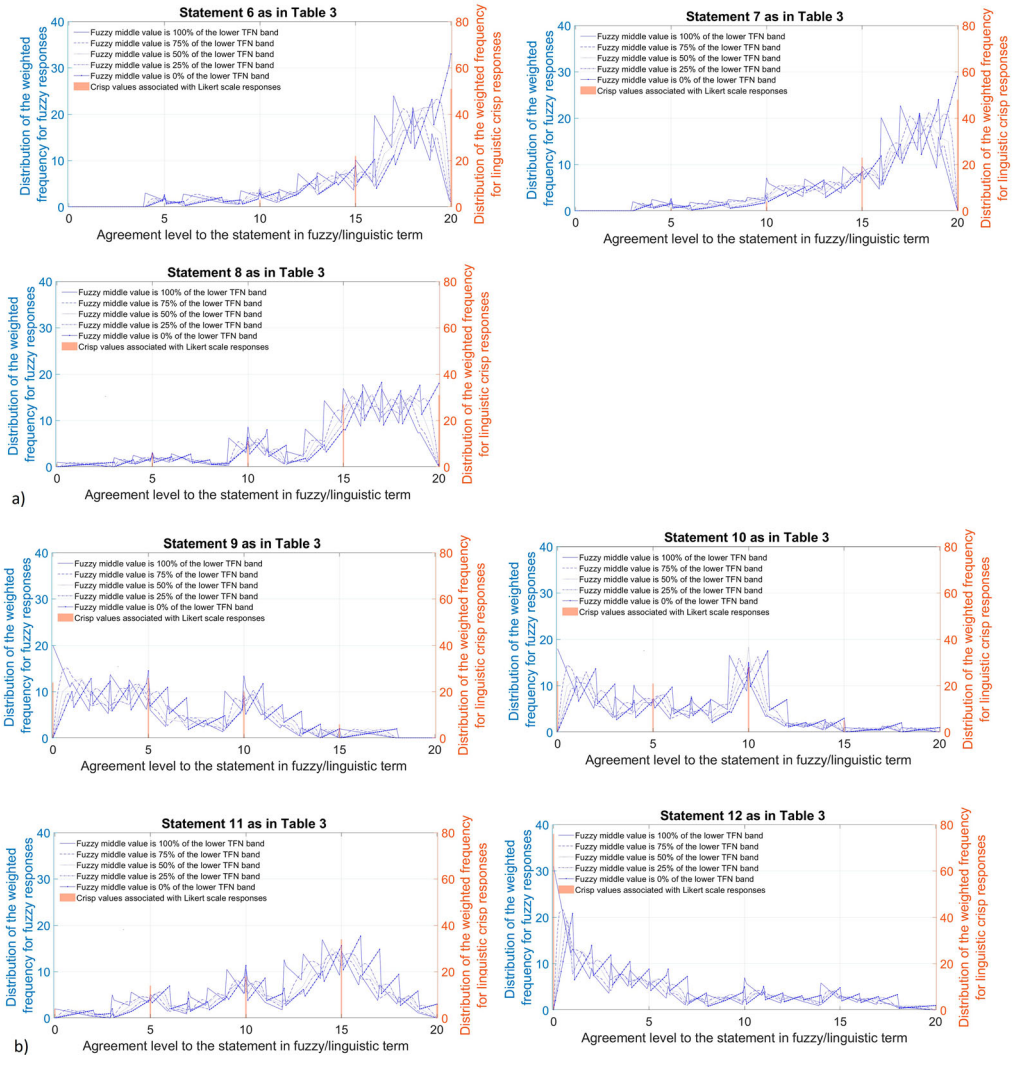

Figure 3. Weighted frequency of responses to the questions regarding industry impression of offsite prefabrication for sub-themes (a) Current and (b) Actor Barriers. Distributions for all assumed mid-point values are given, as well as frequency of linguistic values as presented on the numerate scale.

Table 6 shows that the 6th most effective way to increase OP uptake, based on the average fuzzy response, is a greater and clearer government endorsement of OP. This again differs from participants' discrete response which showed that it is considered the 2nd most effective way to increase uptake.

5. Discussion

The application of fuzzy-set theory to the discrete choice survey has enabled a greater examination of the uncertainties in the held perception of OP for an industry sample population. Alone, as it has frequently been used in previous research on industry perception, the discrete choice survey does not provide an accurate reflection of the population sample views and can lead to inaccurate results (Gibb and Isack 2003; Blismas, Pasquire, and Gibb 2006; Goodier and Gibb 2007; Pan, Gibb, and Dainty 2007; Nadim and Goulding 2010; Nadim and Goulding 2011; Mao et al. 2015). In contrast, the fuzzy results demonstrate that the

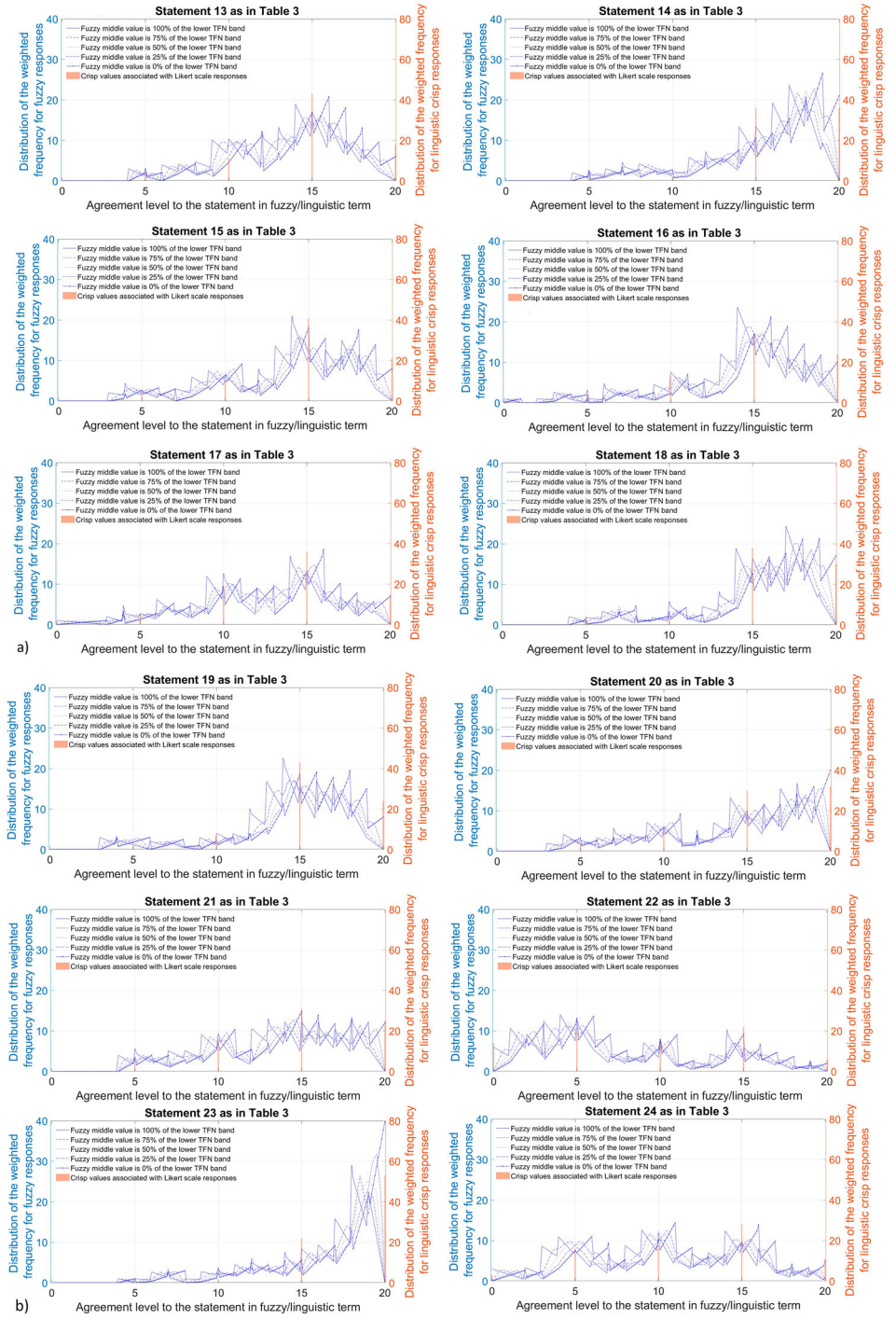

Figure 4. Weighted frequency of responses to the questions regarding strategies to increase uptake for sub-themes (a) Increasing Trust, (b) Upskilling, and (c) Business practice and Incentives. Distributions for all assumed mid-point values are given, as well as frequency of linguistic values as presented on the numerate scale.

application of fuzzy logic reduces information distortion and yields a far greater amount of information that can be analysed in a variety of ways. The fuzzy scale provides greater choice, in terms of both size and freedom of representation on the imposed scale of response.

Despite Goodier and Gibb's (2005) recognition that interest in OP has been increasing in the UK and Taylor's (2010) assertion that uptake has been growing, the findings in Table 6 suggest that the use of OP is still limited across the sector. The findings also suggest that the use of OP varies considerably by sub-sector (Figure 2(b)). These findings, nevertheless, indicate that the U.K. commercial sector's adoption of OP is similar to its counterparts in Austria, Germany, Sweden, Denmark, Norway, USA, and Japan (Linner and Bock 2012). The infrastructure sector, on the other hand, is more likely (albeit marginally) to use OP than to not. This suggests that OP uptake has increased in this sector since Goodier and Gibb's (2004) statistic of 0.5% for OP in new build infrastructure work was produced. In the residential sector, the findings suggest that OP's market share is limited. To a certain extent, therefore, they reflect the existing market share data for the sector (Zhao and Riffat 2007; Johnson 2007; Blismas and Wakefield 2009) but highlight that the residential sector is where OP's main opportunity to increase uptake lies.

Contrary to Gibb (2001) and Kamali and Hewage's (2016) assertion that U.K. design culture is conducive to OP uptake, Figure 2(a) highlights an opposing perception of design culture amongst the sample population. This perception aligns with the Science and Technology Select Committee (2018) report on designer's desire for maximum design freedom so as not to hinder creativity and originality. Clients, consultants, and contractors on the other hand are not recognised as in opposition to, or advocates of, OP. The results, therefore, somewhat contradict Pan et al.'s (2004) assertion that clients can often oppose OP use due to the lack of understanding about its impact to design.

Despite studies such as Nadim and Goulding (2011) and Arif et al. (2017) identifying negative perception as one of the largest barriers to OP uptake, the perception amongst industry professionals is more nuanced. Whilst Arif et al. (2017) indicate that over time the idea of OP fell into disrepute, the sample population response demonstrates that its benefits are not only recognised but perceived in many instances to outweigh noted drawbacks (Figure 3(a)). Despite this, Figure 2 indicates a perception of low uptake of OP across industry and with a different likelihood of uptake by construction sub-sector.

When ranked, only the first and tenth ranked strategy was shared between the discrete and fuzzy responses, and only 3 strategies were found in the top half of both rankings (Table 5). Government intervention (by incentives such as grants) and endorsement were ranked first and sixth, respectively, by the fuzzy set analysis. This demonstrated a greater distinction in the importance of the type of government support than suggested by the discrete choice analysis that would otherwise more strongly support Pan, Dainty, and Gibb (2004) and Mao et al.'s (2015) acknowledgment of the significance of government promotion in driving uptake.

Similar to Kamali and Hewage (2016) and Alonso-Zandari and Hashemi (2017) suggestion, the findings indicate that greater marketing of OP is required sector-wide to improve knowledge and awareness and address any negative perceptions about OP since most of its drawbacks are derived from industry perception (i.e. risks and fears). The rankings that are given in Table 6 also suggest, like the conclusions of Farmer (2016), that change to the sector's procurement models, design culture (customisation), models for businesses, and how they interrelate through the construction supply chain are required if OP is to be embedded into the sector. OP manufacturing processes and technologies must also be developed. Under a discrete choice analysis, the ranking of perception of importance shifts towards industry knowledge and training.

6. Conclusions

This paper has examined the perception of OP amongst a sample of Quantity Surveyors, Construction Managers, Programme Managers, Commercial Managers, and Directors in over twenty construction firms in the U.K. The study provides an updated view on perception, reflecting on recent growth in OP uptake, past study findings, and the implications of survey and response type to interpretation. Using fuzzy set theory to more fully account for diversity in response (both internal to each respondent and across the sample population) analysis of the level of membership of agreement to statements on OP has highlighted that there is no single consensus on the drivers and barriers to OP uptake. Membership of single responses also highlights uncertainties held by individuals for the statements associated with OP uptake. As the first construction-related paper to employ fuzzy set theory when engaging industry perception, it highlights the added value gained in comparison to the discrete choice survey.

The findings suggest, as opposed to the indication in past papers that negative perception is one of the key constraints to uptake, it is in fact the overall culture of the U.K. sector that is limiting uptake. The sector's design culture, risk-averse nature, and limited appetite to change. Sub-sector variations in OP used are

also clearly indicated, with uptake being comparatively high in the commercial sector than the infrastructure and residential sectors.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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