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A Perception Survey of Lean Management Practices for Safer Off-Site Construction

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Abstract: Lean practice is recognised for having a great potential in promoting safety risk management in off-site construction (OSC). This paper presents results of a study conducted to assess the impact of lean practice on safety risk management in OSC in a developing country. A quantitative approach using a survey-based questionnaire was adopted. Lean management practices (LMPs) identified from a literature review were empirically tested using a sample survey of 103 OSC contractors. The survey responses were subjected to descriptive and inferential statistics. The top ranked LMPs for safety risk management in OSC included two mistake-proofing practices, i.e., use of personal protective equipment (PPE) and use of hazard warning equipment; two last planner system (LPS) practices, i.e., involvement of workers in safety planning and providing necessary working equipment; and one first run studies (FRS) practice, i.e., critical analysis of work methods. These LMPs are useful in controlling high-consequence safety risks in OSC. Based on evidence found in this study, the paper argues that lean practice can bring great value to safety risk management in OSC in countries where OSC is transitioning.

Keywords: developing country; lean management tools; lean management practices; lean practice; Malawi; off-site construction; safety; safety hazards; risk management

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Citation: Simukonda, W.; Emuze, F. A Perception Survey of Lean Management Practices for Safer Off-Site Construction. *Buildings* **2024**, *14*, 2860. https://doi.org/10.3390/buildings14092860

Academic Editor: Pramen P. Shrestha

Received: 19 August 2024
Revised: 2 September 2024
Accepted: 5 September 2024
Published: 10 September 2024

1. Introduction

Off-site construction (OSC) refers to a process where modules are manufactured and partly assembled in a specialised off-site factory, then transported and assembled on-site into a complete building structure [1,2]. The term OSC is espoused in the international literature under various terminologies such as modularised, prefabricated, standardised, volumetric [3], modular integrated construction (MiC) [4], and design for manufacture and assembly (DfMA) [5]. The terminologies are used interchangeably in the extant literature to describe prefabricated construction [2,6].

OSC gained momentum as a result of its sustainability benefits. Compared to traditional construction, OSC is believed to promote robust safety risk management, causing its acceptability and wider adoption in recent years [7]. Across the spectrum of off-site production systems, the products of modular building are the most complete components made in-factory that are delivered partially or fully finished, with minimal finishing and installation operations performed on-site [2,8]. Actually, modular building products are engineered and manufactured to 95% completeness in an off-site environment [9]. Higher degree of off-site prefabrication and assembly entails significant safety benefits. Transferring hazardous and risky on-site building operations from site to factory forestalls the occurrence of accidents. By its nature, modular building entails a higher degree of prefabrication with minimal finishing work performed on-site, and the number of on-site workers is significantly reduced. The proportion of off-site to on-site workers for OSC operations in modular building oscillates between 30% and 70%, respectively [10]. Obviation of the need for a large on-site workforce in the construction process is a major safety benefit of modular building production system, especially because human behaviours are correlated with accident causality in the construction industry.

However, OSC processes present unique safety risks that are a cause of concern [11,12]. OSC operations involve material imports and loading, cutting, welding, lifting, unit assembly, interior and exterior finishing, and packing, i.e., in the manufacturing phase, and unit transport, site preparation, unit lifting/hoisting, unit/s assembly and installation, screwing, roof, interior and exterior finishing, i.e., in the construction phase [13,14]. The nature of these operations increases workers' safety risks. Most of the OSC operations involve working at high altitudes or under heavy loads to assemble and install modules [3]. The use of elevated work platforms, such as ladders, mobile scaffolding, and cranes, is attributable to accidents in OSC [13]. During the manufacture of modular units, workers are required to produce units of varying sizes due to the uniqueness of each project. This complicates the work processes and increases the frequency of irregular work positions, manual work and extra steps [13]. Due to its meticulous operations, OSC processes require well-trained workers, which are available in limited numbers [13]. Use of untrained workers results in improper operations which expose workers to safety hazards [13]. Oftentimes, accidents are also caused by conflicts between workers' activities and machinery during the construction process. Falling and struck-by are the commonest types of accidents experienced in OSC [3]. They are believed to be caused by complex production and construction processes of OSC, lack of OSC experience and competencies, and conflicts between machinery mobility and workers' activities [13].

Lean practice is recognised for having a great potential in promoting safety risk management in OSC. Lean practice is characterised as a set of management practices for eliminating waste and non-value-adding activities in the production process. It is aimed at minimising construction wastes, such as accidents, to achieve efficiency in OSC [15]. The philosophy is argued to eliminate most of the causative agents of accidents in the construction industry [15–18]. Lean practice is an approach that advocates for identification of operational conflicts or root causes of waste/accidents, removing the waste/accidents using related LC tools and practices, and promoting prevention of waste/accidents and its negative effects. While lean management tools (LMTs) are higher-level methodologies adopted to realise reliable construction activities, lean management practices (LMPs) are specific qualitative practices that define how certain activities should be executed safely.

The safety impact of LMPs has been documented in the literature. Han et al. [19] highlighted the use of visualisation tools to abate accidents caused by crane operations. Li et al. [20] approved the use of visualisation tools to plan arrangements of construction assets on-site to improve workplace design. The motion-based applications were recommended for identification of unsafe human behaviours [20]. Safety training and communication were recommended for safety management in construction processes [21]. Liu et al. [22] emphasised the importance of safety meetings and the involvement of workers in training and communication events in improving the safety climate. Goh et al. [23] proposed a simulation-based training which allowed workers to experience real-life activity in an augmented reality. Worker's safety skills and knowledge imparted through organised safety trainings are an important element to maintain higher safety standards in OSC [24,25]. For this reason, training programmes designed to impart knowledge based on the needs of the workers are considered pivotal to create a safe workplace environment. Continuous safety training and education can enrich workers safety behaviour and eliminate unsafe human behaviours caused by inappropriate working procedures and mistakes [20,22]. Furthermore, lean techniques are used in the planning and management of OSC workplace design to improve safety [24,26,27]. Employee task allocation [28], planning, and proper management of OSC tasks [29] were recommended as measures for safety improvement in OSC. Formulation of a safety plan based on anticipated safety risks was promoted as a technique for fulfilling OSC tasks safely [30]. Mao et al. [31] suggested the creation of a workplace environment that supports safer movement of people and machines. This is critical in OSC, where most of the operations are executed by machines. Additionally, OSC involves multiple stakeholders with varying and sometimes conflicting responsibilities working at different locations to design, manufacture, transport, and install the components [24]. Extensive collaboration among stakeholders and workers can improve coordination and communication in overcoming safety issues in OSC [24]. The foregoing discussion shows that a plausible link exists between lean practice and safety risk management in OSC.

This paper presents the results of a study conducted to assess the impact of lean practice on safety risk management in OSC. The paper departs from prior studies that characterise construction as the most hazardous industry and lean practice as a philosophy for addressing safety issues in construction. Additionally, the compelling vantage point from which to examine the connections between lean practice and safety risk management in OSC is from the perspective of the urgent need for OSC as an alternative construction method to the hazardous conventional stick-built construction method. The shift to OSC provides a platform for deriving optimal lean manufacturing and construction interventions for OSC projects. This apparent potential relationship is significant to imbue an exploration of lean practice's optimal contribution to safety in OSC. This could in turn demonstrate its full breadth of potential to safety in OSC processes and increase its global employment. In addition, an increasing number of scholars have begun exploring the safety considerations in OSC projects using modern advanced construction technologies. Chattzimmichailidou and Ma [3] reviewed how BIM could be used in safety risk management of modular construction. Banks et al. [32] and Chen et al. [33] examined the safety benefits of DfMA in OSC. This trajectory makes safety risk management a key area of research in OSC and application of lean for safety improvement in OSC an urgent mission. Furthermore, in countries where advanced construction technologies such as BIM have not been assimilated, mature production systems, such as lean practice, become essential to establish reliable manufacturing and construction activities to minimise process and production waste.

Additionally, very little research exists that provides a generic overview of how various LMPs control safety hazards in construction. Soltaninejad et al. [34] explored the safety climate improvement at construction workplaces using 5S + safety. 5S refers to the first letters of five Japanese words, i.e., seiri (sort), seiton (set in order), seiso (shine), seiketsu (standardise), and shitsuke (sustain) [34]. James et al. [26] focused on the safety impact of Kaizen, i.e., continuous improvement, in modular home manufacturing. Bashir et al. [35] reviewed the safety impact of three lean principles of the last planner system (LPS), 5S housekeeping, and mistake-proofing. Bajjou et al. [15] explored the potential safety effectiveness of LPS, visualisation management, 5S housekeeping and mistake-proofing. Thus, studies that offer a thorough analysis of the impact of lean practice on safety risk management in OSC are limited. Similar studies in the context of countries where OSC is transitioning are practically non-existent. The dearth of literature on this topical issue could lead to pseudo-implementation of LMPs with consequential negative impact on the overall safety risk management in OSC. Consequently, this paper investigates the impact of various lean practices on safety risk management in OSC. Based on results presented in this paper, lean practice can bring great value to the safety management of OSC. Integrating lean concepts in safety risk management in OSC will result in a more comprehensive conclusion on ways to enhance safety in OSC. LMPs could be taken as a first intervention for proactively preventing high-consequence safety risks where adoption of OSC is still in the transition phase. The findings contribute to the body of knowledge in lean practice and safety risk management in OSC.

2. Materials and Methods

The study adopted a quantitative research design within the confines of positivism epistemology, where statistical analysis formed the basis for evaluating the impact of LMPs on safety risk management in OSC. The study implemented a multi-stage methodological framework comprising a prior literature, survey design and administration, pre-testing of the dataset, and data analysis. A similar methodological approach (see Figure 1) is widely used in construction engineering and management (CEM) research, i.e., [1,36–38].

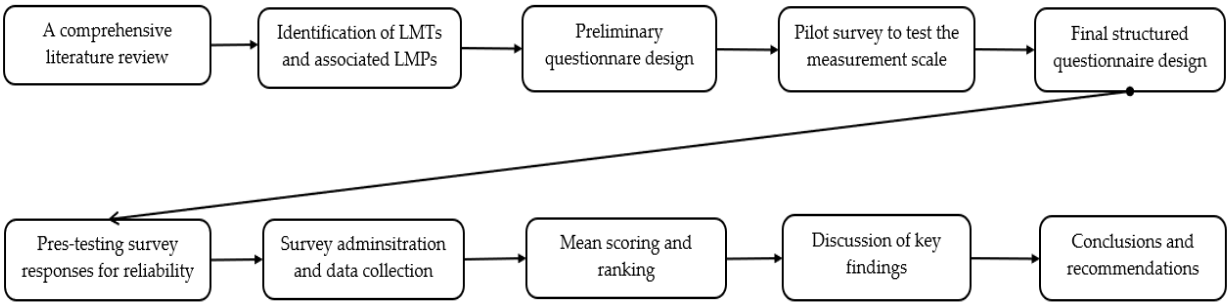

Figure 1. Methodological schema of the study.

2.1. Prior Literature Review

A prior review of the relevant literature was undertaken to identify LMPs that control safety hazards in OSC. In developing items to be included in the survey, consideration of whether to develop new scale items around LMPs (option 1) or use existing ones (option 2) as available in the literature was made. The study relied on option 2 for two reasons. First, due to time limitations, it was impossible to develop new constructs. As observed by the seminal work of Prajogo and Sohal [39], the development of new constructs is a complex task. Second, as argued by Ta et al. [40], the use of pre-tested survey constructs from previous empirical studies ensures their validity and reliability. Consequently, the relevant literature on lean tools and practices was reviewed. There are several lean tools and practices being applied in the construction industry [41]. However, only those that were considered relevant in safety risk management in construction were considered. This was based on the empirical evidence in the reviewed literature. A similar approach is common in CEM research, i.e., Chileshe et al. [36], Hwang et al. [42], and Ameyaw [43]. Some of the selected studies with relevant lean tools and practices for safety risk management in construction include [15,22,35,44–48]. Consequently, a total of 6 LMTs comprising 30 LMPs (see Table 1) were identified as having an impact on safety in OSC. These included daily huddle meetings (DHM) with 5 LMPs, first run studies (FRS) with 2 LMPs, mistake-proofing (i.e., 6 LMPs), 5S housekeeping (i.e., 5 LMPs), improved visualisation (IV) (i.e., 4 LMPs), and LPS (i.e., 8 LMPs). The LMPs formed the basis for designing the survey instrument to collect respondents' perceptions on how the LMPs control safety hazards in OSC. A methodological approach that uses the comprehensive literature review for identification of variables for questionnaire design is common in lean practice research, i.e., [49,50].

Table 1. Lean management practices for safety improvement in construction.

Lean Management Technique	Lean Management Practice	Source
Daily huddle meetings—routine meetings of managers and workers to discuss pertinent project issues.	Two-way communication	[22,47,48]
	Hazard identification and elimination	[48]
	Information sharing	[22,45,48]
	Review previous work	[48]
	Identify good and bad practice	[24]
First run studies—modelling of construction processes to identify root causes of errors and their mitigation measures.	Critical analysis of work methods	[44,48]
	Use video files, photographs, and illustrations to review work	[44,48]
Mistaking proofing—checking the construction processes ahead of errors to avoid free flow of errors in the construction operations.	Use of personal protective equipment	[35,44,47,48]
	Use of hazard warning equipment	[35,44]
	Use of safeguards	[44,48]
	Visual inspection	[35,48]
	Use of audible or visual alarm devices	[15,35,48]
	Use of visual tools	[15,22,35]

Table 1. *Cont.*

Lean Management Technique	Lean Management Practice	Source
5S housekeeping—achieving good construction site management through management of workers, materials, machines and other site factors.	Organising	[15,35,44,46,48]
	Cleanliness and orderliness	[15,35,44,46–48]
	Improved circulation around the workplace	[15,24,35,46–48]
	Eliminate emplacements	[15,35,46–48]
	Standardise work procedure	[15,35,44,46–48]
Improved visualisation—passing specific information to workers through signs and posts.	Use of graphical dashboards and digital billboards	[15,44,47]
	Use of safety borders and demarcations	[44,46–48]
	Use of safety signs and labels	[22,44,46–48]
	Visibility improvement	[44,48]
Last planner system—planning and control tool for monitoring construction process using master planning, phase planning, looking-ahead planning and weekly planning.	Providing necessary work equipment	[22]
	Involvement of workers in safety planning and training	[15,22,24,35,44,46–48,51]
	Eliminate all potential work constraints	[44,46]
	Correlate work methods with workers' abilities and skills	[15,35,44,48]
	Schedule site activities and simultaneous supervision plan	[44,50]
	Empower safety workers in schedule planning	[15,35,44,46,48]
	Undertake pre-task hazard analysis	[44,48]
	Select the most appropriate and safest method	[15,44]

2.2. Survey Design and Administration

A questionnaire is an instrument used most frequently for data collection in quantitative studies. It contains standardised and comparable questions [52] to which participants provide responses. The choice of questionnaire for solicitation of data in this study was mainly influenced by two reasons. First, the study draws on the cumulative experiences and knowledge of OSC contractors regarding LMPs [1]. Questionnaires are more appropriate for measuring lived experiences [53]. Second, the statistical analysis of the data required quantitative data that was consistent and specific. Such data could only be collected through a questionnaire. The questionnaire design focused on answering specific research questions and had two sections. Section 1 comprised relevant respondents' and company characteristics, including respondents' role, experience, and the size of the organisation. Section 2 was designed to solicit respondents' views on what LMPs control safety hazards in OSC. The survey instrument contained 30 LMPs under five categories, i.e., DHM, FRS, mistake-proofing, 5S housekeeping, IV, and LPS. The respondents were asked to rate the likelihood with which LMPs can control safety hazards in OSC. A 5-point rating scale was used, where 1 = extremely unlikely, 2 = unlikely, 3 = neutral, 4 = likely, and 5 = extremely likely. A 5-point rating scale was chosen for various reasons. First, it generates unbiased data that is valid and reliable. Second, it maximises communication within its rating scale gradations, thereby allowing respondents to concisely convey their thoughts [54]. Third, it captures data in a quantitative manner for robust statistical analysis [43] and has remained a preferred data collection tool in CEM discourse [44,46]. It has been used in investigating management and implementation issues in OSC [42], occupational health and safety (OHS), and lean practice [44]. The survey was administered using two respondents' preferred methods, including a completion of an online "Survey Monkey" and physical administration of the questionnaire at the respondents' offices. Data were collected in Malawi between May and August 2023.

2.3. Sampling

The study targeted technical management personnel working with OSC contractors. Due to the unavailability of a central database for OSC contractors, purposive sampling was used to select the respondents. The list of potential OSC contractors was downloaded from the national construction industry council website, and initial telephone enquiries were made to ascertain the companies' involvement in OSC. Since OSC is still in its infancy in Malawi, the potential respondents were asked to state if they have ever been involved in projects where two- or three-dimensional building components, such as beams, columns, shower rooms, toilet pods, etc., or modular construction were used. This approach was augmented by site visits to ascertain the potential respondent's organisation involvement in OSC. According to Battglia [55], a sample size for purposive sampling may be large, i.e., 1000 + respondents; medium, i.e., 100–999 respondents; or small, i.e., less than 100 respondents. The study targeted a medium sample size for a purposive sampling of 100–999 respondents [55]. After a considerable period of searching and tracing, a total of 360 contractors were identified and invited to complete the questionnaire. Before the survey was carried out, the research ethics committee (REC) at Nelson Mandela University (NMU) granted ethical clearance (reference number H23-ENG-CMA-001) based on a low-risk classification. The ethical considerations relating to participants' confidentiality were considered; questions relating to the identity of the respondents were excluded from the survey to ensure anonymisation of the respondents.

2.4. Data Analysis Procedures

The collected data were analysed using IBM Statistical Package for Social Sciences (IBMSPSS) version v.26. The internal consistency of the survey instrument containing 30 LMPs was measured using Cronbach's alpha statistic. Cronbach alpha is a popular reliability statistic that determines the average correlation of items in a survey instrument [56]. The Cronbach's alpha reliability coefficient values range from 0 to 1, with $0.7 \leq \alpha < 0.9$ deemed the acceptable range [57].

Shapiro–Wilk test was conducted to examine the normality of the dataset. This comes on the backdrop of many statistical tests assuming a normal distribution in the dataset, thereby employing parametric testing [58]. Shapiro–Wilk test is the most popular omnibus test for normality distribution and has been employed in many previous CEM research studies, i.e., Hwang et al. [42] and Wuni and Shen [1]. Furthermore, a Kruskal–Wallis test was conducted to determine whether there were statistically significant differences in the responses of the raters. The Kruskal–Walli's test is widely used to conduct inter-group comparisons for checking significant differences among respondents [42,59]. The approach forms the basis for treating collected data as a unified whole for analysis [1].

Descriptive statistical methods of mean score (MS) and standard deviation (SD) were used as a basis for ranking LMPs. The MS formed the basis for ranking the LMPs, while the SD was used to rank LMPs with the same MS values. LMPs with lower SD were ranked higher than LMPs with higher SD. MS analysis is a widely adopted statistical tool in CEM studies for determining the impact of a set of constructs [37]. Furthermore, the minimum statistical MS value for determining the impact of LMPs on safety risk management in OSC was 4.0. The traditional cut-off point for a rating scale depends on the fuzzy linguistic variables assigned to each number on the scale [1]. The 5-point Likert scale used in this study implied that the values 4.0 and 5.0 represent likely and extremely likely, respectively. Thus, the value 4.0 is seen here as the level at which LMP is useful in safety risk management in OSC. As such, 4.0 was considered the minimum threshold MS value for determining the safety impact of LMPs. Though other studies, i.e., Wuni and Shen [1] and Mao et al. [31], have used 3.5 as a minimum threshold on a 5-point Likert scale, 3.5 was considered closer to neutral. Finally, the statistical MS values for LMPs were used to calculate the overall average MS value for ranking the relative impact of LMTs.

3. Results

3.1. Survey Response

Out of 360 questionnaires distributed, a total of 103 valid responses were returned. As the number of questionnaires administered physically were few, the result is consistent with the low returns associated with web-based surveys [37]. However, the number of returns is considered adequate considering that it exceeds the 30 minimum valid responses required for the central limit theorem to make valid conclusions [43]. Furthermore, a response rate of 28.6% compares favourably against construction safety studies targeting similar geospatial respondents, i.e., 15.7% [60] and 28% [61]. Regardless, the relatively smaller response rate necessitates cautious application of the study results.

3.2. Respondents Profile

The results of respondents' profile are given in Table 2. The results of the professional roles show that more than half of the respondents (50.9%) were either project managers (26.4%) or quantity surveyors (24.5%). Most of the respondents, i.e., 31.1%, had over 15 years of general experience in construction, with 33.9% having over 11 years of experience in OSC. Regarding company size, most of the respondents' companies were medium-sized organisations (45.6%). The majority of the companies, i.e., 65.0%, undertake both building and civil engineering works. Taken together, the respondents' profile could depict a true reflection of their perceptions regarding the safety impact of LMPs on OSC.

Table 2. Respondents' profile.

Attribute	Sub-Attribute	Responses	% Responses
Professional roles [a]	Company director	28	25.5
	Safety officer/manager	9	8.2
	Project manager	29	26.4
	Quantity surveyor	27	24.5
	Site engineer/agent	7	6.4
	Site manager	1	0.9
General experience in construction	1–5 years	20	19.4
	6–10 years	30	29.1
	11–15 years	21	20.4
	Over 15 years	32	31.1
Experience in OSC	1–5 years	33	32.0
	6–10 years	35	34.0
	11–15 years	16	15.5
	Over 15 years	19	18.4
Size of company	Small	29	28.2
	Medium	47	45.6
	Large	27	26.2
Work undertaken by company	Building	22	21.4
	Civil	14	13.6
	Building and civil	67	65.0

[a] Sum of responses and % responses for professional roles are <103 and <100%, respectively. This was due to non-response by some respondents.

3.3. Pre-Testing Survey Response

The Cronbach's alpha reliability coefficient value of 0.833 was obtained, which is higher than the standard value of 0.7 espoused by Nunnally [62]. It is also within the acceptable range of $0.7 \leq \alpha < 0.9$ proposed by Surucu and Maslacki [57]. This indicates that the responses had internal consistency, and as such, the survey instrument used for data collection was significantly reliable. The assessment of normality using the Shapiro–Wilk test shows that there was a statistically significant difference between collected data and normal distribution (see Table 3). The observed p value of 0.01 was less than the common alpha value of 0.05, thereby confirming that the data were not normally distributed at a 95% confidence level. This implied that only non-parametric statistical methods could be used for data analysis. The results of a rank-based non-parametric Kruskal–Wallis test undertaken at a significance level of 5% are also shown in Table 3. The observed p values are greater than the alpha value of 0.05. Thus, the responses of the respondents were unanimous to the effect that none of the LMPs were perceived statistically different by various respondents, which rendered the data credible for further analysis.

Table 3. Ranking of lean management practices.

Code	LMPs	MS	SD	Rank	Shapiro–Wilk Test (p-Value)	Kruskal–Walli's Test (p-Value)
LMP_1	Use of personal protective equipment	4.41	0.619	1	0.001	0.311
LMP_2	Involvement of workers in safety planning	4.35	0.652	2	0.001	0.897
LMP_3	Providing necessary work equipment	4.30	0.639	3	0.001	0.305
LMP_4	Use of hazard warning equipment	4.30	0.725	4	0.001	0.321
LMP_5	Critical analysis of work methods	4.28	0.569	5	0.001	0.726
LMP_6	Two-way communication	4.28	0.569	6	0.001	0.975
LMP_7	Use of safeguards	4.28	0.736	7	0.001	0.403
LMP_8	Visual inspection	4.25	0.606	8	0.001	0.780
LMP_9	Illumination	4.25	0.637	9	0.001	0.603
LMP_{10}	Use video files, photographs, and illustrations to review work	4.25	0.670	10	0.001	0.833
LMP_{11}	Organising	4.25	0.532	11	0.001	0.427
LMP_{12}	Use of graphical dashboards and digital billboards	4.24	0.633	12	0.001	0.318
LMP_{13}	Use of audible devices	4.23	0.675	13	0.001	0.128
LMP_{14}	Improved circulation around the workplace	4.23	0.689	14	0.001	0.559
LMP_{15}	Cleanliness and orderliness	4.23	0.703	15	0.001	0.920
LMP_{16}	Hazard identification and elimination	4.23	0.716	16	0.001	0.511
LMP_{17}	Use of safety borders and demarcations	4.23	0.770	17	0.001	0.027
LMP_{18}	Information sharing	4.22	0.576	18	0.001	0.866
LMP_{19}	Eliminate all potential work constraints	4.22	0.625	19	0.001	0.452
LMP_{20}	Correlate work methods with workers' abilities and skills	4.22	0.685	20	0.001	0.104
LMP_{21}	Review previous work	4.21	0.618	21	0.001	0.511
LMP_{22}	Identify good and bad practice	4.21	0.635	22	0.001	0.378
LMP_{23}	Select the most appropriate and safest method	4.20	0.632	23	0.001	0.331
LMP_{24}	Eliminate emplacements	4.20	0.705	24	0.001	0.422
LMP_{25}	Standardise work procedure	4.19	0.482	25	0.001	0.713
LMP_{26}	Use of visual tools	4.19	0.728	26	0.001	0.542
LMP_{27}	Use of safety signs and labels	4.18	0.751	27	0.001	0.159
LMP_{28}	Schedule site activities and simultaneous supervision plan	4.17	0.596	28	0.001	0.606
LMP_{29}	Empower and involve safety workers in schedule planning	4.17	0.663	29	0.001	0.783
LMP_{30}	Undertake pre-task hazard analysis	4.14	0.715	30	0.001	0.852

3.4. Mean Score Analysis and Ranking of LMPs

Table 3 provides results of the perceptions of the respondents on the impact of lean practice on safety risk management in OSC. The five top most ranked LMPs with high likelihood of controlling safety hazards in OSC include LMP1, i.e., use of PPE with MS = 4.41 and SD = 0.619; LMP2, i.e., involvement of workers in safety planning with MS = 4.35 and SD = 0.652; LMP3, i.e., providing necessary working equipment with MS = 4.30 and SD = 0.639; LMP4, i.e., use of hazard warning equipment with MS = 4.30 and SD = 0.725; and LMP5, i.e., critical analysis of work methods with MS = 4.28 and SD = 0.569. As pointed out, SD was used to measure how far the overall rating of LMPs deviated from the associated MS. It was also used to rank LMPs with the same MS, in which LMPs with lower SD were ranked higher, i.e., LMP3 and LMP 4; LMP5, LMP6, and LMP7; and LMP8, LMP9, etc. The SD also helped to measure the consensus in the ratings of the respondents on the safety impact of LMPs on OSC. Though there are no minimum and maximum thresholds for SD, smaller values suggest higher a consensus among the respondents. As can be seen from Table 3, all LMPs had an SD of less than 1.0, indicating a higher consensus in the rating of LMPs among the respondents. The least ranked LMPs include LMP26, i.e., use of visual tools with MS = 4.19 and SD = 0.728; LMP27, i.e., use of safety signs and labels with MS = 4.18 and SD = 0.751; LMP28, i.e., schedule site activities and simultaneous supervision plan with MS = 4.17 and SD = 0.596; LMP29, i.e., empower and involve safety workers in schedule planning with MS = 4.17 and SD = 0.663; and LMP30, i.e., undertake pre-task hazard analysis with MS = 4.14 and SD = 0.715. Though the ranking of the LMPs indicate different levels of their safety impact, they all exceeded the minimum threshold of 4.0, signifying that they were perceived to be likely to control safety hazards in OSC.

3.5. Average Mean Score Analysis and Ranking of LMTs

LMTs were ranked based on average MS values calculated from individual MS values of LMPs within a particular LMT. As shown in Table 4, mistake-proofing had the highest average MS of 4.33 and SD of 0.682. The second-ranked LMT was FRS, with an average MS of 4.27 and SD of 0.620. The third-ranked LMT was DHM with an average MS of 4.23 and SD of 0.623, while IV was the fourth-ranked with an MS and SD of 4.23 and 0.698, respectively. 5S housekeeping was fifth-ranked with an average MS of 4.22 and SD of 0.622, while LPS was the lowest ranked with an average MS of 4.22 and SD of 0.651.

Table 4. Average mean scores for ranking LMTs.

LMTs	Av. MS	Av. SD	Overall Rank
Mistaking proofing	4.33	0.682	1
First run studies	4.27	0.620	2
Daily huddle meeting	4.23	0.623	3
Improved visualisation	4.23	0.698	4
5S housekeeping	4.22	0.622	5
Last planner system	4.22	0.651	6

4. Discussion

The results of the MS analysis show that all 30 LMPs are useful in safety risk management in OSC, having scored an MS exceeding 4.0 on the 5-point rating scale. Additionally, the minimal differences in the MS values among the LMPs suggest that respondents unanimously pereceived the LMPs as almost equally likely, i.e., significant, in safety risk management in OSC. However, construction companies would usually prioritise the selection and implementation of LMPs that focus on aiding elements of practicality and efficiency to the construction processes [63], as well as those that provide immediate initial successes, i.e., in terms of safety, beside those that improve project success factors such as time, cost, and productivity [64]. Furthermore, construction companies would prioritise

LMPs in which they have organisational expertise and those that have spillover benefits [64]. Thus, companies would implement LMPs in which they have operational capacity to manage. Furthermore, they select LMPs that would give maximum value in terms of cost, time, and productivity [64], as well as those that would complement other existing management tools. It is understood that only LMPs that are affordable, compatible, and efficient contribute significantly to the overall outcome of the project [64]. This could be the basis for the results of the ranking of LMPs shown in Table 3. Thus, for example, LMP1, i.e., use of PPE, is deemed efficient and affordable, a significant factor in project success, an LMP that can easily be implemented, and thus effective in safety risk management in OSC. Unlike top-ranked LMPs such as LMP1, low-ranked LMPs such as LMP30 could be viewed as lacking in helping organisations to realise immediate initial gains in safety. They could also be difficult to actualise due in part to a lack of organisational expertise in managing the LMPs. The following section discusses the perceived impact of LMPs on safety risk management in OSC in chronological order of their significance. Accordingly, LMPs are discussed under their respective LMTs.

4.1. LMPs for Safer OSC

4.1.1. Mistake-Proofing

Table 4 illustrates that mistake-proofing is the overall top-ranked LMT for safety risk management in OSC with MS = 4.33 and SD = 0.682. Mistaking proofing involves the implementation of LMPs that prevent the free flow of inadvertent errors in the construction process. It is widely useful in the prevention of accidents caused by human errors and equipment failure [15,35]. OSC involves extensive use of machines and tools in the manufacture, transportation, and assembly of OSC modules. Equipment failure or fall of improperly fixed modules, materials, and tools may result in struck-by accidents. Struck-by accidents are reported to be among the frontline accident causal factors [13] in countries where OSC is an established model, making it a critical safety hazard in countries where OSC is transitioning. Table 5 shows that use of PPEs was the overall top-ranked LMP with MS = 4.41 and SD = 0.619, implying that it is perceived as more likely to control safety hazards in OSC than any other lean practice considered in this study. PPEs are a form of body insulation consisting of hard hats, overalls, work suits, gloves, boots, or gumboots, googles, as well as masks. PPEs protect the workers from a wide variety of hazards, including burns, laceration potential from impaling and striking objects, strikes against objects, struck-by moving equipment or flying objects, trip and slip hazards, and falling hazards [65]. In OSC operations, workers face consistent threats of falling from elevated work platforms and struck-by accidents posed by on-site equipment and falling objects. PPEs protect workers from being directly struck by or hit against machines or objects. Similarly, hazard warning systems (ranked 2nd within group) predict workers and equipment real-time movements and exact positions on construction sites [66] for avoidance of collision accidents [67]. Avoidance of collisions on construction sites could further be prevented with visual inspections (ranked 4th) and audible devices such as alarms (ranked 5th). Enshassi et al. [44] found that using alarms provides warning from crossing unsafe boundaries. Essentially, construction equipment and machine-related accidents such as crane failure and collapse, use of faulty equipment and tools, collision of machines, and failure to safely use machines could be avoided through the implementation of mistake-proofing practices. It could be asserted that mistake-proofing practices should be promoted to control critical safety risks related to struck-by accidents in OSC.

Table 5. Ranking of mistake-proofing practices.

Code	LMP	MS	SD	Overall Rank	Rank within Group
	Mistaking Proofing				
LMP_1	Use of personal protective equipment	4.41	0.619	1	1
LMP_4	Use of hazard warning equipment	4.30	0.725	4	2
LMP_7	Use of safeguards	4.28	0.736	7	3
LMP_8	Visual inspection	4.25	0.606	8	4
LMP_{13}	Use of audible devices	4.23	0.675	13	5
LMP_{26}	Use of visual tools	4.19	0.728	26	6

4.1.2. First Run Studies

The second overall ranked LMT was FRS, with an average MS = 4.27 and SD = 0.627. FRS are a systematic method for critically analysing work methods to identify the most appropriate and safest method that matches the ability and skills of the workers [44]. It minimises accidents caused by low levels of knowledge and skills [14,20], which impairs workers safety situation awareness. Due to complex OSC operations and associated high-consequence safety risks, OSC workers are required to have high professional skills and adequate safety knowledge and experience. However, due to limited projects, there are only a few skilled and experienced workers in OSC globally [3]. Furthermore, in countries where OSC is transitioning, its implementation confronts various challenges, including inadequate and immature safety education and training, resulting in low levels of knowledge and skills, critical to safety risk management in OSC. As such, the construction industry relies on in-training workers, who are required to master multiple skills and quickly adapt to new working procedures. FRS offer an opportunity to review work methods and select appropriate methods that correlate with workers abilities, skills and experience. Table 6 shows that FRS practices were ranked 5th and 10th among all LMPs. LMP5 and LMP10 entail critical analysis of work methods and illustration of work methods through videos and photos, respectively. LMP5 could be useful in correlating work methods with workers level of ability to execute a particular task safely. Thus, safety supervisors should assess workers technical proficiency and allocate tasks within their functional capability. They can also devise tailor-made safety trainings to uplift workers safety knowledge and improve their resilient skills in OSC operations [24]. LMP10 should be used to demonstrate how tasks can be performed safely by OSC workers. The visual aids help employees become more aware of, comprehend, and anticipate the safety situations at work [22]. LMP10 can also be used to train workers using internal or external benchmarked success stories. The emergent implication of the above finding is that FRS designed to improve skills and knowledge of the OSC workforce are critical for safety in countries where OSC is a novel construction method. However, rapid change in technology warrants far more advanced visualisation tools, such as virtual reality (VR), that can allow OSC workers to have an immersed feel of augmented reality.

Table 6. Ranking of first run studies practices.

Code	LMP	MS	SD	Overall Rank	Rank within Group
	First Run Studies				
LMP_5	Critical analysis of work methods	4.28	0.569	5	1
LMP_{10}	Use video files, photographs, and illustrations to review work	4.25	0.670	10	2

4.1.3. Daily Huddle Meetings

The third overall ranked LMT was DHMs, with an average MS = 4.23 and SD = 0.623. DHMs provides a platform for brief daily start-up meetings of project stakeholders to review previous work, discuss good and bad aspects, and suggest ways of improving performance [50,51]. It is mainly used to minimise accidents caused by poor communication [16], stressful work [68] and ergonomic hazards [35]. Table 7 illustrates that two-way communication (LMP6) was ranked 6th among all practices with MS = 4.28, SD = 0.569. Within group rank, LMP6 was ranked top, followed by hazard identification and elimination (LMP16; MS = 4.23, SD = 0.715) and sharing of information (LMP18; MS = 4.22, SD = 0.576). Thus, DHMs provide an interactive platform for managers, supervisors, and workers to critically review work methods, identify good and bad practices or safety risks, and exchange and share working information. According to Liu et al. [22], such interventions could promote safe attitudes towards behaviour and a positive safety climate in an OSC working environment. Ghosh [16] asserts that two-way communication improves coordination between employers and employees, raises morale among workers, and increases job satisfaction as workers feel to be an important part of the harmonious construction team. This may lead to employee agility in relation to handling safety issues, where employees develop capabilities to appropriately respond to any safety issues as a result of proactivity, adaptability, and resilience [69]. DHMs allow workers to deal with challenges with speed, flexibility and decisiveness [70], which are vital in the dynamic OSC processes. Furthermore, two-way communication and sharing of information create a supportive environment in which safety issues are handled with a unified front due to the fluid interaction and employee networking fostered by DHMs. In consonance with findings of Ghosh [16], Noorzai [63], James et al. [26], Li et al. [20], Sarhan et al. [47], Hwang et al. [42] and Bashir [50], DHM-related practices promote safety awareness, communication and coordination which improves workforce safety behaviour. LMP21, i.e., review of past work and LMP22, i.e., identification of good and bad practices, are critical in developing safe behavioural tenets. Safety supervisors should use DHMs to correct wrongs and reinforce good safety practice, which can lead to sustained habitual safe behaviours. The emerging results foster the need for adoption of lean tools that promote open communication and sharing of information among a turnover of in-service training workers, with the aim of improving safety awareness and developing capabilities to respond to safety issues intuitively.

Table 7. Ranking of daily huddle meetings practices.

Code	LMP	MS	SD	Overall Rank	Rank within Group
	Daily Huddle Meeting				
LMP_6	Two-way communication	4.28	0.569	6	1
LMP_{16}	Hazard identification and elimination	4.23	0.716	16	2
LMP_{18}	Information sharing	4.22	0.576	18	3

Table 7. *Cont.*

Code	LMP	MS	SD	Overall Rank	Rank within Group
LMP_{21}	Review previous work	4.21	0.618	21	4
LMP_{22}	Identify good and bad practice	4.21	0.635	22	5

4.1.4. Improved Visualisation

IV was the fourth overall ranked LMT with an average MS = 4.22 and SD = 0.655. Use of IV on construction sites eliminates safety hazards caused by poor site awareness, poor communication and extensive use of equipment [35,50,51]. Elimination of such safety hazards is crucial in OSC operations where extensive use of machinery requires good site awareness and proper communication among site workers. Though improved visualisation techniques were overall ranked low among the LMPs, i.e., 9th, 12th, 17th, 25th, and 27th (See Table 8), their relevance in safety risk management in OSC cannot be ignored. Graphical dashboards and digital billboards (LMP9) are usefulin safety education and training through broadcasts of safety issues in real-time. Such tools provide much-needed proactivity and flexibility in dealing with safety issues. According to Liu et al. [22], such intervention can help in reminding workers of their safety responsibilities, including consequences of ignoring safety standards, and, in a way, enhance positive safety attitudes and behaviours. Enshassi et al. [44] and Bajjou et al. [15] found that positioning safety signs at different locations on construction sites improves safety awareness and reduces human errors. Safety signs can prevent entry into unauthorised and dangerous areas by workers or members of the public. Furthermore, signs and labels provide information that is self-explanatory and easy to interpret for workers. Such safety interventions are critical in preventing accidents caused by machine operations in OSC [19].

Table 8. Ranking of improved visualisation practices.

Code	LMP	MS	SD	Overall Rank	Rank within Group
	Improved Visualisation				4.23
LMP_{9}	Use of lights for activities performed at night	4.25	0.637	9	1
LMP_{12}	Use of graphical dashboards and digital billboards	4.24	0.633	12	2
LMP_{17}	Use of safety borders and demarcations	4.23	0.770	17	3
LMP_{27}	Use of safety signs and labels	4.18	0.751	27	4

4.1.5. 5S Housekeeping

The 5S housekeeping was the fifth overall ranked LMT with average MS = 4.23 and = 0.651. 5S housekeeping is a site planning management tool [45], aimed at optimising the arrangement and formation of various off-site/on-site factors to improve efficiency and eliminate waste [46]. This lean tool addresses safety hazards related to unsafe site conditions [46], site congestion [71], and extra steps and confusion [72]. OSC operations demand extensive use of machines such as overhead cranes, loaders, and forklifts, with workers being required to work in close proximity with such heavy equipment [25]. This necessitates creating an optimised workspace that supports safe movements of people and machinery. 5S housekeeping-related practices, including organising, improved circulation around the workplace, and cleanliness/orderliness were ranked 11th (MS = 4.25; SD = 0.532), 14th (MS = 4.23; SD = 0.689), and 15th (SD = 4.23; SD = 0.703), respectively (see Table 9). These lean practices ensure that construction assets, including materials, tools and plant are placed in regular, illuminated, and accessible locations and that the site has clearly marked routes and adequate working space to improve circulation [73,74]. By providing a conducive workplace, 5S provides a platform for the effective implementation of all other

LMTs [68]. In OSC operations where machines and people work in close proximity, optimal site layout becomes a critical site management factor in safety risk management.

Table 9. Ranking of 5S housekeeping practices.

Code	LMP	MS	SD	Overall Rank	Rank within Group
	5S Housekeeping				
LMP_{11}	Organising	4.25	0.532	11	1
LMP_{14}	Improved circulation around the workplace	4.23	0.689	14	2
LMP_{15}	Cleanliness and orderliness	4.23	0.703	15	3
LMP_{24}	Eliminate emplacements	4.20	0.705	24	4
LMP_{25}	Standardise work procedure	4.19	0.482	25	5

4.1.6. Last Planner System

The least ranked LMT was LPS, with an average MS = 4.22 and SD = 0.651. An LPS minimises waste and improves reliability in production flow through robust planning, control, scheduling and mutual coordination among project stakeholders [15]. Table 10 shows that two of the LPS practices, i.e., LMP2 and LMP3, were ranked 2nd and 3rd as more likely to control safety hazards among all practices. These practices, i.e., ranked 1st and 2nd in the rank within the group include the involvement of workers in safety training (MS = 4.35; SD = 0.652) and providing necessary working equipment (MS = 4.30; SD = 0.639), respectively. In consonance with the existing literature, provision of safety equipment was ranked 5th commonly applied LMP for reducing accidents in construction [44]. Unlike in the current study, involvement of workers in safety planning was ranked 23rd in a study by Enshassi et al. [44]. Regardless, the prominence of LMP2 and LMP3 in safety risk management has been demonstrated in previous studies. According to Camuffo et al. [75], workers involvement in safety planning reduces accidents related to poor work methods and physical and mental limitations. It also minimises accidents resulting from poor planning and control, as well as unsafe acts of workers [76]. Ghosh [16] affirms that workers' involvement in safety planning promotes behavioural tenets critical to safety, including workers commitment, enhanced self-esteem, sense of belonging, and cohesiveness. Liu et al. [22] echoes the importance of establishing systematic safety training as a tool of influencing positive safety behaviours of novice OSC workers. Employee attitudes towards safety are recognised as a crucial antecedents to unsafe acts and implies that changing workers attitudes and altering their unfavourable safety behaviours through their involvement in safety education and training could have a significant effect on safety risk management in OSC.

Table 10. Ranking of last planner system practices.

Code	LMP	MS	SD	Overall Rank	Rank within Group
	Last Planner System				
LMP_2	Involvement of workers in safety planning	4.35	0.652	2	1
LMP_3	Providing necessary work equipment	4.30	0.639	3	2
LMP_{19}	Eliminate all potential work constraints	4.22	0.625	19	3
LMP_{20}	Correlate work methods with workers' abilities and skills	4.22	0.685	20	4
LMP_{23}	Select the most appropriate and safest method	4.20	0.632	23	5
LMP_{28}	Schedule site activities and simultaneous supervision plan	4.17	0.596	28	6
LMP_{29}	Empower safety workers in schedule planning	4.17	0.663	29	7

Similarly, provision of necessary working equipment is critical in safety risk management. It was ranked top as the most commonly implemented practice within the LPS group in a study by Enshassi et al. [44]. Liu et al. [22] argue that workers safety behaviours increase if they have access to safety resources. Such basic safety resources include helmets, gloves, overall, etc. Similarly, though other LPS practices had low rank, their role in safety risk management in OSC should be emphasised. Pre-task hazard analysis is used to identify and mitigate safety risks [50]; selecting and correlating workers abilities with work methods to is used to reduce accidents caused by poor work methods [76]; allocating work to individuals with suitable abilities reduces accidents related to lack of skill and experience; and having a robust supervision plan ensures that safety rules are followed and corrected when broken [22]. Previous results have demonstrated that LMP20 and LMP23 are useful in safety risk management to prevent accidents related to lack of skill and experience, especially where inexperienced in-service workers are used to execute OSC-related trade works. Overall, safety training and provision of safety resources are critical in safety risk management in OSC.

5. Theoretical and Practical Implications of the Study

The originality of the paper lies in the paper's serious attempt to explore lean practice techniques for safety risk management in OSC. It provides useful academic and practical reference material where OSC is a new construction model. Cohen et al. [77] acknowledged that empirical research provides theoretical and practical knowledge, which provides a bedrock for future research and industrial practice. The current study identified LMPs for safety risk management in OSC in the context of countries where OSC is in early stages. Overall, the study makes a unique contribution to the lean practice body of knowledge through identification of LMPs for safety risk management in OSC. From a theoretical lens, the study constitutes generic research findings on lean practice for safety risk management in OSC, drawing on perspectives from the sub-Saharan region. The study provides a rank of LMPs that are considered significant for safety risk management in OSC. Thus, the study provides the basis for future research on LMPs for safety risk management in OSC. This could be regarded as relevant to academic researchers in lean practice, safety, and OSC.

In the context of practice and management, the ranked LMPs will serve as a guide for the implementation of lean practices for safety improvement in OSC. Implementation of top-ranked LMPs may have positive safety outcomes in OSC. Regardless, since all LMPs were rated significant, lean improvement efforts need to be directed at helping companies understand the importance of low-ranked LMPs for comprehensive safety risk management. Further, since the study was conducted in a country with specific socio-economic characteristics, the top-ranked LMPs in this study may be associated with contextual issues, which may be different in other countries. As such, country specific studies may be conducted for identification of prioritised LMPs. Such studies may provide a basis for comparing lean practices for safety risk management in OSC between countries.

6. Conclusions, Contributions, and Limitation of the Study

Lean practice leverages significant safety risk management in OSC. Lean practice is considered a mechanism for reducing waste in the construction industry. Construction accidents are an example of waste, and the implementation of LMPs contributes to the reduction of accidents. However, studies conducted to identify LMPs for safety risk management in countries where OSC is a novel construction method are limited. The study assessed the impact of 30 LMPs on safety risk management in OSC. A structured questionnaire survey was used to collect quantitative data for statistical analysis on a 5-point rating scale. The LMPs with the most significant impact on safety in OSC projects based on MS analysis included two mistake-proofing practices, i.e., use of PPE and use of hazard warning equipment; two LPS practices, i.e., involvement of workers in safety planning and providing necessary working equipment; and one FRS practice, i.e., critical analysis of work methods. However, the respondents unanimously rated all LMPs as having significant impact on safety in OSC, with MS exceeding 4.0. The inclusive findings of the study highlight the significant role of lean practice in promoting safety in OSC and have useful implications. The study has ranked LMPs critical for safety risk management in OSC in the context of countries where OSC is in developing stages. Thus, the study provides a generic checklist of LMPs for implementation to improve OSC project safety success rate. The results of the study are applicable where OSC is its early stages, though though bespoke studies are recommended. The current study may provide a basis for future studies to explore how lean practice can enhance safety risk management in OSC. In the main, future studies are recommended to develop a decision-making model for analysis and selection of the most appropriate LMPs for safety risk management in OSC. Further studies are recommended to explore the contribution degrees of the LMPs to safety performance in OSC and their correlation to organisations' characteristics using either structural equation modelling or fuzzy synthetic evaluation analyses. However, some limitations of the research are worth acknowledging. First, the study provides findings for OSC safety risk management using lean practice in the context of Malawi. However, due to the varying economic and social landscapes in different countries, generalisability of the study findings may be limited. Regardless, future comparative studies may unravel such differences. Second, since OSC is still in its embryonic development in Malawi, a thin line existed between OSC contractors from whom data were collected and general contractors. Moreover, most of the respondents had a higher cumulative experience in general construction than OSC. As such, some respondents' experiences with LMPs may have been based more on general construction. Regardless, the study provides useful generic findings regarding lean practice for safety risk management in OSC in the context of countries where OSC is a new phenomenon.

Author Contributions: Conceptualisation, W.S. and F.E.; methodology, W.S. and F.E.; validation, W.S. and F.E.; formal analysis, W.S. and F.E.; data curation, W.S.; writing—original draft preparation, W.S.; writing—review and editing, W.S.; supervision, F.E. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Ethical clearance for this study was obtained from the Faculty of EBET Research Ethics Committee (Human), (H23-ENG-CMA-001), approval date 12 January 2023.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Acknowledgments: The authors would like to acknowledge that the text was written by the authors without the use of AI text generator systems.

Conflicts of Interest: The authors declare no conflict of interest.

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