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Big Data Adoption in the Construction Industry: Status Quo, Drivers and Challenges

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Abstract: Under the influence of pervasive digital revolution, the world is overwhelmed with data with an increasing speed of data generation. The accessibility and analysis of 'big data' can provide useful insight and help various industry sectors revolute. Although the concept of 'big data' has gained popularity in the construction industry in recent years, the construction industry remains at a nascent stage in the adoption of big data technologies and lags behind other sectors. To the best of our knowledge, few empirical studies have been done to examine the status quo of big data adoption in the construction sector and its influencing factors. This paper fills the gaps and examines the current status of big data adoption in companies with different sizes and roles and projects with different types, and the drivers and challenges in adopting big data technologies. After an extensive literature review, a questionnaire survey and post-interviews were conducted. The results of the analysis show that the big data adoption in the construction sector is affected by the size of companies and the work experience of employees. Technology advancement, competitiveness, government plan, and policy initiatives are the main drivers of the big data adoption, while design appropriate system, difficulty in data collection and the lack of knowledge and experience were found to be the major challenges for the big data adoption in the construction sector. Finally, the identified top three strategies to overcome challenges and promote big data adoption are 'clear organization structure', 'government incentives' and 'the training of IT personnel'. The findings of this study guide construction practitioners in different companies and projects put domain specific strategies in place to enhance the big data adoption.

Key words: Big data engineering, Construction industry, Status quo, Driver, Challenge

1. INTRODUCTION

The total amount of data circulating worldwide is expected to increase exponentially and reach 175 zettabytes by 2025 [1]. The data growth brought about digital transformation create both opportunities and challenges to business and research. The accessibility and utilization of massive heterogeneous data help break the established business management approaches and enable more responsive and real time decision making [2]. Data storage and management of large volumes of data also challenge the traditional statistical and algorithmic methods [3], thus push companies take innovative techniques to harness the data.

The construction industry is not an exception to the data boom. The construction industry traditionally collect data through drawings, material supply, work breakdown schedule, specifications and many more, thus deal with relatively less data compared to retailers or financial sectors [4]. With the advancement of technologies such as sensors and the Internet of Things (IoT), the construction industry faces with increasing data collected from diverse parties throughout the life cycle of facilities [3]. The analysis of 'big' data can be potentially utilized to address the current construction challenges and improve productivity.

Big data is a broad term with diverse definitions. Some scholars defined it as a collection of data sets that are relatively vast and complex which could be difficult for user to process using manual database management tools and conventional data processing applications [5]. Many believed that the concept of 'big data' is characterized with three attributes, namely: Volume, Velocity, or Variety (a.k.a. 3Vs) with the ability to capture, manage and process data rapidly [3, 6]. Volume refers to the size of the data. The huge amount of data from diverse sources provide hidden information and patterns [7]. The sources of construction data include not only the project-related design, schedule, cost and quality data, but also stakeholders-related corporate data such as enterprise resources planning system and financial data. The pervasive use of BIM supports the easily capture of multi-dimensional geometric and nongeometric encoded building data [8]. Variety refers to the heterogeneous formats of data. The construction data format includes text, graph, sensor, audio, report and more, which brings the challenges for data storage, mining and analysis. Velocity refers to the rate of data generation [9].

The big data adoption in construction projects has become the trend in solving low productivity issue since the construction industry embrace many innovative technologies that rely on enormous volume of data [4]. Government initiatives have been made to promote the big data uptake and IoT, such as Internet platform for China construction industry with the aim of transforming society and businesses through digital innovations, Smart Nations since 2014 promoted by Singapore [10]. However, the construction sector is lagging behind on the integration of big data with construction process and makes relatively slow progress on the adoption of innovations [4]. Limited studies comprehensively examined the status of big data adoption in the construction sector. Construction companies are often unclear about the potential application areas of big data, big data analytical techniques, and the benefits and potential risks of using big data. This study aims to explore the status quo of big data adoption in the construction sector from the following aspects:

- Examine the status of big data adoption in different organizations and project types
- Identify the drivers and challenges faced by companies in implementing big data in construction projects, and
- Propose feasible strategies to address the challenges and unleash the potential of big data in the construction industry.

2. RESEARCH BACKGROUND

2.1 Drivers of big data adoption in the construction industry

Nine key categories of driving factors for big data adoption in the construction sector have been identified from a systematic literature review, as showed in Table 1.

Table 1. An overview of drivers of big data adoption in the construction industry

Code	Drivers	References											
		1	2	3	4	5	6	7	8	9	10	11	12
D1	Economic condition	√			√	√	√	√		√		√	
D2	Government support and policy initiatives	√	√				√		√		√	√	√
D3	Technology advancement			√	√	√	√					√	
D4	Employment opportunities	√		√	√		√	√					√
D5	Competitiveness	√	√	√	√	√			√	√	√	√	
D6	Sustainable development			√	√			√			√	√	
D7	Initiative to reduce reliance on foreign labour	√	√					√	√	√		√	
D8	Workplace safety and health improvement		√	√	√	√	√					√	
D9	Increase transparency	√	√		√		√				√		√

Note: 1. Warsaw Institute for Economic Studies (WISE) (2014), 2. Buchholtz et al., 2014, 3. GCP, 2015, 4. SNDGO, 2018, 5. Ahmed et al. 2017, 6. Oudjehane and Moeini [4], 7. IDC, 2016, 8. Bilal et al., 2016, 9. Ahmed, Tezel [20], 10.Bibri (2019), 11. Shi et al. (2013); 12. Zhao et al. (2018)

2.2 Challenges in adopting big data in the construction industry

Despite the opportunities presented by big data, companies need to address many challenges in dealing with big data. For the construction sector, 21 challenges have been identified from a comprehensive literature, as showed in Table 2. These challenges can be are grouped into four categories, namely technical (TC), management (MC), economic (EC) and organizational challenges (OC).

Table 2. An overview of challenges of big data adoption in the construction industry

Code	Challenges	References										
		1	2	3	4	5	6	7	8	9	10	11
TC1	Storage issue of surging amount of data	√		√		√						
TC2	Data transfer time taken from data collection to processing	√				√						√

TC3	Difficulty of processing big data variety in the construction sector						√					√
TC4	Data ingestion and velocity management	√			√	√						√
TC5	Difficulty of real-time data transmission from construction sites due to limited bandwidth and networking infrastructure	√		√								
TC6	The life cycle management and update of big data			√	√			√			√	√
TC7	Improper representation of data collected			√					√		√	
TC8	Lack of effective big data analytical frameworks to meet different stakeholders’ needs		√		√	√						√
MC1	Difficulty of data collection due to the fragmented feature of construction sector	√		√	√		√				√	
MC2	Relatively low data quality due to the poor information input environment in construction		√	√				√				
MC3	Data privacy concern from data sources/ owners		√	√					√	√		
MC4	The lack of adequate data security control system	√		√						√		
MC5	Reluctancy of data sharing among various stakeholders					√				√	√	
MC6	Data interoperability issue in the construction sector	√				√	√				√	
EC1	Extra investment of companies on hardware and skilled IT personnel			√				√	√			
EC2	Cost incurred from continuous technology and skill upgrade							√	√		√	
OC1	Necessity of organization structure and daily operation workflow changes for big data adoption			√				√	√		√	
OC2	Shortage of skilled data specialist in construction companies	√		√				√				
OC3	Lack of knowledge absorptive capacity in innovation		√				√			√		
OC4	Challenge for construction workers to accept real time data collection			√				√	√		√	
OC5	Possible conflict of interest between stakeholders	√		√		√					√	

Note: 1. Ahmad et al. (2017); 2. Bhadani and Jothimani (2018); 3. Bilal et al. (2016); 4. Cai and Zhu (2015); 5. Kaisler et al. (2013); 6. Koseleva and Ropaite (2017); 7. Manyika et al. (2011); 8. Halaweh and Massry (2015); 9. Sivarajah et al. (2017); 10. Oudjehane and Moeini [4], 11. Zicari et al. (2016).

3. METHODOLOGY AND DATA PRESENTATION

A mixed approach of qualitative and quantitative methods has been applied in this study to achieve the research objectives. First, the application areas and benefits of big data adoption, as well as the drivers and challenges of big data adoption were identified through a comprehensive literature review. Afterwards, a questionnaire script was developed based on the results of literature review. A pilot study was conducted to test the validity of the survey script. Three construction industry’s professionals with more than ten years of work experience and two academia with research focus at the big data area were invited to participate in the pilot study. The finalized questionnaire consists of five sections: first, the profile of the survey respondents and their companies; second, the status quo of big data adoption by various roles, organization size and project types; third, the significance and likelihood on the drivers of big data adoption; fourth, the significance and likelihood on the challenges of big data adoption; fifth, strategies to promote big data adoption in the construction sector. A 5-point Likert scale (1 represents extremely insignificant/ very unlikely; 5 represents most significant/ very likely) was used to evaluate the respondents’ opinions.

The targeted survey respondents are the construction industry practitioners from companies in China with different roles including developer, architect, contractor, consultant, quantity surveyor etc. 800 targeted respondent were randomly selected from industrial associations including National certified Constructor Registration System, China Construction Industry Society, China Civil Engineering Society. The questionnaires were disseminated between January and June 2023 via email and online survey tool. By the end of June 2023, 90 responses were collected. Two incomplete responses were removed, yielding 88 valid responses and a response rate of 11%.

58 percent of respondents have more than ten years of work experience, 58 percent of surveyed organizations have more than 20 years of experience in construction practices. All of the organizations have experience in construction projects, amongst 83 percent have over ten years of experience. The surveyed respondents and organizations cover various stakeholders in the construction process and have delivered a wide diversity of construction project, which ensures the quality of the collected data and help yield convincing research outcome.

A series of statistical methods were applied to analyze the data collected from the survey using the software IBM SPSS statistics 25, as showed in Fig. 1. First, one sample Kolmogorov-Smirnov test was conducted to examine whether the sample data comes from a normally distributed population. If the p value obtained from the test is less than the chosen alpha level (0.05 at a confidence interval of 95% in this paper), it is suggested that the sample comes from a population that is not normally distributed. In the condition of distribution-free sample data, nonparametric tests are used as an alternative method to parametric tests such as T-test and One-way ANOVA. Second, as a non-parametric equivalent of one sample t-test, one-sample Wilcoxon signed-rank test was conducted to test whether the mean of a subject is greater than a critical value, i.e. 3. The objective is to identify the key drivers and challenges of big data adoption in the construction industry.

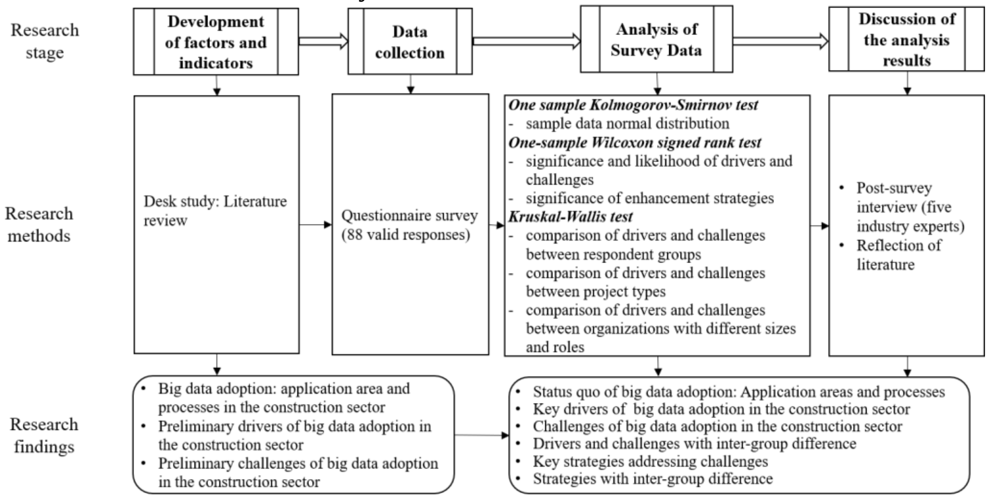

Figure 1. Research methodology roadmap

Third, as a non-parametric equivalent of analysis of variance (ANOVA), Kruskal-Wallis was conducted to test the potential difference of means between independent groups. Since the collected survey data can be categorized based on respondents' experiences and roles, Kruskal-Wallis test were used for inter-group comparison. Fourth, one sample Wilcoxon signed-rank test were adopted to identify the key strategies that help enhance the big data adoption. Finally, a post-survey interview with five selected professionals from survey respondents were conducted to give an in-depth discussion and validation of the survey data analysis results. All of the interviewees have at least 13 years of experience in construction projects and 3 years of experience in big data adoption.

4. RESULTS OF DATA ANALYSIS

4.1 Status quo of big data adoption in the construction sector

The first section of the questionnaire survey investigated the number of construction projects adopted big data over the past five years, the application areas and perceived benefits of big data. The results are presented in Table 4. The data collected from the survey suggest a lack of knowledge on big data in the construction sector. Many respondents have misunderstood the definition of big data, especially small contractors which assumed that any kind of data used in the operation is considered as big data.

Table 3. Profile of projects adopted big data

Project type	No. of projects over past five years	Percentage in total (%)	No. of projects adopted big data	Percentage in each project type (%)
Residential building	1207	25.9	53	4.4
Institution and commercial buildings	1003	21.5	73	7.3
Industrial	874	18.7	82	9.4
Infrastructure	1001	21.5	66	6.6
Others (Church, Recreation etc.)	579	12.4	59	10.2
Total	4664	100	333	7.1

Table 4 presents the application areas and benefits of big data in various project types. It is showed that 'improve tendering and bidding' and 'optimizing project design pattern' are the top two areas of big data application. Tender price evaluation is one of the important areas of big data application. With the improvement of information technologies, projects' cost-related data can be recorded systematically in real time, which support the tender price evaluation and decision making for the cost management of construction projects. In addition, the surging data amount and data sources represent an opportunity to innovate how firms design, such as data-driven design and iterative design. According to respondents' feedback, the building information collected can be fed back into the early design stage, which allows the design team to understand how occupants interact with the built environment and to tweak and adjust the design. The results of Chi-squared test show that the p-values obtained are above the significance level of 0.05, which suggests that there is no significant dependency between project types and big data application areas.

Likewise, the perceived benefits of big data application include the improvement of construction productivity, project quality, resource and energy efficiency, and the reduction of labour and costs. The results of Chi-squared test show that there is no significant dependency between project types and perceived benefits. 'Improve productivity' and 'increase resource and energy efficiency' are ranked as the top two benefits of big data application by construction practitioners. Tools such as BIM help make the construction industry more economically and environmentally sustainable, and play a massive role in improving energy efficiency. Comparatively, 'reduce labour' and 'reduce cost' received lower ranks. Many respondents believed that big data have little effect on labour reduction and cost saving, the results of which might associated with the challenges of big data adoption.

4.2 Key drivers of big data adoption in the construction sector

Table 5 presents the analysis results of the drivers for big data adoption in different organizations and project types. The p-values of D1-D9 obtained from Kolmogorov-Smirnov (K-S) test are below the alpha value of 0.05 at a confidence interval of 95%, which indicates that the sample data have a non-normal distribution. Therefore, non-parametric Wilcoxon signed rank test was used to examine the significance of these drivers. The means of D1-D9 are above 3. Moreover, the p-values of D1-D9 are also below 0.05, which indicates that all the drivers examined are significant to the big data adoption in the construction sector. The top five drivers are Technology advancement (D3), Competitiveness (D5), Government support and policy initiatives (D2), Sustainable development (D6), Workplace safety and health improvement (D8).

'Technology advancement' is perceived as the most important driver of big data adoption. Technologies such as ICT, cloud-computing, BIM and drone not only enable organizations to gather more data from diverse sources, but allow improvements in data storage and analysis. 'Competitiveness' is ranked as the second top driver in adopting big data. The multiple players in the construction industry drive organizations to keep competitive advantage and outperform their rivals. Kruskal-Wallis test results show that significant differences were found in the significance of 'employment opportunities' (D4) between organizations with different natures. D3 received highest significance in multi-nation companies with a mean of 4.53. Respondents with more experience in big data give more emphasize on technology advancement.

4.3 Key challenges of big data adoption in the construction sector

The significance of challenge factors can be measured by multiplying the impact of each factor with its likelihood of occurrence. The p-values of the 21 challenge factors from Kolmogorov-Smirnov test are below the alpha value of 0.05 at a confidence interval of 95%, which indicates that the sample data have a non-normal distribution. As showed in Table 6, the results of Wilcoxon singed rank test show that all the 21 challenge factors are significant. The top five challenges with most impact are EC1(4.23), OC1(4.16), OC3(4.05), MC5(3.98), TC5& OC4(3.95). The top five challenges with most likelihood of occurrence are MC6, EC2, OC2, MC4, TC5 and OC3. Ranked by the overall significance, the top five challenges are OC1(16.22), OC3(16.00), OC2(15.80), EC1 (15.78) and MC5(15.74). The results suggest that the most significant challenges in adopting big data exist in the organizational aspect. The establishment of appropriate organization structure, knowledge absorptive capacity and data specialists are necessities for a company in adopting big data. Besides, the extra investment on big data and the reluctancy of data sharing are major concerns for companies in the big data adoption.

4.4 Strategies for enhancing big data adoption in the construction sector

The p-values of K-S test indicates that the sample data have a non-normal distribution. The results of Wilcoxon signed rank test indicate that all the strategies are significant to the big data adoption in the construction sector. The top three strategies are 'government incentives' (S2), 'clear data governance structure' (S6) and 'training of skilled IT personnel' (S1).

‘Government incentives’ is perceived as the most important strategies for improving big data adoption, with a mean of 4.35. The government should strengthen top-level design and optimize the management mode of enterprise big data application, build a unified standard system and accelerate the formulation and promotion of standards for the design and construction, technical application, acceptance assessment, and safety assurance of big data in the construction industry. ‘Clear data governance structure’ is ranked as second in promoting big data adoption. It is the key to ensure the data is handled smoothly. According to the experts’ viewpoint at the post survey interview, data governance structure involves “decision-making, management and accountability related to data in an organization, and …… specifies the data ownership and the responsibilities of stakeholders”. The working group for data governance should also be established to liaise between business and data-related technologies. “The team drives the big data use and ensures data quality for specific areas, should involves experts specialized at both business and IT issues”.

5. CONCLUSIONS

The objectives of this study were to assess the status quo of big data adoption in the construction sector. Firstly, the results revealed a lack of knowledge on big data in the construction sector. The industrial projects, institutional and commercial buildings, and other project types have relatively higher big data adoption rate. The main contributions of big data applications are in two areas of ‘improving tendering and bidding’ and ‘optimizing project design pattern’. ‘Improve productivity’ and ‘increase resource and energy efficiency’ are being considered as the major benefits of big data application.

Secondly, the study also identified five major drivers of the big data adoption in the construction sector, including ‘technology advancement’, ‘competitiveness’, ‘government support and policy initiatives’, ‘sustainable development’, ‘workplace safety and health improvement’. The impact and likelihood of occurrence of each challenge factor also investigated by this study, showing that the most significant challenges in adopting big data exist in the organizational aspect. Furthermore, the extra investment on big data and the reluctancy of data sharing are major concerns for companies considering big data adoption. Finally, strategies were proposed for construction practitioners to improve big data adoption. The top three strategies were ‘government incentives’, ‘clear data governance structure’ and ‘training of skilled IT personnel’.

Despite the research outcomes, there are some limitations existed. First, the sample size in this study cannot encompass all construction industry practitioners, leaving the conclusions open to mistake. Second, the results of this study are based on the China context and cannot guarantee generalizability to other countries. Future studies could investigate the association between the drivers of big data application in construction sectors and establish an evaluation model to test the effectiveness of the proposed strategy in promoting big data application.

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Table 4. Application areas and benefits of big data adoption in various project types

Project type	Residential		Institution and commercial		Industrial		Infrastructure		Others		Total		χ2 test
Area of big data adoption	**Frequency**	**Rank**	**Frequency**	**Rank**	**Frequency**	**Rank**	**Frequency**	**Rank**	**Frequency**	**Rank**	**Frequency**	**Rank**	
Assess feasibility of projects	1	4	3	5	3	5	4	4	1	3	12	5	0.263
Improve relationships with clients	3	3	4	3	5	3	3	7	2	1	17	3	0.241
Build stakeholder relationships	1	4	2	6	3	5	2	9	1	3	9	8	0.265
Optimize project design pattern	4	1	6	1	5	2	7	2	1	3	23	2	0.220
Optimize business decisions	0	10	2	6	2	10	1	10	0	6	5	10	0.265
Facilitate construction document management	1	4	2	6	3	5	4	4	0	6	10	6	0.220
Facilitate equipment and asset management	0	9	2	6	3	5	3	7	0	6	8	9	0.265
Reduce safety hazard and risks	1	4	2	6	3	5	4	4	0	6	10	6	0.220
Optimize site management	1	4	4	3	4	4	5	3	0	6	14	4	0.241
Improve tendering and bidding	4	1	5	2	8	1	8	1	2	1	27	1	0.241
Benefits of big data adoption													
Improve productivity	76	1	75	1	77	1	76	1	76	1	380	1	0.265
Improve quality	71	3	71	3	69	3	70	3	68	3	349	3	0.241
Increase resource and energy efficiency	74	2	74	2	76	2	76	1	73	2	373	2	0.265
Reduce labour	60	4	61	4	59	4	61	4	60	4	301	4	0.265
Save cost	60	4	58	5	58	5	59	5	59	5	294	5	0.265

Table 5. Data analysis results of the drivers of big data adoption in different types of organizations and respondents

Code	Mean	Rank	p value (Kolmogorov-Smirnov test)	p-value (Wilcoxon signed rank)	p-value for inter-group comparison					
					Organization nature	Organization size	Organizations' year of experience	Role of respondents	Respondents' year of experience	Respondents' experience in big data
D1	3.60	7	0.00*	0.00**	0.33	0.56	0.18	0.40	0.52	0.93
D2	3.80	3	0.00*	0.00**	0.05	0.62	0.06	0.73	0.26	0.52
D3	4.00	1	0.00*	0.00**	0.09	0.02***	0.97	0.15	0.19	0.04***
D4	3.40	9	0.00*	0.00**	0.02***	0.25	0.41	0.19	0.80	0.38
D5	3.83	2	0.00*	0.00**	0.42	0.58	0.12	0.07	0.13	0.69
D6	3.78	4	0.00*	0.00**	0.89	0.66	0.96	0.92	0.74	0.77
D7	3.58	8	0.00*	0.00**	0.33	0.25	0.21	0.24	0.89	0.66
D8	3.78	4	0.00*	0.00**	0.46	0.05	0.63	0.13	0.62	0.76
D9	3.63	6	0.00*	0.00**	0.30	0.77	0.71	0.05	0.41	0.48

Note: * The Kolmogorov-Smirnov test was significant at the significance level of 0.05

** The one sample Wilcoxon signed-rank test was significant at the significance level of 0.0

***The Kruskal-Wallis test was significant at the significance level of 0.05, suggesting the drivers were assessed differently between groups

Table 6. Intergroup comparison results of challenges for big data adoption in different types of organizations and respondents

Code	p-value for inter-group comparison (Impact)						p-value for inter-group comparison (Likelihood)					
	Organization nature	Organization size	Organizations' year of experience	Role of respondents	Respondents' year of experience	Respondents' experience in big data	Organization nature	Organization size	Organizations' year of experience	Role of respondents	Respondents' year of experience	Respondents' experience in big data
TC1	0.10	0.45	0.45	0.10	0.15	0.01*	0.23	0.50	0.58	0.23	0.55	0.01*
TC2	0.78	0.06	0.53	0.78	0.53	0.36	0.02*	0.06	0.18	0.02*	0.18	0.36
TC3	0.32	0.47	0.92	0.32	0.47	0.83	0.27	0.49	0.84	0.26	0.34	0.83
TC4	0.14	0.94	0.76	0.14	0.90	0.96	0.08	0.87	0.61	0.08	0.61	0.96
TC5	0.23	0.16	0.46	0.23	0.09	0.09	0.08	0.74	0.65	0.08	0.12	0.09
TC6	0.40	0.58	0.62	0.40	0.02*	0.27	0.65	0.29	0.99	0.65	0.20	0.27
TC7	0.28	0.21	0.40	0.28	0.25	0.09	0.05*	0.26	0.26	0.05*	0.96	0.09
TC8	0.17	0.38	0.61	0.17	0.79	0.37	0.59	0.23	0.25	0.59	0.35	0.37
MC1	0.08	0.35	0.13	0.08	0.80	0.91	0.45	0.73	0.58	0.45	0.38	0.91
MC2	0.05	0.75	0.09	0.05*	0.67	0.15	0.06	0.97	0.50	0.06	0.51	0.15
MC3	0.55	0.23	0.63	0.55	0.08	0.33	0.22	0.92	0.37	0.22	0.07	0.33
MC4	0.16	0.71	0.17	0.16	0.99	0.39	0.19	0.91	0.64	0.19	0.84	0.39
MC5	0.09	0.09	0.17	0.09	0.17	0.20	0.03*	0.20	0.09	0.03*	0.14	0.20
MC6	0.11	0.15	0.22	0.11	0.92	0.15	0.16	0.43	0.10	0.16	0.64	0.15
EC1	0.20	0.19	0.18	0.20	0.78	0.14	0.20	0.93	0.70	0.19	0.95	0.14
EC2	0.02	0.16	0.20	0.02*	0.91	0.48	0.32	0.40	0.59	0.32	0.88	0.48
OC1	0.52	0.36	0.71	0.52	0.63	0.99	0.49	0.10	0.75	0.49	0.83	0.99
OC2	0.45	0.33	0.29	0.45	0.70	0.80	0.07	0.67	0.15	0.07	0.45	0.80
OC3	0.01	0.63	0.70	0.01*	0.98	0.92	0.02*	0.48	0.81	0.02*	0.80	0.92
OC4	0.25	0.91	0.67	0.25	0.79	0.96	0.23	0.13	0.81	0.23	0.70	0.96
OC5	0.17	0.27	0.57	0.17	0.22	0.17	0.05*	0.66	0.71	0.05*	0.36	0.17

Note: *The Kruskal-Wallis test was significant at the significance level of 0.05, suggesting the impact or likelihood of challenges was assessed differently between groups