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Using safety system during the design phase to minimize waste in construction projects

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ABSTRACT

Achieving construction projects (CPs) with minimal waste requires not only good construction planning, but also effective management for safety and waste of resources through the project cycle. The aim of this paper is to identify and rank safety factors (SF) during the design phase (DPh) of a project that have positive effects in minimizing waste (cost, time and materials) during its construction. Data and information was gathered from available literature, structured interviews, and questionnaire conducted for 111 randomly selected construction organizations. Triangulation method to enhance the validity and reliability of the study findings was used. The research revealed 18 important SF that had positive effects on minimizing waste in CPs during the DPh. The five most important SF that should be considered to minimise waste are: capabilities and behaviour of the design team in the safety field, appropriateness of quantities and specifications for safety system (SS), appropriateness of foundation system for SS, appropriate public and special conditions for SS and appropriate electrical design for SS. The best linear model was developed on the basis of the importance index of the identified factors. A model was developed to minimize waste in CPs by using SS during the DPh. It is recommended that adequate attention must be given to safety criteria during DPh to minimize resources waste.

1. Introduction

Safety is a key for increasing productivity and efficiency in CPs. For the completion of CPs at the lowest cost, the highest quality, and the least period, an increased commitment to SS during the DPh must be achieved. The International Labour Organization's annual report for 2015 indicated that every day, 6300 people die from workplace-related poor safety, resulting in 2.3 million annual deaths, while 317 million accidents of various types occur annually. Additionally, the human cost of this daily challenge is enormous, and the economic burden of poor occupational safety and health (OSH) practices is up to 4% of the annual global gross domestic product (GDP) (Gonzalez-Delgado et al., 2015). Therefore, it is necessary to incorporate safety into construction plans, to protected worker health, minimized costs, and increased value. This is confirmed by a large number of studies (Ghosh and Young-Corbett, 2009; Nordlöf et al., 2015; Nahmens and Ikuma, 2009, 2012; Nahmens and Mullens, 2011; Tayeh et al., 2020).

On the other hand, waste can affect success of CPs and has major impact on construction in terms of productivity, sustainability, time, cost and environment (Abarca-Guerrero et al., 2017; Zhao et al., 2010; Ali et al., 2013; Tayeh et al., 2019). Activists of construction waste management (CWM) are innate through the whole-cycle of a CP from the design until demolition. Construction waste (CW) is usually clustered into two types: physical and non-physical (Nagapan et al., 2012; Asgari et al., 2017) Physical CW consists from materials including land excavation, clearance, building renovation, demolition and roadwork (Katz and Baum, 2011; Mahfuth et al., 2019). Non-Physical CW are cost overrun and extra time for a CP including any inefficiency in the use of money, equipment, materials labour as waiting time and unnecessary movement of labours (Nazech et al., 2008; Formoso et al., 2002).

Over the past few years, the concept of prevention through design (PtD) has emerged. This concept relies on applying methods

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early in the design process that would maximize safety later on. PtD encourages the thought for safety concepts during the design stage. Hence, PtD requires designers to spend efforts on anticipating and designing out threats to workers who will execute the designs (wang et al., 2014). The research described in this paper falls into the PtD concept. Indeed, the research team believes that it is possible to find safety features during the DPh that would minimize CW, both physical and non-physical, while constructing the project. The research seeks the relationship between SS and waste in CPs by identifying and ranking SF that have the most positive effects on waste minimization in CPs during the DPh and builds a model based on these factors to minimize CW by using SS.

2. Literature review

The literature search included both standard approaches (databases' searches such as ScienceDirect, Google Scholar, TRIS, etc.) as well as the research team extensive contacts, both domestic and abroad, to find data and pertinent citations that have not been formally published on the topic. The literature searches included journals' and conferences' papers as well as books. The data addressed the practices and concepts of construction safety (CS) and CWM, and the SF having positive effects on minimizing CW through DPh.

2.1. Design for construction safety (DfCS) concept

Safety management system is comprehensive and a systematic business method to managing safety risks. It must contains policy of safety, planning, control, communication, training and incentives for employee participation (Muñiz et al., 2007). The most hazardous industries are CPs due to the nature of the work resulting from integration of environment, tools and various human factors (Haro and Kleiner, 2008; Nordic council of ministries, 2017). In fact, CPs has one of the highest accident incidence rates compared to other industries (Laitinen and Päivärinta, 2010; Jo et al., 2017). Statistics indicate that CPs is still facing a safety problem. In the US, construction employs 7% of the workers, but accounts for 21% of the injuries (Zarges and Giles, 2008). In the UK, workers in CPs and agriculture account for 46% of total fatal injuries. In British Columbia, the overall injury rate in CPs is more than twice the local average for all industries (Village and Ostry, 2010). Many studies showed that it is possible to reduce (by 40% to 60%) or even eliminate risks and accidents by addressing safety through DPh and if DfCS concept have been utilized (Frijters and Swuste, 2008; Behm, 2005; Gambatese, 2008; Rwamamara and Holzmann, 2007; Toole et al., 2006; Manuele, 2008; Malekitabar et al., 2016). In addition, Manuele (2008) stated that by applying DfCS concept, the benefits that could be obtained are increased productivity, minimized operating costs, significant risk and expensive retrofitting.

DfCS concept is a collaborative process, where designers benefit from field experience to produce designs that could be executed safely. DfCS is defined as the safety consideration in construction site in DPh of CPs with the goal of minimizing the inherent risks to construction worker (Toole et al., 2006; Orihuela et al., 2017). Design decisions related to design, construction methods and materials used should incorporate the consideration of worker safety during projects cycle. The opportunities to address worker safety in this phase are considerable where it is possible to design out hazards and/or integrate risk control measures that comply with the original design concept and structural and functional requirements of CP. The success of DfCS concept depends upon the joint effort among all parties involved in CP in addition to researchers and educators' efforts. From an ethical point of view, designers should accept this responsibility to ensure the wellbeing of end users, third parties, and construction workers (Culvenor et al., 2007; Bansal, 2011; Micheli et al., 2018).

2.2. DFCs around the globe

In the US, the American Society of Civil Engineers (ASCE) believes that increasing safety in CPs requires commitment from all involved legs. The ASCE and the National Association of Professional Engineers state in their code of ethics that designers should have ethical obligations towards safety, and health of the public and should take action even if the hazard is not imminent. DfCS will increasingly progress in the US through: facilitate prefabricated construction, select systems and materials that are safer than other alternatives, perform construction engineering, and apply spatial considerations to minimize construction hazards (Toole and Gambatese, 2008). In the European Union, whilst designers previously had some responsibilities for minimizing risk under common law provisions, the Temporary and Mobile Construction Site Directive was the first explicit legislation that placed duties on designers (Aires et al., 2010). It requires designers to take working conditions during construct, maintenance and demolition work into account in their designs. Its key concern is planning and coordination of construction activities through improved transfer of information between all parties involved in DPh of projects (Bluff, 2004; Kawuwa et al., 2018). Construction (design and management) regulations place duties for addressing construction workers' safety and health on designers. It places a duty on the designer to ensure that any design should avoid unnecessary foreseeable risks to workers (Toole and Gambatese, 2008). Nonetheless, Behm (2005a) cited that the success of the construction design management (CDM) in reducing construction fatalities has been difficult to establish since designers in the UK has been slow in meeting their responsibility under the construction regulations. Brace et al. (2009) found that after fifteen years of CDM, many designers still believe it is not related to them. Even the small groups who want to engage are having difficulty doing this. The designers in the UK often treat OSH plans merely as a paperwork requirement. In South Africa, designers are required to make available all relevant information about the design, communicate hazards to contractors, and modify design or use a substitute material to improve worker safety (Smallwood, 2008).

2.3. DfCS suggestions

The literature mentions many DfCS suggestions that if considered by designers through the DPh could enhance worker safety during the implementation and maintenance phases. Many individuals and organizations reported several DfCS suggestions that cover different engineering fields and types of engineering projects (Work Safe Victoria, 2005, 2007; Behm, 2006; European Federation of Engineering Consultancy Associations, 2006; Toole et al., 2006; Hinze and Marini, 2008; Kawuwa et al., 2018). The DfCS suggestions are related to project position and layout, material selection, contractor storage places, mechanical and electrical installations, falling from heights, trenches, communicating hazards to contractors, sequence of work and maintenance requirements regarding safety, construction documentation, and work schedule (Al-Hajj and Hamani, 2011). Many researchers reported different SF that minimize construction waste such as project site, project plan, detailed design, procurements, technologies, designers capacities, behaviour and attitude, and external mechanism (Bluff, 2004; Work Safe Victoria, 2005, 2007; Behm, 2006; European Federation of Engineering Consultancy Associations, 2006; Toole et al., 2006; Rwamamara and Holzmann, 2007; Hinze and Marini, 2008; Zarges and Giles, 2008; Durdyev et al., 2017).

3. Research methodology

Triangulation method, through cross verification from these three sources, was used to enhance the validity and reliability of the study findings. The methodology was summarized in Fig. 1. A questionnaire (Ques.) distributed to 111 construction companies. The Ques. was divided into three main parts as shown in Table 1.

The structured interviews with professional engineers was performed. During all interviews, the questions were given in the same order and wording. Additionally, observations of CPs and site documentary sources as site instructions, safety plan, meeting, drawings, and progress reports were consulted. Then, in order to test the appropriateness, reliability and validity of the used scales for some of the questions, a pilot study was undertaken in two procedures. In the first, face-to-face interviews with 15 experts, projects mangers, and engineers from different contracting companies were conducted. In the second procedure, 15 professionals reviewed the draft Ques. All invited professionals had more than 10 years of experience in CP. Some of them were academians while others were professionals. The interviews as well as the pilot study helped in identifying problems in the draft Ques. In addition, many of the given questions were improved in terms of their wordings for better understanding and to avoid misinterpretation and possible different readings for the same question.

The interviews and the pilot study were very helpful in filtering SF that have positive effect on minimizing CW during DPh. In fact, the professionals were asked to give their opinion about the SF found in the literature and were welcomed to add other possible SF based on their experience. All collected data was then taken into a final version of the Ques., which was then distributed to the target group.

Table 1
Ques. content.

Section	Variables	Objective
Part 1: Profile of respondent		
Respondent	Organization and personality	Respondent type, Company classification, Numbers and value of CPs
Respondent position,	Study the relations based on characteristic of respondent type between DfCS and minimizing CW.	qualification, classification and experience.
Part 2: Safety practice in CPs		
Safety	management practices	Data record, Safety plan, producers, training, regulation and law of safety
To highlight the safety	management practices in CPs	
SF have impacts on minimizing the CW	Commitment degree to SS SF have effect on waste in CPs during DPh	Determine the commitment and the effect of DfCS on reducing CW then ranking it according its RII.
Part 3: respondent recommendations to reducing CW by using SS in CPs		

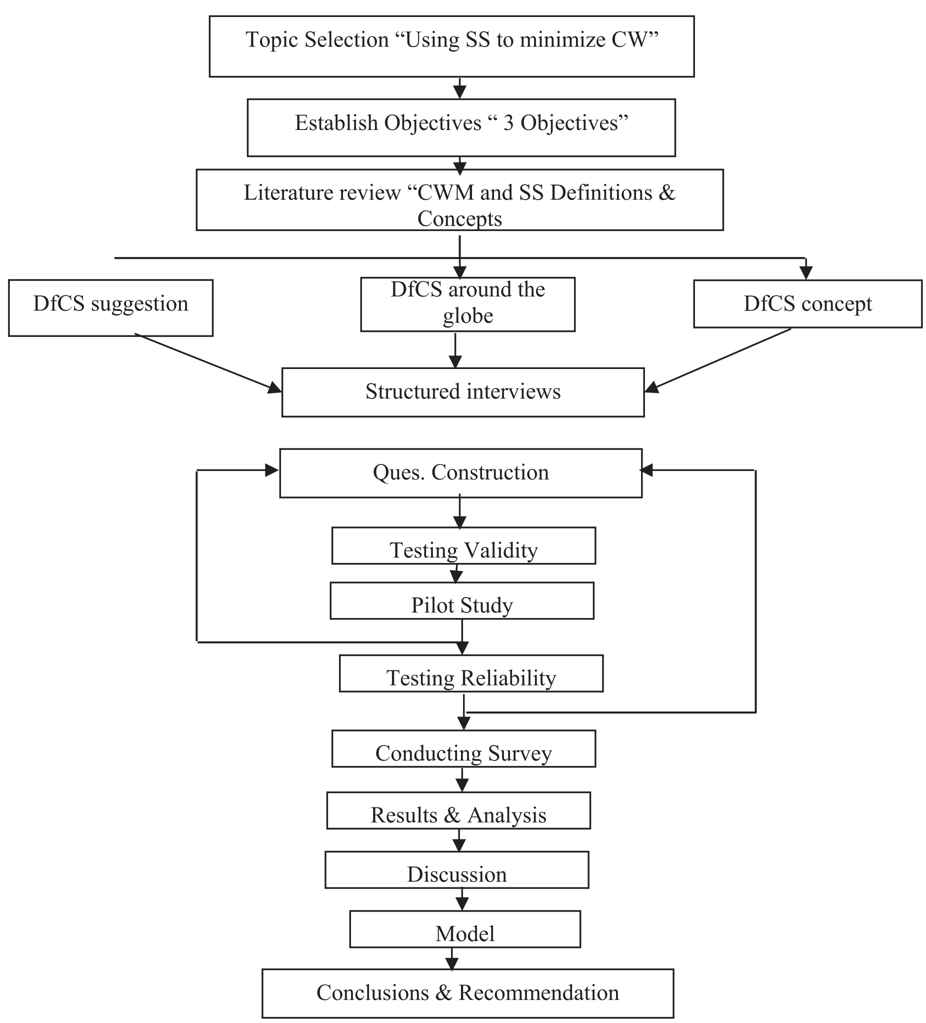

Fig. 1. Methodology flowchart.

3.1. Study population and sample size

The target group included contracting companies, consulting offices, owners and donors' agencies. Contracting companies, which are registered in the country's contractors' union and classified by the "National Classification Committee" (NCC) to have valid registration were targeted in this study. Only companies that are classified according to the NCC as "first class" were sought; the other classes of companies were neglected due to their low practice in CS and waste management as well as their limited administration experience. In total, 66 active companies exist in the country that met the study target criteria. For the consulting offices, 68 offices, which are registered in the country's engineers syndicate were targeted. The owner agencies, with a total of 15, consist of all ministries, municipalities, international agencies, Non-governmental organizations (NGOs), and public project owners. Ten active donors' agencies were also contacted. The total sample size needed for this research determined by Eq. (1), while Eq. (2) was used to correct the outcome of Eq. (1) for finite population (Casella and Berger, 2002).

$$S = \frac{Z^2 \times P \times (1 - P)}{C^2} \quad (1)$$

$$S_{new} = \frac{SS}{1 + \frac{SS-1}{pop}} \quad (2)$$

where S is the sample size; Z is the Z-value from the normal distribution table, taken as 1.96 that corresponds to 95% confidence interval; P is the percentage picking a choice, expressed as decimal (assumed to be 0.50); and C is the maximum error of estimation (assumed to be 0.08). Using Eq. (1) with the assumed values, a population size of 150 is obtained. This number is reduced using Eq. (2) and the resulting values are shown in Table 2 for the different types of contacted companies and agencies. The figure shows also the number of returned Ques. with the % responses. In total, 111 filled Ques. were returned to the study team and were all used for analysing the responses (Casella and Berger, 2002).

3.2. Factors of SS during DPh and its impact on minimizing CW in CPs

From the literature review, structured interviews, and pilot study, 18 factors of SS during the DPh were identified as having impact on minimizing CW. Table 3 shows these factors. The table shows also the number of paragraphs used under each of these evaluated factors. For example, Table 4 shows the paragraphs considered for factor F18 (The capabilities and behaviour of the design team in the safety field).

3.3. Data measurement and analysis

The collected data was analysed using both descriptive and inferential statistical tools. All Ques. results were input into Statistical Package for the Social Sciences (SPSS 22). 9 types of data analysis techniques were used in this paper as follows: Frequency analysis, Spearman brown, Pearson correlation coefficients, Smirnov test, One sample *t*-test, Independent samples *t*-test, ANOVA, Linear regression model, Effect size (ES). For more detail, refer to Probability and Statistics Cookbook (Vallentin, 2011). In addition, the relative importance index (RII) was used to determine the ranks of all Ques. RII was computed using Eq. (3).

Table 3
SF during DPh identified as having positive effects on minimizing CW.

#	Factor	Number of Paragraphs
F1	Appropriate project site for SS	5
F2	Appropriate project planning for SS	4
F3	Appropriate choice of quality materials for SS	7
F4	Appropriate choice of lengths, sizes and dimensions for the SS	7
F5	Appropriate staircase design for SS	4
F6	Appropriate foundation system for SS	4
F7	Appropriate structural design system for SS	14
F8	Appropriate protection edges & height areas for SS	2
F9	Appropriate movement from and to the site for SS	3
F10	Appropriate design of scaffolding work for SS	4
F11	Appropriate design of the openings for SS	3
F12	Appropriate electrical design for SS	15
F13	Appropriate mechanical design for the SS	10
F14	Appropriate plan and drawing for SS	8
F15	Appropriate public and special conditions for SS	5
F16	Appropriate schedule for SS	17
F17	Appropriate quantities and specifications for SS	4
F18	The capabilities and behaviour of the design team in the safety field	8

Table 4
Paragraphs used under factor F18.

1.	High educational background of the designer on the OSH
2.	High work experience of the designer at safety field
3.	Simplifying the design and avoiding complexity
4.	High awareness of the designer of the environmental requirements, the regulations and the laws related
5.	Good coordination between all members of the design team
6.	Prepare full and detailed plans for all works with high quality and without having a lack of design information
7.	The design team should know the machines available to local contractors to implement the project on this basis
8.	The design team should understand implementation methods, and plans which can be implemented in reality

$$RII = \frac{\sum W}{A \times N} \times 100\% \quad (3)$$

where *W* is the weighting given to each factor by the respondents, *A* is the highest weight (10 in this research), and *N* is the total number of respondents. RII value has a range from 0 (0 not inclusive) to 100%, the higher the value of RII, the more impact of the attribute.

4. Research findings and discussion

4.1. General information about the institutions and participants

Table 5 shows the distribution of the organizations who participated in this research. It is noted that the sample included all parties directly related to the design activities: the consultant as the

Table 2
Sample size and determination.

Type	Total	Sample size by using Eq.	Distributed	Returned	Percentage of responding
Contracting company "first class"	66	46	50	42	84%
Consulting offices	68	47	50	48	96%
Owner agencies	15	14	15	11	73.3%
Donors agencies	10	10	10	10	100%

Table 5
General information about the institution and the participant.

Variables	Variable items	Frequency		Percentage%
Organization Classification	Owner	11		9.9
	Donner/Mediator	10		9.0
	Contactor	42		37.9
	Consultant office	48		43.2
	Total	**111**		**100.0**
Work field and Classification of contractors	Buildings	First	42	100
		Second	0	0.0
	Roads	First	35	85.4
		Second	6	14.6
	Water &Sewage*	First	27	75.0
		Second	9	25.0
	Electro mechanic*	First	24	66.7
		Second	12	33.3
Organization C.P value through last 5 years (by million)	<3	between 3 and<10	between 10 & <15	more than 15
	14	17	23	57
Organization C.P number through last 5 years	<10 projects	between 10 & <15	between 15 and<20	more than 20 projects
	21	27	24	39
Average labors number per day through year	<15 labors	between 15 & <30	between 30 and<50	more than 50
	14	12	21	64
Qualification for the participant				
	Diploma	bachelor	master	doctorate
	1	45	63	2
Scientific specialization for the participant (engineering)	civil	architectural	mechanic	electronic
	90	8	7	6
Experience (year) for the participant	<5	between 5 to<10	between 10 to<15	more than 15
In construction field	7	37	30	37
in CS field	37	32	26	16
in CWM				
	43	47	11	10
Training courses for the participant				
	No coursing	only one course	two courses	three or more
in CS	19	40	29	23
in CWM	36	29	13	6
Projects value (million) supervised by the participant through last 5 years	<2	between 2 to <4	between 4 and <6 million	more than 6
	18	20	15	58
Projects number supervised by the participant through last 5 years	<5	between 5 and <10	between 10 and <15	more than 15
	26	28	24	33

designer and supervisor, the contractor as the executor and the owner as a beneficiary and financier. Therefore, the opinions of all parties involved in a construction project were collected in this paper. Furthermore, the experts that participated in this study have academic and practical cultural and scientific diversity, which gives the results of the study a universal aspect.

4.2. General findings about the questionnaire questions

The Kolmogorov-Smirnov (KS) test of normality resulted in p-values greater than the 0.05 level of significance, which means that each field of DPh in CPs could be assumed to be normally distributed. Table 6 presents some of the results for this test for some fields used in the Ques.

Two statistical tests were performed to insure the validity of the Ques.: the first test is Pearson test to measure the correlation coefficient (R) between each paragraph in one field and the whole field (Internal validity). The second test is structure validity test (Pearson test) to test the validity of the Ques. structure by testing the validity of each field and the validity of the whole Ques. (Structure validity). It measures R between one field and all the fields of the Ques. that have the same level of similar scale. The test resulted in R of each paragraph of DPh during DPh significant at α = 0.05, so it can be said that the paragraphs of this field are consistent and valid to measure what it is set for. Table 7 presents some of

Table 6
Results of the KS test of normality.

Field		Statistic	df*	p-value
Safety management practice in CPs		0.054	111	0.200
SF related to effect on reducing the CW during DPh	Degree of commitment	0.048	111	0.200
	Materials waste	0.041	111	0.200
	Time overrun	0.085	111	0.069
	Cost overrun	0.075	111	0.161
CWM in construction projects		0.084	111	0.051
Degree of commitment to reduce CW during DPh		0.055	111	0.200

* Degrees of freedom.

Table 7
R of each paragraph of two of the DPh factors.

No.	Commitment degree		Waste in material		Time overrun		Cost overrun	
	R	p-value	R	p-value	R	p-value	R	p-value
F1: Appropriate of the project site for the safety system								
P1	0.847	0.000	0.784	0.000	0.910	0.000	0.609	0.000
P2	0.867	0.000	0.788	0.000	0.741	0.000	0.596	0.001
P3	0.906	0.000	0.769	0.000	0.920	0.000	0.815	0.000
P4	0.770	0.000	0.706	0.000	0.906	0.000	0.858	0.000
P5	0.687	0.000	0.479	0.007	0.586	0.001	0.465	0.010
F2: Appropriateness of project planning for the safety system								
P1	0.640	0.000	0.940	0.000	0.796	0.000	0.827	0.000
P2	0.910	0.000	0.940	0.000	0.891	0.000	0.946	0.000
P3	0.846	0.000	0.948	0.000	0.739	0.000	0.935	0.000
P4	0.937	0.000	0.947	0.000	0.830	0.000	0.976	0.001

this test results for the first two considered factors and their respective paragraphs.

4.3. Testing of the hypotheses

The hypotheses were tested in this paper are , as following: “there is an inverse relationship, statistically significant at α = 0.05, between commitment to DfCS and waste in (time, cost overrun, material overrun) in CPs”.

Parametric tests were used to perform the hypotheses testing of the study. The output of these test approved all hypotheses so there is an inverse relationship, statistically significant at $\alpha \leq 0.05$, between commitment to DfCS during DPh and waste (cost, time and materials) in CPs.

4.4. Main factors of SS that have positive impacts on minimizing CW during DPh

Table 8 Summarizes the main SF related to positive impacts on reducing waste of cost, time and materials during DPh. The highest factor ranked in minimizing waste in (materials and time) is “The capabilities and behaviour of the design team in the safety field” but the highest factor ranked in minimizing waste in cost is “Appropriate movement from and to the site for SS”. While the lowest ranked in minimizing waste in materials is “appropriate protection edges and height areas for SS” but the lowest ranked in minimizing waste in time is “appropriate design of the opening for SS” finally the lowest ranked in minimizing waste in cost is “appropriate structural design system for SS”. The respondents agreed to these factors, as the sign of the test is positive (RII greater than 60%). Table 8 shows RII and rank of the SF during DPh.

The highest ranked in minimizing waste of materials is factor no. 18 “The capabilities and behaviour of the design team in the safety field” with RII (83.90%) and p-value<0.001. also this factor had the highest ranked in minimizing waste of time, while ranked as the third factor in minimizing cost overrun. This result is in agreement with findings from previous studies (Frijters and Swuste, 2008; Gambatese et al, 2008; Manuele, 2008) that confirm that DFSC reduces accidents by (40% – 60%) during the project cycle. The importance of this factor in reducing waste is highlighted for its Association with high scientific knowledge, educational background and practical experience of the designers on the OSH. High awareness of the designers about safety requirements as well as its related regulations and laws, makes the design team, by the ethical issue, simplify the design and avoid complexity, thus reducing accidents, financial compensation during implementation and accelerates the execution, thereby saving time and materials. The above results are in agreement with those of Culvenor et al, 2007. The good coordination between all members of the design team to prepare full and detailed plans for all works with high quality and without having a lack of design information results on minimizing waste in material, time, and cost. In addition, if the design team knows the machines available with the contractors to implement the project, understand implementation methods, and plans, the waste in material, time, and cost will be reduced.

The second highest ranked in minimizing waste (cost, time and materials) is factor no. 17 “Appropriate quantities and specifica-

Table 8
RII and rank of the SF during design phase.

Factors	Commitment to SS			Waste in material			Waste in time			Waste in cost		
	RII	p-value (Sig.)	ES	RII	p-value (Sig.)	ES	RII	p-value (Sig.)	ES	RII	p-value (Sig.)	ES
F1	80.30	<0.001	1.47	74.05	<0.001	1.10	76.23	<0.001	1.29	77.58	<0.001	1.60
F2	80.74	<0.001	1.50	75.29	<0.001	0.92	77.09	<0.001	1.28	75.87	<0.001	1.07
F3	81.46	<0.001	1.80	74.34	<0.001	0.90	73.54	<0.001	0.93	76.15	<0.001	1.31
F4	79.93	<0.001	1.64	74.99	<0.001	1.31	73.88	<0.001	1.18	75.08	<0.001	1.36
F5	86.77	<0.001	2.30	76.78	<0.001	0.87	75.74	<0.001	0.90	76.28	<0.001	1.02
F6	83.78	<0.001	1.85	80.90	<0.001	1.64	80.63	<0.001	1.61	80.51	<0.001	1.66
F7	76.38	<0.001	1.52	74.86	<0.001	1.38	73.04	<0.001	1.24	71.06	<0.001	0.91
F8	78.06	<0.001	1.32	73.19	<0.001	0.90	73.15	<0.001	0.67	72.47	<0.001	0.85
F9	82.25	<0.001	1.74	74.08	<0.001	0.87	75.55	<0.001	1.09	84.05	<0.001	2.02
F10	79.16	<0.001	1.35	75.81	<0.001	1.12	76.57	<0.001	1.26	75.99	<0.001	1.18
F1111.	80.18	<0.001	1.63	74.53	<0.001	0.97	71.92	<0.001	0.75	73.57	<0.001	0.84
F12	82.40	<0.001	2.41	76.93	<0.001	1.52	77.65	<0.001	1.57	75.84	<0.001	1.37
F13	80.80	<0.001	1.75	76.14	<0.001	1.28	75.76	<0.001	1.24	75.83	<0.001	1.23
F14	73.88	<0.001	0.72	73.24	<0.001	0.83	75.02	<0.001	0.96	73.86	<0.001	0.81
F15	83.71	<0.001	1.69	78.28	<0.001	1.28	79.92	<0.001	1.46	80.27	<0.001	1.46
F16	76.89	<0.001	1.27	75.20	<0.001	1.28	75.87	<0.001	1.48	76.46	<0.001	1.23
F17	86.77	<0.001	2.20	81.14	<0.001	1.56	81.30	<0.001	1.45	83.51	<0.001	1.82
F18	81.90	<0.001	2.01	83.90	<0.001	1.24	82.08	<0.001	2.40	82.66	<0.001	2.38

tions for SS" with RII (81.14%, 81.30% and 83.51% respectively) and p-value<0.001. This result is very realistic. Materials and their specifications represent the largest proportion of the cost of any project and are closely associated with the project completion period. The agreement between bill of quantities, technical specifications and the precise characterization of the materials to be safe and good quality, reduce the wastes, which may result from supplying extra quantities or non-conforming to specifications. Using hazard materials need a special condition in storing and implementation. The above is compatible with Toole et al., 2008 and Aires et al., 2010.

The third highest ranked in minimizing waste (materials- time) is factor no. 6 "Appropriate foundation system for SS" with RII (80.90% and 80.63% respectively) and p-value<0.001. This result agreed with Nangan et al., 2017. The importance of this factor lies in conduct site investigation to examine the need of shoring system for temporary excavations and the appropriate foundation system. Foundation failure is caused by multiple reasons as drainage problems, poor soil preparation, plumbing issues, dry heat and large trees (factor related to safety in design phase). Design for safety concept requires accurate structural analysis as well as the in-depth review of the supporting soil. Fortunately, the failure of modern radical foundations is rare. This is significant because of the recognized need to analyse and test the correct geological location as well as to improve foundation design. On the other hand, knowing the tools and equipment available locally with contractors should minimize waste which may result from extra excavation, landfill, shuttering, and levelling (Shash and Ghazi, 2003)

The fourth highest ranked in minimizing waste (materials-time) is factor no. 15 "Appropriate public and special conditions for SS" with RII (78.28% and 79.92% respectively) and p-value<0.001. This result agreed with Cenovus, 2017. The importance of this factor lies in its containment: (1) the requirements of occupational health and safety for all the work, and the mandatory of its implementation; (2) the necessity of providing prevention and safety equipment by the contractor; (3) providing health and safety plan by the contractor and it should be approved by the supervisor and the relevant authorities; and (4) clear penalty clauses for each violation of any condition of the safety conditions in the site. This factor contains all requirements from contractors and their subcontractors to support OSH commitments, approaches and goals (Enshassi, et al., 2012). It is imposed on the contractor to develop and implement such, practices, procedures, programs, policies, training, guidelinesand other documentation to effectively meet or exceed safety requirements. If the contractor would commit in the implementation phase to the above safety requirements, it will inevitably result in no accidents or injuries and will effectively contribute to reducing waste.

The fifth highest ranked in minimizing waste (materials- time) is factor no. 12 "Appropriate electrical design for SS" with RII (78.28% and 79.92% respectively) and p-value<0.001. The result is compatible with that of Wong et al., 2018. Electrical installations are key activities in all CPs. Electrical works includes installation and maintenance of electrical wiring, air-conditioning system, fire services system, lift and escalators, and drainage and plumbing system. It involves lots of high-risk activities, for examples, welding, using handheld tools, etc. so electrical safety is a vital issue in promoting CS.

The lowest ranked factor in minimizing waste in materials is factor no.8 "Appropriate protection edges & height areas for SS" with RII (73.19%) and p-value<0.001. The lowest ranked factor in minimizing waste in time is factor no.11 "Appropriate design of the openings for SS" with RII (71.92%) and p-value<0.001. The lowest ranked factor in minimizing waste in cost is factor no.7 "Appropriate structural design system for SS" with RII (71.06%) and p-value<0.001. The explanation of these results lies on the fact that these elements do not require special attention during the design stage, and the resulting risk can be reduced by using safety equipment during the implementation phase.

4.5. Prediction equations

The best linear models relating variables (commitment to safety system during DPh and minimizing waste (materials time and cost) in CPs, based on the results of the Ques. were developed. Fig. 2 shows, for example, the results obtained, for "minimizing waste of materials" as a function of "commitment to DFCS", "minimizing waste of time" as a function of "commitment to DFCS", and "minimizing waste of cost" as a function of "commitment to DFCS".

The equations obtained, shown in Table 9, are used as predictive equations to minimize waste (materials, time and cost) according to the degree of commitment to each factor of SS during DPh. There is statistical significant relationship at ($\alpha < 0.05$) between commitment to DFCS and minimizing CW in (material- time- cost) through DPh. For example, the relation between the appropriateness of the project planning for SS and minimize CW in: material equals 0.457, that for time is equal to 0.308, and that for cost is equal to 0.375. This result means that there is positive relationship between commitment to DFCS and minimizing CW. The coefficient of determination, R^2, equals 0.209 for material, 0.095 for time, and 0.141 for cost. This means that 20.9%, 9.5% and 14.1% of the variability of commitment to the appropriateness of the project planning for the SS is due to minimize CW in materials, time and cost, respectively. Since the found p-value are<5%, reducing CW has significant positive effect on the degree of commitment to DFCS. Table 9 presents the prediction equations relating commitment to all the factors studied in this research with the three types of CW (Material, time, and cost).

5. Conclusions and recommendations

This study identified and ranked 18 SF and their positive effects on reducing waste (materials, time and cost) in Cps during DPh and the following are the conclusions:

- The five most important factors to be considered in minimizing material and time wastage are: capabilities and behaviour of the design team in the safety field, appropriateness of quantities

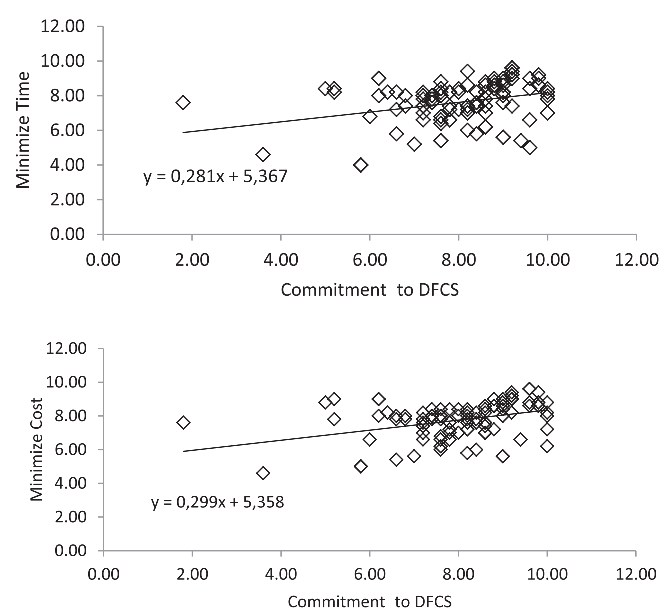

Fig. 2. Appropriateness of the project planning for safety system.

Table 9
Predictive equations to minimize waste according to the degree of commitment to each factor of SS during DPh.

Commitment	Material		Time		Cost	
Appropriate project planning for SS	r	0.457	r	0.308	r	0.375
	r^2	0.209	r^2	0.095	r^2	0.141
	$Y = 4.018 + 0.422X$		$Y = 5.367 + 0.281X$		$Y = 5.358 + 0.299X$	
	std 0.641 0.079		*std* 0.677 0.083		*std* 0.576 0.071	
	sig 0.000 0.000		*sig* 0.000 0.001		*sig* 0.000 0.000	
Appropriateness of the project site for SS	r	0.598	r	0.527	r	0.537
	r^2	0.357	r^2	0.278	r^2	0.288
	$Y = 1.775 + 0.713X$		$Y = 5.625 + 0.506X$		$Y = 2.974 + 0.571X$	
	std 0.750 0.092		*std* 0.640 0.078		*std* 0.705 0.086	
	sig 0.020 0.000		*sig* 0.000 0.000		*sig* 0.000 0.000	
Appropriate choice of quality materials for SS	r	0.649	r	0.516	r	0.553
	r^2	0.421	r^2	0.266	r^2	0.306
	$Y = 0.429 + 0.860X$		$Y = 2.222 + 0.630X$		$Y = 2.961 + 0.571X$	
	std 0.795 0.097		*std* 0.824 0.100		*std* 0.679 0.082	
	sig 0.591 0.000		*sig* 0.008 0.000		*sig* 0.000 0.000	
Appropriate choice of lengths, sizes and dimensions for SS	r	0.722	r	0.717	r	0.667
	r^2	0.522	r^2	0.514	r^2	0.445
	$Y = 2.046 + 0.682X$		$Y = 1.813 + 0.698X$		$Y = 2.638 + 0.609X$	
	std 0.506 0.063		*std* 0.525 0.065		*std* 0.526 0.065	
	sig 0.000 0.000		*sig* 0.001 0.000		*sig* 0.000 0.000	
Appropriate staircase design for SS	r	0.523	r	0.456	r	0.473
	r^2	0.274	r^2	0.208	r^2	0.224
	$Y = 0.198 + 0.862X$		$Y = 1.644 + 0.683X$		$Y = 2.020 + 0.646X$	
	std 1.177 0.134		*std* 1.118 0.128		*std* 1.009 0.115	
	sig 0.867 0.000		*sig* 0.144 0.000		*sig* 0.048 0.000	
Appropriate foundation system for SS	r	0.800	r	0.664	r	0.523
	r^2	0.640	r^2	0.441	r^2	0.274
	$Y = 1.446 + 0.793X$		$Y = 2.535 + 0.660X$		$Y = 3.827 + 0.504X$	
	std 0.483 0.057		*std* 0.603 0.071		*std* 0.666 0.079	
	sig 0.003 0.000		*sig* 0.001 0.000		*sig* 0.000 0.000	
Appropriate structural design system for SS	r	0.655	r	0.645	r	0.621
	r^2	0.429	r^2	0.416	r^2	0.386
	$Y = 2.492 + 0.654X$		$Y = 2.524 + 0.626X$		$Y = 1.746 + 0.702X$	
	std 0.557 0.072		*std* 0.548 0.071		*std* 0.654 0.085	
	sig 0.000 0.000		*sig* 0.000 0.000		*sig* 0.009 0.000	
Appropriate protection edges and height areas for SS	r	0.499	r	0.437	r	0.538
	r^2	0.249	r^2	0.191	r^2	0.290
	$Y = 3.186 + 0.530X$		$Y = 2..444 + 0.6X$		$Y = 2.774 + 0.573X$	
	std 0.699 0.088		*std* 0.976 0.123		*std* 0.681 0.086	
	sig 0.000 0.000		*sig* 0.014 0.000		*sig* 0.000 0.000	
Appropriate movement from and to the site for SS	r	0.548	r	0.583	r	0.879
	r^2	0.301	r^2	0.340	r^2	0.772
	$Y = 1.705 + 0.693X$		$Y = 2.222 + 0.648X$		$Y = 1.666 + 0.819X$	
	std 0.843 0.101		*std* 0.720 0.087		*std* 0.355 0.043	
	sig 0.046 0.000		*sig* 0.003 0.000		*sig* 0.000 0.000	
Appropriate scaffolding work for SS design	r	0.449	r	0.440	r	0.396
	r^2	0.201	r^2	0.193	r^2	0.157
	$Y = 4.056 + 0.445X$		$Y = 4.433 + 0.407X$		$Y = 4.619 + 0.376X$	
	std 0.683 0.085		*std* 0.641 0.080		*std* 0.673 0.084	
	sig 0.000 0.000		*sig* 0.000 0.000		*sig* 0.000 0.000	
Appropriate design of the openings for SS	r	0.480	r	0.450	r	0.396
	r^2	0.230	r^2	0.202	r^2	0.157
	$Y = 2.794 + 0.581X$		$Y = 2.588 + 0.574X$		$Y = 3.206 + 0.518X$	
	std 0.826 0.102		*std* 0.885 0.109		*std* 0.932 0.115	
	sig 0.001 0.000		*sig* 0.004 0.000		*sig* 0.001 0.000	
Appropriate electrical design for SS	r	0.503	r	0.475	r	0.478
	r^2	0.253	r^2	0.225	r^2	0.228
	$Y = 2.750 + 0.581X$		$Y = 3.060 + 0.571X$		$Y = 2.706 + 0.592X$	
	std 0.819 0.099		*std* 0.841 0.101		*std* 0.865 0.104	
	sig 0.001 0.000		*sig* 0.000 0.000		*sig* 0.002 0.000	
Appropriate mechanical design for SS	r	0.617	r	0.653	r	0.599
	r^2	0.381	r^2	0.426	r^2	0.359
	$Y = 2.345 + 0.652X$		$Y = 1.967 + 0.694X$		$Y = 2.353 + 0.647X$	
	std 0.650 0.080		*std* 0.630 0.077		*std* 0.677 0.083	
	sig 0.000 0.000		*sig* 0.002 0.000		*sig* 0.001 0.000	
Appropriate plan and drawing for SS	r	0.729	r	0.733	r	0.740
	r^2	0.532	r^2	0.538	r^2	0.547
	$Y = 2.877 + 0.602X$		$Y = 3.100 + 0.596X$		$Y = 2.561 + 0.653X$	
	std 0.413 0.054		*std* 0.404 0.053		*std* 0.434 0.057	
	sig 0.000 0.000		*sig* 0.000 0.000		*sig* 0.000 0.000	
Appropriate public and special conditions for SS	r	0.577	r	0.606	r	0.615
	r^2	0.333	r^2	0.367	r^2	0.378
	$Y = 2.938 + 0.584X$		$Y = 3.058 + 0.589X$		$Y = 2.939 + 0.608X$	
	std 0.672 0.079		*std* 0.629 0.074		*std* 0.633 0.075	
	sig 0.000 0.000		*sig* 0.000 0.000		*sig* 0.000 0.000	
Appropriate schedule for SS	r	0.695	r	0.691	r	0.640

Table 9 (*continued*)

Commitment	Material		Time		Cost	
	r^2	0.483	r^2	0.477	r^2	0.409
	$Y = 2.746 + 0.621X$		$Y = 3.289 + 0.559X$		$Y = 2.676 + 0.646X$	
	std 0.480 0.061		*std* 0.437 0.056		*std* 0.580 0.074	
	sig 0.000 0.000		*sig* 0.000 0.000		*sig* 0.000 0.000	
Appropriate quantities and specifications for SS	r	0.523	r	0.455	r	0.629
	r^2	0.274	r^2	0.207	r^2	0.396
	$Y = 3.074 + 0.581X$		$Y = 3.390 + 0.546X$		$Y = 2.556 + 0.668X$	
	std 0.794 0.091		*std* 0.898 0.102		*std* 0.693 0.079	
	sig 0.000 0.000		*sig* 0.000 0.000		*sig* 0.000 0.000	
The capabilities and behaviour of the design team in the safety field	r	0.384	r	0.510	r	0.492
	r^2	0.147	r^2	0.260	r^2	0.242
	$Y = 2.839 + 0.678X$		$Y = 4.685 + 0.430X$		$Y = 4.739 + 0.431X$	
	std 1291 0.156		*std* 0.574 0.070		*std* 0.604 0.073	
	sig 0.030 0.000		*sig* 0.000 0.000		*sig* 0.000 0.000	

and specifications for SS, appropriateness of foundation system for SS, appropriate public and special conditions for SS and appropriate electrical design for SS.

- The five most important factors affecting cost efficiency are: appropriate movement from and to the site for SS, appropriateness of quantities and specifications for SS, capabilities and behaviour of the design team in the safety field, appropriateness of foundation system for SS and Appropriate public and special conditions for SS.
- Based on the statistical tests and the relative important factors, a model was constructed showing the relationship between degrees of commitment to the safety system and minimizing waste (materials, time and cost) in construction projects during design phase.

This developed model is capable of predicting the minimizing of waste in construction projects during design phase by using safety system.

- Safety system should be used during design phase to minimize waste (materials, time and cost) based on the model built in this study.
- It is necessary to design training programs in safety field for design teams to increase their skills and knowledge to design for safety concept.
- General and special conditions about safety requirement (plan, material, equipment, implementation methods, and schedule) must be confirmed in any CP.
- For future research it is suggested to:
  - o Investigate relationship between using safety system in maintenance phase and minimizing waste (materials, time and cost).
  - o Building a computerized program to help the stakeholders of the project to calculate the relationship between the two variables (safety and waste).

6. Data availability

The experimental data used to support the findings of this study are included in the article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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