Construction workers' preference and acceptance of digital data provision on the construction site

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Abstract

The architect, engineering, and construction industry (AEC) are adapting their ways of working, by replacing the paper-based communication through digital information, such as the Building Information Model (BIM). The data provision is an essential aspect of BIM adaptation. This research investigated the obstacles of such adoption and explored the impacts of variated data provision variables and attributes on construction workers' preference and acceptance. A stated choice experiment design and discrete choice modeling were applied. An expert interview and an initial questionnaire were conducted to gain knowledge about the important attributes and levels which may have impacts on construction workers' communication on site. In addition, the initial questionnaire also captured the construction workers' awareness of different digital interfaces and data formats, general understanding of new ways of working, and their motivations for adoption if any. Based on the interview and the initial questionnaire results, a stated choice experiment was designed. The experiment focused on the adoption regarding the different format of communication. In total, 178 respondents from the construction sector were recruited in the Netherlands between June - Sep 2018. After cleaning the data, finally, 156 valid questionnaires were used for analysis. Mixed logit (ML) model has been applied for estimations. From the estimation of the stated choice experiment, it can be concluded that construction workers prefer a digital interface over a paper. Important attributes which increase the likelihood of digital data provision to be chosen are the tablet size, interface, and level of integration. From these results, we can conclude that construction workers are in general willing to accept more innovative data formats. Therefore, current prejudges in the industry as conservatism is not accurate, at least in the Netherlands.

Keywords: Construction workers, Stated choice experiment, Data provision, Construction site

1. Introduction

In contrast with many other industries, the construction sector has limited innovations regarding the way of working during the last decades (Styhre, 2011). With the rapid development of ICT tools, new ways of working are emerging. Building information modeling (BIM), which is one of the most promising technologies and a new way of working, allows improving the efficiency in architect, engineering, and construction industry (Liu, Xie, Tivendal, & Liu, 2015). BIM was initially set up for designers to reduce design errors and to improve communication with other stakeholders. The concept of BIM also presents the excellent potential for the construction sector for improving the workflow on the construction site (Svalestuen, Knotten, Laedre, & Professor, 2017). The traditional form of data provision on site (2D on paper) is not effective in handling the work complexity and the number of actors (Bryde, Broquetas, & Volm, 2013; van Berlo & Natrop, 2014). Davies & Harty (2013) argued that data provision could be more efficient and by bringing BIM onto the construction site, which can also contribute to the prevention of errors (Davies & Harty, 2013). As widely acknowledged in the literature that the information used on the construction site is not up to date (Harstad, LÃ¦dre, Svalestuen, & Skhmot, 2015; Ibrahim, Krawczyk, & Schipporiet, 2004; Mäki & Kerosuo, 2015). A server-based system such as BIM is able to handle last minutes changes from stakeholders, such as client and contractor and deal with external factors efficiently (Bargstädt, 2015; Ibrahim et al., 2004). Moreover, BIM provides a much richer information source comparing to paper. Many researchers argued that the communication based on both visual information and data linked information is the most effective way (Liu et al., 2015; Svalestuen et al., 2017).

There is a substantial amount of research have studied the benefits of implementing BIM on site, the BIM technology itself, and ways of implementation of BIM. However, this body of research focusses mostly on possible applications of BIM tools, methods, and workflows, not on the readiness of construction workers and the extent to which this can be implemented (Eastman, 2008; Hardin, 2009). To be more specific, they did not address the implementation readiness from the user point of view (Bryde et al., 2013). A few case studies have been conducted recently, in which specific applications have been monitored (Moum, Koch, & Haugen, 2009; Ruwanpura, Hewage, & Silva, 2012). However, these case studies evaluate one specific way of adopting BIM on the construction site. They did not explore the preference of site workers or compare their preferences between new methods of working. Moreover, there is no consensus in which way or which solutions should be adopted (Mäki & Kerosuo, 2015).

Therefore, in this research, we will explore whether construction workers are willing to work with digital formats and which forms of data provision are preferred by the current generation of construction workers on site by implementing a stated choice experiment in the Netherlands. The remaining of the paper is organized as follows. The second section explains in details about the stated choice experiment design and data collection. It is followed by the model explanation and estimation results in section 3. The paper is finalized with a conclusion and discussion.

2. Experiment design and data collection

2.1 Stated choice experiment design

A stated choice experiment design is used to systematically vary data provision attributes, and capture the construction worker's preference regarding different forms of data provision. As shown in the book of Hensher et al. (2015), the design includes two main steps, which are selecting related attributes and levels, and designing choice profiles (Hensher, Rose, & Greene, 2015). In this research, related attributes and levels are collected and defined based on existing technologies and initial interviews with innovation managers, BIM managers, and construction supervisors. In total, ten attributes with two levels each were selected to describe the different data provision format of paper or digital. Detailed information is shown in Table 1.

Table 1: Selected attributes and levels

	Attributes	Explanation	Levels
Paper	Data format	This can be either 2D or 3D, 2D means you can see the width and the length of an object on a drawing. 3D means you can also see the height	2D
			3D
	Size canvas	Size canvas is based on paper sizes. A3 is the double size, and A0 is the standard large foldable drawing.	A3
			A0
	Integration drawings	It indicates the level of information, in which a low level only shows one profession and a high level also shows the relevant information of other professions to prevent clashes between professions.	Low
			Normal
	Speed to accessing	How fast you can get updated information.	5 min
			15 min
	Updating speed	The speed of a change will be updated.	2 weeks
			4 weeks
Digital	Data format	This can be either 2D or 3D. 2D means you can see the width and the length of an object on a drawing. 3D means you can also see the height	2D
			3D
	Size canvas	Two digital interfaces are used on construction sites which are tablets and large size screens; which are approximately a size of A4 and A2. Moreover, the A2 sized screens would usually be attached to a wall (in the construction site office) or mounted in an information booth.	A4
			A2 (fixed screen)
	Integration drawings	Integration drawings indicate the level of information, in which a low level only shows one profession and a high level also shows the relevant information of other professions to prevent clashes between professions.	Normal
			High
	Speed of accessing	How fast you can get updated information.	1 min
			5 min
	Updating speed	The speed of a change will be updated.	3 days
			1 week

A full factorial factor design was applied for the labeled experiment, which includes all possible combinations of the 10 attributes with 2 levels each. In total, 2^10 = 1024 different profiles were generated. To reduce the number of profiles, an orthogonal fractional factor design was used. It selected a subset of 12 profiles that show zero correlation, which was estimated in the SAS software. The selected profiles were systematically varied in 12 choice sets. Each choice set consists of two labeled data provision profiles and the "none of these" option. To further reduce the burden on respondents, the 12 choice sets were blocked into 2 blocks of 6 choice sets each. For each respondent, the 6 choice sets from one randomly selected block were presented.

The stated choice experiment design was set together with context variables since some attributes of data provision may be more preferred in certain activities on the construction site. Four main tasks are identified with the intention to capture the differences, which are structural work, finishing work, reporting flaws, and filling out checklist/forms. Construction workers were requested to choose the data provision alternative they like best under the situation of conducting a certain type of activities on site. They can also choose the "none of above". Figure 1 provides an example of a choice set.

"Please, read the descriptions in the table carefully and choose the column which you find most suitable to your preference, for the ***Finishing work****."*

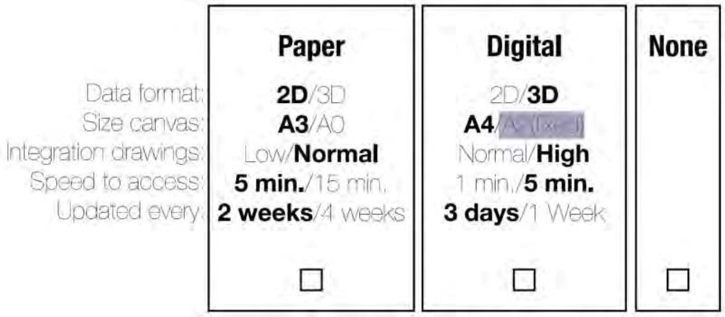

Figure 1: An example of a choice set

In addition to the stated choice experiment, socio-demographic information and attitude towards technology readiness were collected. A selection of ten questions from technology readiness index, which was developed by Parasuraman (2000) has been asked (Parasuraman, 2000).

The questionnaire was implemented in the Bergênquete system, which is a web-based questionnaire system developed by the Eindhoven University of Technology. A six-minutes instruction video was included at the beginning of the questionnaire. The introduction video includes a short explanation of why this research was conducted, how to fill out the questionnaire, and more elaborately explainations of the variables. The presentation was recorded both in English and Dutch. It provideed sufficient information for respondents to fill the questionnaire by themselves.

2.2 Data collection and descriptive analysis

The data collection was collaborated with the company named TBI contracting , which is a big construction company in the Netherlands, and companies from the TBI holding. After getting permission at the management level, it was allowed to get contact information of the construction workers and able to conduct the data collection on site. For on-site data collection, we gathered respondents from construction site group by group to avoid disruption of their work. For each group, around five random respondents were invited to join the data collection. It took around 6 minutes for introduction, and approximately ten minutes for filling the questionnaire. The questionnaire was filled by either personal smartphones or provided tablets. To increase the number of respondents, we also asked the foreman to send the request for completing the questionnaire by email or via Whatsapp.

In total, 178 respondents have filled the questionnaire. Out of 178, 151 respondents have completed the questionnaire correctly. Five respondents have completed the first two parts of the questionnaire, which is sufficient for this research. Twenty-two respondents have missing values due to the technical issues of the questionnaire system, which has been removed for the data analysis. Finally, 156 respondents were used for analysis for this research.

The distribution of age groups is shown in Figure 2. Based on the age distribution of TBI, our data sample under-represents the age group 55-65 and over-represents the age group 40-45 and 15-20. As shown in the data that the majority of the employees is above 45 years old. This can be explained by the last economic crisis and a growing number of freelancers. Recruiting or keeping new employees is difficult for construction companies, which cause a lack of young employees. The current profession and years of work experience in the current profession are shown in Figure 3. Majority of workers are carpenter and stone mason. Besides, there are workers from the Mechanics, Electrical engineers and Plumbers (MEP), and managers. The manager consists of (assistant) site managers and foremen. It shows that a large percentage of the respondents remains in their current profession for a long time. The highest attained level of education was asked as well. The results show that majority has attained either the level of pre-vocational secondary education (43%), intermediate vocational education (8%), or secondary vocational education (41%). 4% of them has complete higher professional education, which are project supervisors and site managers. Only 4% of them have attained primary education.

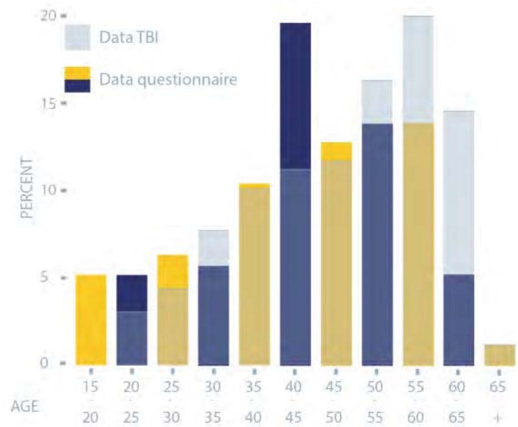

Figure 2: Age distribution of respondents compared to the age distribution of TBI

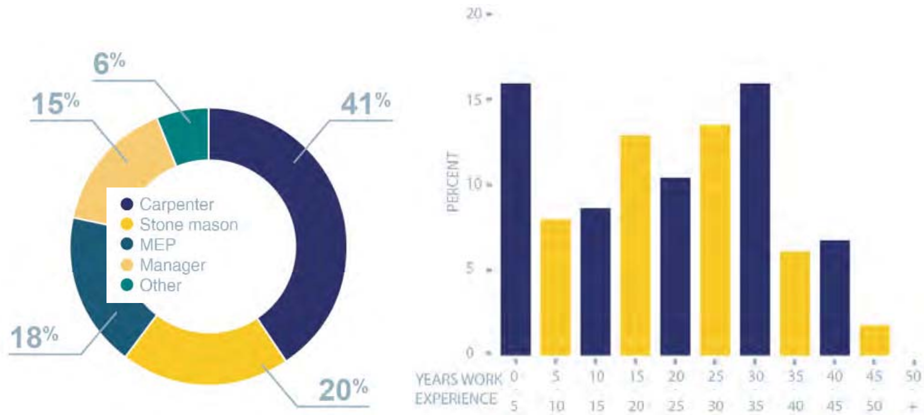

Figure 3: Current profession and years of work experience

3. Model and Results

3.1. Multinomial logit model (MNL) and Mixed logit model (ML)

Discrete choice models are widely used for predicting the acceptance of new technologies or decisions for choosing one alternative from a finite set of mutually exclusive alternatives. It can determine the influence of various attributes with different levels in people's decision making (Ben-Akiva & Bierlaire, 1999; For et al., 2006). The estimated parameters are used to interpret the impacts of certain attributes or attributes' level on people's preference. It can be based on random utility theory, which assumes that each individual selects the option, which is economic rationally and utility maximization(Kløjgaard *et al.*, 2012). The utility is described in equation (1).

$$\mathrm{U}_{ij} = \alpha_{ij} + \beta_j'^{A} \mathrm{X}_{ij}^{A} + \varepsilon_{ij} \quad (1)$$

Where U_{ij} is the utility of alternative j for individual i, α_{ij} is the alternative specific vector, X_{ij}^{A} is a (A×1) vector of the attributes of alternative j. It includes the variables of data format, size canvas, integration drawings, speed of accessing, and updating speed. The (1×A) vector $\beta_j'^{A}$ is the associated parameters. ε_{ij} is a random term that is IID distributed across choice alternatives. The probability of alternative j be chosen is shown in equation (2). This is the basic format of MNL model.

$$\mathrm{Prob}\big(\mathrm{U}_{ij} > \mathrm{U}_{ip}\big) = \frac{\exp\,(\alpha_{ij}+\beta_i'^{A}\mathrm{X}_{ij}^{A})}{\sum_{q=1}^{J_i}\exp\,(\alpha_{qi}+\beta_i'^{A}\mathrm{X}_{qi}^{A})} \tag{2}$$

Considering the digital form of communication is relatively new products, and the preference may differ in terms of personality and attitudes towards new technologies. Therefore, it is better to take into consideration the preference heterogeneity in a mixed logit model. It accounts for the unobserved heterogeneity among populations and relaxes the restrictive independence of IIA assumption of the MNL model. The random effects of the main variables was considered. The random effects across individuals are assumed to be independent and identically distributed. We assume that they follow a normal distribution. Therefore the utility function (1) can be extended to (3), where $\beta_{ki}'^{A} = \beta_k + \sigma_k v_{ik}$. β_k is the population mean, v_{ik} is the individual specific heterogeneity, with mean zero and standard deviation one, and σ_k is the standard deviation of the distribution around β_k. The choice specific constants α_{ij}, and the elements of β_i are distributed randomly across individual with fixed means (Revelt & Train, 1998).

$$\mathrm{U}_{ij} = \alpha_{ij} + (\beta_k'^{A} + \sigma_k v_{ik})\mathrm{X}_{ij}^{A} + \varepsilon_{ij} = V_{ij} + \varepsilon_{ij} \tag{3}$$

The probability for an alternative will be chosen based on the utility maximization. We assume that people will select the alternative which has the highest utility, which is the same as MNL model. The probability of alternative *j* be chosen is shown in equation (4)

$$\mathrm{Prob}\big(\mathrm{U}_{ij} > \mathrm{U}_{ip}\big) = \frac{\exp\,(V_{ij})}{\sum_{q=1}^{J_n}\exp\,(V_{ij})} \tag{4}$$

3.2. Results

Both the MNL and the ML models were applied for model estimation. The adjusted rho-square was used to evaluate model performance. The results show that the ML model performance (0.27) is much better than the MNL model (0.14). It indicates significant improvements by including the heterogeneity. The detailed results are shown in table 1. The column Pr(>|z|) refers to the two-tailed p-values testing the null hypothesis that the coefficient is equal to zero. 0.05 has been used as the value to judge whether there is a significant effect. Due to the page limitation, only significant results from the ML model are explained.

For the alternative option of paper, the coefficients for data format 2D was positively significant at 10 percent. It means that construction workers are more likely to choose paper if it is shown in a 2D format. For the digital way of data provision, they were more likely to choose it once the canvas size is A4, and the integration drawings level is normal. It means that they prefer an easy carry digital format with a lower extent of relevant information from other professions. For socio-demographic variables, the results show that for the digital alternative, the workers from the sectors of residential & utility and others were less likely to choose digital data provision format comparing to other sectors. The workers who were profession stone mason and MEP were less likely to choose the digital data provision, whereas managers were more likely to choose digital comparing to carpenters. The coefficients of age showed that the worker who is between 25-35 years old preferred the digital alternative comparing to the age cohort of 15-25. The results of innovativeness proved our assumption that the more innovative worker were more likely to accept digital data provision. For the tasks impacts, the results showed that for reporting flaws tasks, workers had a significant preference to the digital interface.

For the standard deviation parameters, the results showed that all attributes have significant variations except for the low integration drawings of the paper. Most standard deviations are rather large compared to the means values which indicate that preferences of the respondents were diverse.

Table 2: Results of MNL and ML model for data provision

Alternative	Attribute	Level	MNL		ML	
			coefficients	Pr(>|z|)	coefficients	Pr(>|z|)
Paper	Data format	2D	0,103	0,495	0,789.	0,092
		3D	-0,103		-0,789	
	Size canvas	A3	0,162	0,282	0,373	0,379
		A0	-0,162		-0,373	
	Integration drawings	Low	-0,109	0,474	0,187	0,656
		Normal	0,109		-0,187	
	Speed to access	5 Minutes	-0,103	0,495	-0,230	0,583
		15 Minutes	0,103		0,230	
	Updated every	2 Weeks	0,051	0,736	-0,070	0,866
		4 Weeks	-0,051		0,070	
Digital	Data format	2D	0,158	0,281	0,192	0,689
		3D	-0,158		-0,192	
	Size canvas	A4	0,156	0,287	1,098*	0,040
		A2 (fixed)	-0,156		-1,098	
	Integration drawings	Normal	0,236	0,114	1,345*	0,029
		High	-0,236		-1,345	
	Speed to access	1 Minute	-0,043	0,772	-0,460	0,386
		5 Minutes	0,043		0,460	
	Updated every	3 Days	-0,115	0,431	-0,807	0,149
		7 Days	0,115		0,807	
Socio-demographic variables & attitudes						
Digital	Constant		1,333**	0,006	2,820	0,107
	Company	Residential	2,705		6,970	
		Installation	-0,096	0,802	1,217	0,344
		Residential & utility	-0,888***	0,000	-2,724***	0,001
		Other	-1,721***	0,006	-5,463***	0,001
	Current profession	Carpenter	0,538		3,089	
		Stone mason	-0,486.	0,056	-1,472	0,074
		MEP	-0,383	0,300	-3,293*	0,015
		Manager	0,620*	0,044	2,687*	0,016
		Other	-0,290	0,474	-1,011	0,473
	Work experience	0 - 5 years	0,744		1,911	
		5 – 15 years	0,022	0,952	-0,616	0,670
		15 – 30 years	0,007	0,987	0,069	0,967
		30 + years	-0,772.	0,079	-1,364	0,431
	Age	15 – 25 year	-1,422		-8,334	
		25 – 35 year	0,871*	0,041	5,142*	0,004
		35 – 45 year	-0,145	0,720	0,729	0,652
		45 -55 year	0,030	0,944	0,549	0,752
		55 + year	0,666	0,198	1,914	0,313
	Innovativeness	0 – 2.5 score	-1,459**	0,001	-4,002***	0,000
		2,5 – 3,0 score	-0,292	0,288	-0,282	0,768
		3,0 – 3,5 score	-0,711**	0,006	-2,418**	0,006
		3,5 – 4,0 score	-0,513	0,054	-1,927.	0,038
		4,0 + score	2,976		8,629	
	Tasks	Structural work	-0,650		-2,939	
		Finishing work	-0,345	0,182	-0,480	0,577
		Reporting flaws	0,776**	0,007	1,178.	0,062
		Check-lists/forms	0,219	0,252	2,241**	0,002
None	Constant		-4,513**	0,000	-6,150*	0,049
	Company	Residential	2,897		4,149	
		Installation	-0,492	0,496	0,617	0,762
		Residential & utility	-0,870.	0,099	-1,720	0,272
		Other	-1,535.	0,068	-3,046	0,404

	Current profession	Carpenter	-0,834		-3,710	
		Stone mason	-0,076	0,871	0,846	0,311
		MEP	-1,080	0,220	-2,365	0,295
		Manager	0,711	0,245	2,979	0,174
		Other	1,278	0,140	2,251	0,449
	Work experience	0 - 5 years	5,317		7,621	
		5 – 15 years	-0,804	0,214	-3,271	0,205
		15 – 30 years	-2,463***	0,001	-2,534	0,367
		30 + years	-2,049*	0,011	-1,816	0,436
	Age	15 – 25 year	-12,623		-15,001	
		25 – 35 year	2,726**	0,007	3,497	0,342
		35 – 45 year	2,708**	0,006	3,354	0,310
		45 -55 year	3,326**	0,001	3,445	0,316
		55 + year	3,864***	0,001	4,705	0,217
	Innovativeness	0 – 2.5 score	2,067*	0,014	1,715	0,213
		2,5 – 3,0 score	0,673	0,453	0,880	0,562
		3,0 – 3,5 score	1,578.	0,052	1,190	0,371
		3,5 – 4,0 score	1,266	0,130	1,155	0,327
		4,0 + score	-5,584		-4,940	
	Tasks	Structural work	-0,799		-3,432	
		Finishing work	0,211	0,659	1,123	0,336
		Reporting flaws	0,362	0,354	0,498	0,578
		Check-lists/forms	0,227	0,552	1,811*	0,035
Standard deviations for ML model						
Paper	Data format	2D			2,077**	0,004
	Size canvas	A3			1,431*	0,021
	Integration drawings	Low			0,059	0,944
	Speed to access	5 Minutes			1,670*	0,012
	Updated every	2 Weeks			1,846**	0,004
Digital	Data format	2D			-2,728**	0,001
	Size canvas	A4			3,737**	0,002
	Integration drawings	Normal			6,368***	0,000
	Speed to access	1 Minute			3,369**	0,002
	Updated every	3 Days			3,406***	0,000

4. Conclusion and discussion

Many studies have explored new technologies implementation in the construction site. In these studies, they have proved the usability of these new technologies by case studies. However, very limited knowledge has gained so far regarding the construction workers' acceptance of innovative technologies or data provision formats such as tablets, BIM-booths, information screens, and Augmented and Virtual reality. The core difference regarding data format is digital versus paper. Therefore, in this study, we summarised the main attributes based on existing technologies for digital data provision and designed a stated choice experiment to formulate trade-off points for digital and paper data provision formats. Both MNL and ML models have been used for model estimation with 165 respondents' data from the construction site. The results show that construction workers prefer a digital interface. However, there is heterogeneity existed in the population. The attributes such as tablet size and level of integration of the drawings have impacts on their preference. Although in the literature, the speed of access is identified as an important attribute (Bargstadt, 2015; Berlo & Natrop, 2014; Ibrahin et al., 2004), the results did not show a significant variation among construction workers. Moreover, the preference also depends on their socio-demographic status and technology innovativeness attitudes. The innovativeness defined by the Technology readiness index of Parasuraman (2000) is in line with the expectations.

The main outcomes are controversial with the literature, which indicated the construction sector is very conservative, and the construction workers are reluctant to innovate (Harstad et al., 2015). The results of this study show a progressive mindset of construction workers. They are more likely to accept a digital interface over the paper, and the majority is not reluctant to choose for an innovation. A possible explanation might be the adoption of the technologies situation is based on their familiar environment, which creates more trust. There also might be a misunderstanding between construction managers and construction workers on site. The underestimation of construction workers' acceptance and abilities might contribute to the perception of conservatism in the construction sector.

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