

Review

A Systematic Review on High Reliability Organisational Theory as a Safety Management Strategy in Construction

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Abstract: This study examines the available evidence of high reliability organisational (HRO) theory as a strategy to manage construction safety: (1) Background: High reliability organisations (HROs) have been under investigation by organisational scholars to understand how they function at an exceptionally high level with few or no accidents under challenging circumstances. The construction industry is a high risk industry and is also known for a high fatality rate around the world. This systematic review examines the available evidence of HROs as a strategy to manage construction safety; (2) Methods: A systematic review to summarise and critically appraise the literature on high reliability organisational theory, aimed at improving construction safety; (3) Results: Of 2724 articles found, fifteen studies met the inclusion criteria for qualitative synthesis and review. Six of the studies were from construction, four were from general HROs research, two were from health care, and three were from the aerospace, oil and gas, and nuclear industries; (4) Conclusion: Based on the available evidence, transferring the practices and principles of HROs to construction, the validation of proposed assessing tools and a consensus HRO definitions are the major issues identified.

Keywords: high reliability organisations; reliability; construction

1. Introduction

The construction industry is a high risk industry and is known for having high fatality rates worldwide. Safe Work Australia reported that from 2003 to 2015, the construction industry recorded a total of 469 fatalities, with a further 43 from 2016 to June 2017 [1]. Similarly, the Occupational Health and Safety Administration (OSHA) of the United States of America reported that of 4379 workers fatalities in private industry in 2015, 937 occurred in construction [2]. Construction accidents mostly result from interactions between the work team, workplace, equipment, and materials, which account for 70% of injuries and fatalities [3]. Research also suggests that construction accidents occur due to multiple events such as the random interaction of hazards and other casual factors related to deficiencies in management, equipment problems, unsafe site conditions, workers actions, and conditions specific to construction activities. In managing construction activities, some safety management strategies have been implemented in order to minimise accidents and reduce fatality rates. These strategies and approaches improved construction safety to an extent, but accidents continue to occur, and fatality rates are still not acceptable; therefore, other alternatives and strategies are needed to improve the situation.

High reliability organisations (HROs) are known to operate nearly error-free in extremely challenging and uncertain environments, where complex procedures, technology, and guidelines are used to manage complex systems and conditions. The construction industry also operates in an

uncertain environment due to changes in the work environment, unfavourable weather conditions, subcontractors, unskilled tradesmen, management issues, and logistics. However, construction activities are rarely error- or accident-free due to the strategies and procedures implemented in managing safety. HROs are able to attain high safety standards because they apply the principles of collective mindfulness in their daily operations. HRO principles have been mostly applied and investigated in the healthcare sector, but much has not been done in construction. Therefore, it is important to investigate the opportunities of applying the principles as a safety management strategy in construction.

A systematic review was carried out to summarise and critically analyse the body of evidence on HRO theory and its applicability as a safety management strategy in construction.

1.1. Current Safety Management Approaches in Construction

Accidents continue to occur in the construction industry worldwide [4], due to the complexity and unpredictable nature of most construction activities [5]. Managing safety in the construction industry involves dealing with accident prevention and conducting accident investigations [4]. Accident prevention involves safety interventions such as design modifications, technical measures, and behavioural and organisational interventions [4], which are used for hazard controls and accident prevention in managing safety. The analysis of accidents gives an in depth understanding of the hazards, and the what, how, and why of an accident [6].

Over the past years, efforts have been made to improve construction safety management approaches, and there are now a number of recognised safety interventions and approaches. In this review we will focus on the most common safety improvement approaches evident in the literature and in the construction sector: (i) personnel selection, (ii) safety campaign, (iii) risk assessment, (iv) behaviour based safety programs, (v) safety regulations, (vi) safety climate, (vii) prevention through design, and (viii) near miss accident reporting.

1.1.1. Personnel Selection

Risk analysis carried out some years ago in the construction industry observed that most company accidents were caused by a small fraction of employees. The results from the analysis prompted the need for critical selection of personnel as a means to mitigate accidents [4]. It was concluded that some employees were more susceptible to accidents than others [5], so variables such as behavioural and workplace attitude, psychological problems, drug abuse, and alcohol use were identified by researchers for screening future employees [5]. However, the personnel selection method turned out to be less effective for improving occupational safety when put into practice [5], because individual behaviour of workers did not contribute significantly to construction accidents.

1.1.2. Safety Campaign

Research aimed at promoting health and safety in construction activities was conducted in the United States of America in 1990, and resulted in the inauguration of the Centre to Protect Worker's Right (CPWR) [6,7]. As a result of this national initiative, it was recorded that rates of absenteeism and lost-time injuries decreased by 20% [6,7].

1.1.3. Risk Assessment

Risk assessment involves collecting information that provides an understanding of how to assess potential hazards [8]. It takes into consideration how events occur and the probability of such events happening consistently, or a specific combination of events using fault tree analysis to estimate the severity and consequence of such events [8,9]. Risk assessment makes use of three steps: identifying potential hazards, assessing the risk, and ranking the risk.

Risk assessment in construction is mostly carried out using the Preliminary Hazard Analysis (PHA) technique and check-lists [10]. The PHA technique analyses sequences of events that have the

potential to result in an accident. The check-list are designed for this specific task and is also used to control risk associated with a certain task, but it may not be suitable for other operating conditions and might become a potential safety issue [10,11].

1.1.4. Behaviour-Based Safety Programs

Various behavioural-based safety programs have been implemented in various construction industries all over the world, and studies have been conducted to assess the impact of the implemented programs. Urlings and Nijhuis [12], in their study, tested workers views about safety by presenting slides with familiar scenarios on construction sites related to working at height incidents and machinery incidents [12]. Construction workers recognised all scenarios as hazardous but gave different accounts to questions asked on responsibility and on matters about who was required to take certain actions. Their findings indicated that lack of concentration was given to safe behaviour when safety had to compete with production [12]. Another study conducted in Hong Kong and the United Kingdom assessed two interventions implemented for safety management [13,14]. The first intervention was the use of safety training, presenting slides of unsafe situations and demonstrating what amounts to desirable behaviour. The second intervention presented graphic representation of audit results feedback, showing the desired and actual safety scores [13,14]. Their results identified clear positive effect in the United Kingdom and a less positive result in Hong Kong, and the effect rapidly disappeared after the intervention stopped. Limited support from management was identified by the authors as the major setback in the interventions [13].

1.1.5. Safety Regulations

In the United States of America, a national study was carried out in 1996 to assess the influence of OSHA safety standards for scaffolding that were introduced in 1991 [15]. These standards set requirements for the strength and dimensions of scaffolding and fall protection [7,15]. Additionally, the policy involved more regular inspections and higher fines for defaulters [7,15]. The study uncovered that the fatality level and lost time resulting from accidents decreased significantly within a period of five years of introducing the standards [15].

1.1.6. Safety Climate

This is the perceived value placed on safety in an organisation, which reflects the employee's conception about safety; it also predicts the way employees behave with respect to safety in the workplace [16]. The safety climate highlights the existing situation and its impact on employees [17]. A study by Dedobbeleer and Beland [18] on workers perception of safety climate discovered that management approach towards safety and the involvement of workers were the main factors impacting the safety climate [4,18].

1.1.7. Prevention through Design (PtD)

Prevention through design was first conceptualised in 1985 by the International Labour Office (ILO). It discovered that in designing construction projects, health and safety hazards could be eliminated or controlled from the design phase [4]. The process takes into consideration how the project will be executed, the maintenance process, waste disposal and recycling, and the decommissioning of such projects [4,19]. The ILO emphasised that the safety of construction workers should be incorporated by architects and engineers when designing projects [20,21], as it is believed that 60% of accidents and fatalities happen due to choices made in the design stage [4].

1.1.8. Near-Miss Accident Reporting

This is the reporting of events that would have caused an accident but did not. The information from the reports is used as lessons to prevent a repeat of such an occurrence. The information is

analysed and the outcome used to improve safety supervision; the feedback is also given to workers to keep them informed of the safety issue [5]. It is believed that for an accident to happen, close to ten near misses must have occurred [5]. A study in Japan explored the quality of accident data of large construction companies, and it was discovered that the investigations could give detailed information on the nature of unsafe acts associated with different tasks, but the measurement of near misses was difficult due to higher levels of occurrences [22].

1.1.9. Summary of Common Safety Improvement Approaches

The various safety management approaches discussed above have been implemented and assessed where construction activities take place, with most of the outcomes reducing lost time injuries and accidents on site. However, most of the approaches considered by the authors did not keep up with emerging theory on accident causation and safety management [23], because they were developed and implemented over twenty years ago [15]. More advanced approaches and methods are required to address the advancement of construction safety, and one such method is high reliability organisational theory.

1.2. High Reliability Organisations (HROs)

High reliability organisations (HROs) have been under investigation by organisational scholars for over twenty years to understand how they function at an exceptionally high level with little or no accidents under challenging circumstances [24]. A high reliability organisation is one that engages in hazardous operations characterised by complexity and uncertainty, yet achieves relatively high levels of safety [25,26]. The concept of HROs was developed by some researchers in the 1980s at the Berkely campus of the University of California [27]; they came up with the concept while investigating why some organisations function in highly hazardous environment and technologies, almost accident and error-free [27]. HROs original studies were based on three industries: nuclear power generation stations, air traffic controls, and aircraft carriers [28]. Wieck et al. took a step further in their HROs research and developed the concept of collective mindfulness, which identified five aspects present in all HROs: (a) preoccupation with failure, (b) reluctance to simplify operations, (c) sensitivity to operations, (d) commitment to resilience, and (e) deference to expertise [29,30].

There is little published research on HRO approaches in the construction industry, so the utility of HRO to improve construction safety is unknown. This article aims to investigate the utility of HRO as a safety management strategy in the construction industry. This will be achieved by investigating:

- How HRO has been defined,
- How HRO has been conceptualised,
- The theoretical framework that HRO has been used in,
- Dimensions and measures used to inform on HRO, and the
- Level of analysis and industrial context of HRO.

2. Methods

2.1. Study Design

This article is a systematic review reported using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [31] as a guideline. The initial results of our findings were presented and discussed through an oral poster presentation at the World Congress on Safety and Health at Work 2017 in Singapore.

2.2. Search Strategy

Six electronic databases (Cochrane library, Scopus, Google scholar, Science direct, EMBASE and PSYCINFO) were searched for peer-reviewed journal articles, from 1990 to 2017. The date 1990 was

chosen as a starting date, because HROs were conceptualised early in the 1980s and most articles were published from 1990. The keywords used were: (high reliability organisational theory or high reliability organisations) and (high reliability theory or reliability theory) and (high risk industries or high risk construction work or high reliability safety management). At the conclusion of the search for keywords, we used EndNote referencing software to screen and record the titles, abstracts, and full text articles based on the inclusion/exclusion decisions.

2.3. Selection Process

Two reviewers, independently from each other, carried out the eligibility screening assessment for inclusion/exclusion of studies in EndNote using the set criteria. Studies were included if they contained:

- Findings focused on HROs theory and application
- HRO theoretical framework
- High-risk industries such as (aerospace, health care, oil and gas, etc.)
- High-risk construction activities
- Level of analysis and industrial context.

Studies were excluded if they:

- Were duplicates
- Had no abstract
- Focused on HRO theory in non-high-risk industries (e.g., finance)
- Were published prior to 1990
- Were non-peer reviewed articles.

The final 15 studies were included after both reviewers had extensively screened and agreed on them based on the inclusion criteria. There were 48 initial, included full text studies, and 33 were excluded, as majority of them focused on HRO theory review and not application of the theory. The final 15 studies focused on review of HRO theory and application. Because of the low evidence of empirical studies on HRO, we had a small number of studies to systematically review. The list of included studies is provided in (Table A1) in the appendix, and the selection process is illustrated in the PRISMA diagram in Figure 1.

2.4. Data Extraction

The data extracted from each article included author, year, country, industry, study design, outcomes, HRO principle of collective mindfulness discussed, and various definitions of HRO. Data was extracted from included studies by one author (A.E).

2.5. Quality Appraisal

The methodological quality of the eligible selected studies was critically appraised by two authors (A.E, M.P) using a set of screening questions adopted from the Critical Appraisal Skills Programme (CASP) [32]. The tool provides a guide for appraising qualitative research to consider if the results of the study are valid, what the results are, the benefits of the results, and the tool has been used in a range of reviews [33]. The questions and appraisal summary are presented in (Table 1) and (Table 2).

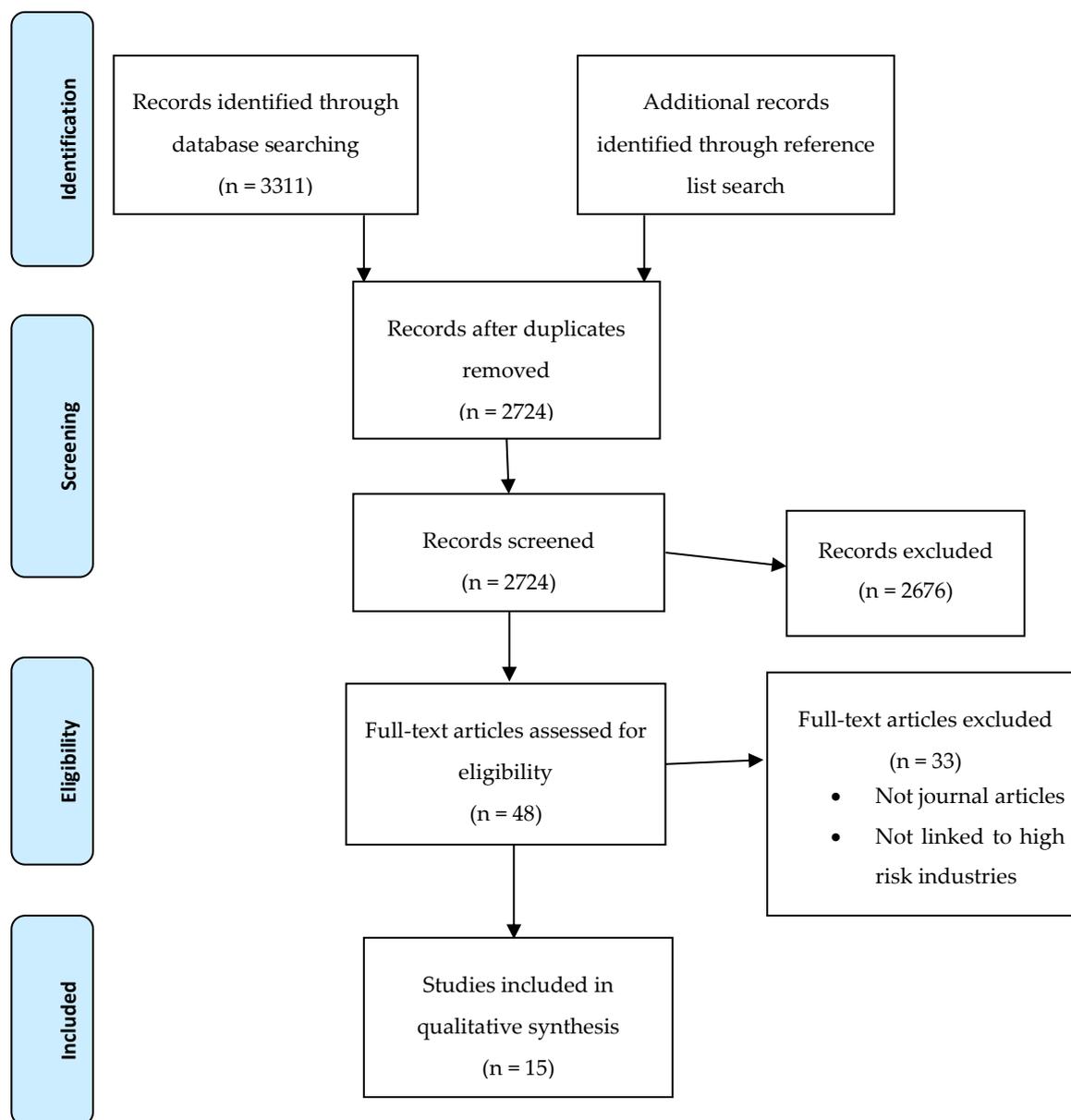


Figure 1. Study selection process [31].

Table 1. Quality appraisal questions.

Screening Questions
1. Aim/s: Was the aim of the research clear?
2. Method: Was the research methodology used appropriate?
3. Design: Did the study design address the aims of the research?
4. Data: Did the data collected address the research aim?
5. Data analysis: Was the data analysis sufficiently rigorous?
6. Bias: Was any bias considered adequately?
7. Findings: Are the findings clearly stated?
8. Gap/s: Have gaps in the literature been clearly identified?
9. Acceptance: Can I accept these findings as true?
10. Value: Can I apply these findings to my own work?

Adapted from [32,33].

2.6. Synthesis of Results

We undertook a narrative synthesis with guidance from Popay et al. [34], because all the included studies were qualitative and used thick description of words and text to summarise and explain findings [34]. This approach of narrative synthesis involved describing, exploring, and interpreting the study outcomes and the methodological adequacy [35]. If possible similarities are to emerge from the findings, they will be presented as themes with explanations.

Figure 1 shows the selection process for the studies. The database search yielded 3311 records. After excluding duplicate studies, the titles and abstracts were screened for 2724 records, and after all inclusion and exclusion criteria were applied 15 studies were included in the qualitative synthesis using the CASP tool (Table 2). Of the 15 studies, seven studies [23,36–41] were identified through hand searching of the reference lists of all studies [23,27,30,36–47].

2.7. Qualitative Synthesis

Six of the studies explored the application and benefits of HRO principles in construction and the barriers [23,38–40,43,45]; four other studies [27,30,42,46] were in general HRO research on origin of HRO, concepts, applicability, and benefits to reliability-seeking organisations. Three studies [36,37,44] were from aerospace, nuclear, and oil and gas industries, and two studies [41,47] were from the health care sector. For this review, our focus is on how HRO theory can improve safety management strategy in construction activities, so our analysis will be centred on studies from construction and general HRO research, while making reference to other industries (aerospace, nuclear and oil and gas). The characteristics and summary of all the studies is shown in (Table 3).

Table 2. Quality appraisal of studies.

S/N	Studies	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
1	The Legacy of the High Reliability Organization Project [42].	Y	Y	Y	Y	L	Y	Y	Y	Y	Y
2	The Relational Aspect to High Reliability Organization [43].	Y	Y	Y	Y	L	Y	Y	Y	Y	Y
3	Revisiting NASA as a High Reliability Organization [36].	Y	Y	Y	Y	L	Y	Y	L	Y	Y
4	Trust Relations in High Reliability Organizations [44].	Y	Y	Y	Y	L	Y	Y	Y	Y	Y
5	Applying HRO and resilience engineering to construction: Barriers and opportunities [45].	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
6	The Problem of Defining High Reliability Organisations [27].	Y	Y	Y	Y	L	L	Y	Y	Y	Y
7	High Reliability Organizations: Unlikely, Demanding and At Risk [46].	Y	Y	Y	Y	Y	L	Y	Y	Y	Y
8	The successes and challenges of implementing high reliability principles: A case study of a UK oil refinery [37].	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
9	High reliability organizing at the boundary of the CM domain [39].	Y	Y	Y	Y	L	Y	Y	Y	Y	Y
10	Safety as an Emergent Property: Investigation into the Work; Practices of High Reliability Framing Crews [38].	Y	Y	Y	Y	L	Y	Y	Y	Y	Y
11	Progressing Zero Harm: a Review of Theory and Applications for Advancing Health and Safety Management in Construction [23].	Y	Y	Y	Y	L	Y	Y	Y	Y	Y
12	The Application of High Reliability Theory to Promote Pain Management [47].	Y	Y	Y	Y	L	L	Y	L	Y	Y
13	Toward High Reliability Project Organizing in Safety-Critical Projects [40].	Y	Y	Y	Y	L	Y	Y	Y	Y	Y
14	Organizing for High Reliability: Processes of Collective Mindfulness [30].	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
15	Assessing your organization's potential to become a high reliability organization [41].	Y	Y	Y	Y	L	Y	Y	N	Y	Y

Y = Yes; N = No and L = Limited.

Table 3. Characteristics and summary of studies.

Study	Industry	Country	Design	Outcomes
Bourrier, 2011 [42]	Research	Switzerland	Literature Review	There is a knowledge gap in the field, and the absence of a framework to transfer HROs principles to other organisations.
Busby et al., 2014 [43]	Construction	UK	Case study	Identified four main types of understanding construction workers have about reliability namely; (1) conformative; (2) performative; (3) adaptive; and (4) informative understanding.
Casler, 2014 [36]	Aerospace	USA	Case study	Dimensions to establish a framework for evaluation of public organizations such as NASA.
Cox et al., 2006 [44]	Nuclear/Oil and Gas	UK	Case study	Downgrading or concealment of accidents, and near misses, as workers feared losing their jobs and apportionment of blame from supervisors and middle managers.
Harvey et al., 2016 [45]	Construction	UK	Critical Review	Identified risk management, organizational principles, and employee-centered principles as the barriers hindering the application of HRO principles in construction.
Hopkins, 2007 [27]	Research	Australia	Critical Review	Identified the absence of a unified definition for HRO.
La Porte, 1996 [46]	Research	USA	Critical Review	Identified attributes of HRO classified into internal and external processes from previous research conducted on HRO.
Lekka et al., 2011 [37]	Oil and Gas	UK	Critical Review	Safety management practices implemented were similar to HROS safety principles.
Olde et al., 2014 [39]	Construction	USA	Critical Review	HRO lens, can be adopted by the construction industry to improve construction activities that are not error free.
Panagiotis et al., 2009 [38]	Construction	Netherlands	Case study	Foremen focused on error prevention as a crucial aspect to enhance production, and also minimize risk of accidents.
Pillay, 2014 [23]	Construction	Australia	Critical Review	The construction is no tightly coupled making it difficult to implement some aspects of HRO theory. Mindfulness capabilities can be used as a means of advancing HRO in construction activities.
Samuels, 2010 [47]	Health care	USA	Case Study	Embracing high -reliability paradigm may help improve pain management outcomes.
Saunders, 2015 [40]	Construction	UK	Critical Review	Construction management personnel require adequate training to improve their state of mindfulness in order to be resilient in managing construction activities.
Weick et al., 2008 [30]	Research	USA	Critical Review	Proposed HRO principles as a conceptual framework for reliability seeking organisations.
Youngberg, 2004 [41]	Health care	USA	Critical Review	Errors can be uncommon and may not be fatal to organisations that are able to achieve high reliability.

3. Results

3.1. Definitions for HRO

The study identified fifteen different definitions for HRO, all defined in different ways but aimed to achieve the same meaning. The definitions are presented in (Table 4).

There is an evidence of some similarities in definitions [37,38,41,46,48–50], in which a common context of hazardous and complex working environment is used to define HRO. Other definitions [42,46,51] suggested HRO to be nearly error and accident-free. These similarities suggest there is a common understanding of HRO, but no unified definition is available for now. In regards to this, Hopkins [27] has argued for a unified definition of HROs, as it will create a better picture and understanding for research and practice. Also, Rochlin and Schulman [50,52] observed that despite most HRO researchers assuming a similar definition, it is still problematic to find a consensus definition for reliability and high reliability organisations.

Table 4. HRO Definitions.

Study	Definitions
Bourrier., 2011; Switzerland [42]	HRO is any organisation that entails some risk to the population, but maintains a failure free operation because failure is not an option [42].
Busby et al., 2014; UK [43]	The capacity to continuously and effectively manage working conditions [48].
Casler., 2014; USA [36]	HROs are organisations that operate potentially hazardous technical systems under very demanding conditions, while maintaining a level of performance and safety far above what might be expected [49].
Cox et al., 2006; UK [44]	HROs are organisations that have not just avoided failure through good fortune or the vagaries of probability, but that have effectively managed to control and reduce the risks of technical operations whose inherent hazards make them prone to catastrophic failure [50].
Hopkins., 2007; Australia [27]	Hazardous systems that produce “nearly accident free performance” [46].
La Porte., 1996; USA [46]	HROs are organisations that exhibit a strong sense of mission and operational goals stressing not only the objectives of providing ready capacity for production and service but an equal commitment to reliability in operations, and a readiness to assure investment in reliability enhancing technology, processes and personnel resources [46].
Lekka et al., 2011; UK [37]	HROs are organisations that are able to sustain excellent safety records over long time periods despite operating in risky and hazardous environment [37].
Panagiotis et al., 2009; USA [38]	HROs are organisations such as aircraft carriers, nuclear power plants, and wildland firefighting crews who function extremely reliably under very uncertain and hazardous environment [38].
Olde et al., 2014; The Netherlands [39]	HROs are organisations that engage in cognitive processes and actions directed at actively avoiding seemingly inevitable organisational holdups and containing errors [39].
Pillay., 2014; Australia [23]	HROs represent a group of those organisations that are likely to operate with a nearly accident free safety records despite operating in hazardous and complex environments as part of their normal work [46].
Samuels., 2010; USA [47]	HROs incorporate an organisational commitment to safety with numerous system checks and balances and strong organisational cultures of learning [51].
Saunders., 2015; UK [40]	HROs claim to be special organisations that have consistently demonstrated safe performance in operating environments, which are simultaneously of high technical complexity, high consequence and high tempo [40].
Weick et al., 2008; USA [30]	HROs are organisations that operate in an unforgiving social and political environment, an environment rich with the potential for error, where the scale of consequence precludes learning through experimentation, and where to avoid failures in the face of shifting sources of vulnerability, complex processes are used to manage complex technology [50].
Youngberg., 2004; USA [41]	HROs are organisations that can handle complex and hazardous activities at acceptable levels of performance with the proper management of people, technology and processes [41].

Safety performance has not been clearly explained in the type of environment associated with HRO, but have been expressed as low incidence of catastrophic events [50], excellent safety records [37], rarely fail [42], and nearly accident-free performance [46].

Sutcliffe [28] suggest HROs have common attributes: their day-to-day operations are conducted in environments full of hazards and uncertainty, where the potential to fail is very high but they rarely fail. They do not have the luxury of learning from accidents so they are always preoccupied with failure, and to avoid failures they use complex processes to manage complex technologies [28,53].

Tod La Porte, one of the early authors of HRO, defined HROs as those organisations that are likely to operate with nearly accident-free safety records, despite operating in hazardous and complex environments as part of their normal work [46]. Rochlin defined HROs as organisations that operate potentially hazardous technical systems under very demanding conditions, while maintaining a level of performance and safety far above what might be expected [49].

Researchers in the construction industry have defined HROs in different ways in their approach to advance the understanding of HROs from the construction perspective. Panagiotis et al. [38], in their investigation on work practices of high reliability framing crew, defined high reliability crews as those construction crews that consistently achieve high levels of both production and safety performance that are better than other crews carrying out the same task [38]. Olde et al. [39] defined HRO as organisations that engage in cognitive processes and actions directed at actively avoiding seemingly inevitable organisational holdups and containing errors. Their definitions are centred on error containment and reliable performance. These concepts can be applied in organisations such as construction to manage occupational health and safety [39]. However, to understand the uniqueness of HROs, there is the need to look closely at ways in which diverse but stable cognitive processes interrelate in detecting and managing errors [30].

3.2. *Collective Mindfulness in HROs*

Different characteristics have been associated with HROs, but Weick and Sutcliffe [30] have distilled those key aspects that assist in achieving and maintaining high levels of safety into a set of five principles of “Collective Mindfulness” [23,30]. The state of mindfulness is created by at least five processes induced by Weick and Sutcliffe from accounts of effective practice in HROs, and from accident investigations [30]. Mindfulness involves inquiry and interpretation grounded in capabilities for action [30]. These principles of collective mindfulness are explained in detailed in the next section.

3.2.1. Preoccupation with Failure

This is the process of operating proactively with much concern about unforeseen circumstances that can affect safety performance [28]. Worries about failures are the attributes that give HROs their distinctive qualities [30]; they hunt for lapses and errors, identifying the fact that they can lead to larger failures, and they believe if warnings are identified and acted on, disaster can be prevented [27]. Harvey et al., in their study, used preoccupation with failure as a framework for accident anticipation in construction activities [45]. Panagiotis et al., in their study of high reliability framing crews, sought to understand which work practices reduced the likelihood of accident and support their productivity. They identified material checking, identification of risk areas, prevention of high risk tasks, and monitoring attention to prevent distractions, as the crews’ driving factors for avoiding errors, reworking and achieving crew stability and reliability [38].

3.2.2. Reluctance to Simplify Operations

This involves gathering information that can be used to monitor activities, identify warning signals, and analyse incidents and near misses in order to enhance safety performance [54]. Cox et al. [44], in their study of HROs, discovered that accidents, near misses, and incident reporting were mostly downgraded or concealed, because workers feared to lose their jobs and other entitlements as a result of the apportionment of blame from supervisors and middle managers [44].

3.2.3. Sensitivity to Operations

This is the ability to obtain and maintain the 'bigger picture' of operations that enables the effective anticipation of potential future failures. In line with this, HROs constantly seek the opinion of front line staff in order to get a realistic picture of operation status within the organisation [54]. Accidents in HROs are very rare, because they operate in environments that discourage learning by experimentation because of the dangers they face [45]; therefore, much has not been said about how they learn from accidents. Instead, mindfulness encourages a focus on the present, because although past experience can be valuable, memory can draw attention away from current events and provoke generalised interpretations based on hindsight [45]. This reactive approach to learning from accidents (or precursors of accidents), in which feedback is immediately acted upon [55], could be beneficial in an industry like construction, in which factors needed for long-term learning, leadership, processes, infrastructure, communication, education, and community are hindered by the dynamic and fragmented nature of temporary multiple organisations [55].

3.2.4. Commitment to Resilience

This is the ability to successfully recover from failures, which is achieved by a real commitment to learning from past incidents both from within and outside of the organisation [54]. The capability to cope with, contain, and bounce back from mishap that has already occurred before it escalates and cause more harm [27].

3.2.5. Deference to Expertise

Deference to expertise is the process of shifting decision making in the event of an emergency to the most experienced person or team, to manage the situation irrespective of organisational rank [54]. Panagiotis and Cupido [38] in their study observed that the high reliability crew foremen applied the principle of matching skills with task demands more consistently compared to the average crew foremen. They observed that more experienced crew members were assigned to more demanding tasks, and only the lead man was allowed to perform the most hazardous tasks, while inexperienced crew members were not allowed to use power tools [38]. Deference to expertise in HROs requires more experienced personnel to make decisions in emergencies [54], while with the framing crew, deference to expertise was implemented at the start of the job to avoid errors and rework [38]. These attributes give HROs their distinctive state of collective mindfulness, which they apply in detecting problems, containing them and quickly recovering from errors [54,56]. These exotic characteristics of HROs can be utilised to safely manage construction activities.

3.3. HRO Studies in Construction

The construction industry is known for high risk activities such as working at height which is a major cause of construction fatalities, but not much has been done in terms of research for prevention of such fatalities using the lens of HROs principles of collective mindfulness.

Harvey et al. [45], in their study through the lens of HROs, investigated the applicability of HRO principles, and the barriers and opportunity for construction industry. Odle et al. [39] explored the opportunities and challenges of HRO principles benefiting construction management (CM). Saunders [40] examined the possibility of previous literature on HROs, providing valuable lessons to improve the management of safety critical projects, in which safety performance is of high importance, and hazard needs to be controlled in order not to harm personnel, the public, and environment [40]. HRO research in construction industry is still emerging although at a slow space, and very few empirical studies are available, and that is reflected in the numbers of our final included studies in this review. While there are arguments that HRO principles may have no place in improving constructions safety management [39], some of HROs principles can be integrated into construction

safety management system. The barriers and opportunities for such integration were identified and are presented in the next section.

3.3.1. Barriers in Applying HRO Principles in Construction

The principles of HRO have been applied in the healthcare sector in medication safety using “checklist” and “sterile cockpit” to mitigate medication error [57]. Checklist and sterile cockpit are safety management tools and procedures in the aviation sector, which is a HROs [57]. The same cannot be said for construction because of following barriers:

Risk management

- There is the belief that HRO is only applicable to safety critical industries, and high reliability is only attainable by organisations where safety is the primary focus [39,45].
- The prominent culture of blame in construction [45].

Organizational principles.

- Construction is loosely regulated, with multiple subcontractors making lines of authority and accountability unclear [45].
- Less reporting of accident and those that report are blacklisted [45].
- Transfer of experience is limited between temporary projects [45].
- Construction was not seen as a high-risk industry [45].

Employee-centred principles

- Contract based employment limits opportunities to invest in people.
- Risk is seen as an inherent part of construction work.

3.3.2. Opportunities of Applying HROs Principles in Construction

The following were identified as possible opportunities for applying HROs principles in construction:

- Focusing on the present when responding to the unexpected to reduce the requirement for long-term plans and learning from experience
- Enhance workers understanding of the big picture to build relationships between subcontractors and prevent silo working
- Avoid simplification of events to maintain a vigilant attitude.

4. Discussion

This paper systematically reviewed previous literature on the applicability of HROs theory in construction as a safety management strategy. We aimed to investigate how HROs have been defined, how they have been conceptualised, and what theoretical framework and measures were used to inform on HRO. We found that there are various definitions of HRO by different authors, but there is no consensus definition, although they all have things in common. The lack of a unified definition makes it difficult to some extent to understand HROs and their principles.

The construction industry operates in conditions that are similar to that of HROs, but the difference is that construction activities are rarely error-free. HROs have stringent procedures that they use to manage safety, because they function in a tightly coupled system, tightly coupled meaning that all their procedures and activities function simultaneously, and any error from one section will affect total system performance [30]. However, in the event of an uncertainty, there is a collapse in hierarchy and the most experienced personnel resolves the situation [58]. The construction industry, on the other hand, is loosely coupled, and activities mostly do not depend on each other for overall safety performance. Accidents and near misses are managed using safety management procedures such

as permit-to-work, job safety analysis (JSA), safe work method statements (SWMS), incident and near miss reporting, and risk assessment. This system of safety management in construction can be linked to HROs principles of preoccupation with failure, reluctance to simplify, and sensitivity to operations [30].

Despite the fact that HROs operate mostly error-free in their daily activities, they can also make mistakes but recover quickly from such mistakes and carry on with their operations [39]. Therefore other organisations like construction industry that operate in environments that are not error-free can learn from HROs [39].

Panagiotis et al. [38] in their investigation on the practices of high reliability framing crews, found that the production practices of high reliability crew showed a clear guiding principle and a set of specific strategies that focused on preventing errors and rework [23,38], compared to the average crew. This discovery indicates that some of the principles of HROs are practiced in some construction activities, but they need to be empirically investigated in order to validate them. They also found out that the strategies used to prevent production errors minimised the likelihood of accidents, restricting work interruptions and control of production pressures; using skilled personnel for specific task played a vital role in managing safety and productivity [38]. Saunders [40], in her study on safety critical projects, observed that there are similarities between safety critical projects and HROs, and lessons can be learnt to improve the management of safety critical projects [40]. Management plays a key role in safety management; therefore, for project management practitioners to succeed, they need to be trained to maintain an attitude of mindfulness and conscious deliberation, and be flexible while maintaining focus on project goals [40]. She proposed an assessment tool to test "Hypotheses about observable practices in high reliability project organising", which needs validation on a set of case study projects in safety critical industries [40].

The low number of studies of HROs research from construction indicates that much has not been done in investigating the applicability of HROs principles as an opportunity to improve safety management strategies. HROs research in general has a wide gap between the levels of knowledge published and argued in academic circle [42]. There is also the problem of transferring knowledge and lesson learnt from HROs into other sectors such as construction, and other organisations that are not error-free [42].

In this review we discovered that construction industry functions in environments that can be compared to HROs. However, because of the complex organisational setup in construction due to multiple contractors, changing work environments, cost cutting, and project deadlines [45], some of the HROs principles can be implemented, and others may be difficult to fully implement. Preoccupation with failure, reluctance to simplify, and sensitivity to operations have attributes that can be linked to risk assessment, incident and near miss reporting, permit-to-work, job safety analysis (JSA), and safe work method statements (SWMS) [59], which are construction safety management tools and procedures. Commitment to resilience and deference to expertise is linked to management responsibility, as it deals with maintaining the overall safety performance of an organisation, ability to recover from unexpected events, and training of personnel to be competent in all aspects of their jobs. HROs principles can be grouped into two categories: operation management (preoccupation with failure, reluctance to simplify and sensitivity to operations) and management resilience (commitment to resilience and deference to expertise). These categories can be used to empirically investigate how these principles can be integrated and implemented as safety management strategies in construction.

5. Implication for Practice and Research

The main aim of this study was to systematically review available research evidence on HROs theory as a safety management strategy, which can be used to improve construction safety. This we have done by reviewing 15 studies identified in our literature search.

The first practical contribution of our present research is to identify the knowledge gap due to the scanty literature in the field, and it also impacted on the number of studies in our review.

The gaps are in relation to how HROs principles can be transferred into other organisations, the lack of understanding about HROs due to the absence of a unified definition, and how reliability-seeking organisations can access the potentials of becoming HROs.

Secondly, we discovered that HROs and construction industry have similarities in their mode of operations, but HROs have unique safety management principles that enable them to function nearly error and accident-free. We have identified some of those principles that can be implemented in construction safety management, and we have grouped them into two categories: operation management and management resilience.

Finally, there is an absence of empirical quantitative studies, theoretical framework, or guidelines demonstrating how HROs principles can be distilled to improve construction safety management. There are indicators and assessment tools to investigate the characteristics of HROs present in high reliability project organising and to assess an organisation's potential to become HROs [40,41]. While there are opportunities to implement some of the principles, the primary research question for this study is: How can high reliability organisational theory as a safety management strategy hinder or enhance construction safety? A first step to answer this will be to test and validate the available indicators and assessment tools [40,41].

6. Limitations

The included studies were restricted to just journal articles only, peer reviewed conference papers were excluded, and articles were only searched from selected databases. Some studies from HRO were excluded as our main focus was on construction. Other studies were included through reference list search. Another limitation was the lack of substantial empirical studies on HROs linked to construction industry, and this affected our final studies.

7. Conclusions

This is one of the first systematic reviews of evidence on high reliability organisational theory as a safety management strategy in construction. The paper systematically reviewed a broad spectrum of HROs literature from 1990–2017, on construction. This systematic review provided a narrative synthesis of evidence of high reliability organisational theory from the construction perspective. The PRISMA [31] statement was used as a guideline for this review, because of its detailed checklist for reporting a systematic review, and it has been used in a range of systematic reviews. All the studies in this review were qualitative studies; quantitative studies were not identified.

Future research should focus on validating the proposed indicators to quantitatively investigate HRO and explore the understanding of HROs in order to advance research and practices in the construction industry.

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Abbreviations

HROs	High Reliability Organisations
ILO	International Labour Organisation
JSA	Job safety analysis
PRISMA	Preferred Reporting Items for Systematic Review and Meta-Analysis
OSHA	Occupational Safety and Health Administration
SWMS	Safe work method statement

Appendix A

Table A1. List of included studies.

S/N	Authors	Study	Industry
1	Bourrier, (2011) [42]	The Legacy of the High Reliability Organization Project	Research
2	Busby et al., (2014) [43]	The Relational Aspect to High Reliability Organization	Construction
3	Casler, (2014) [36]	Revisiting NASA as a High Reliability Organization	Aerospace
4	Cox et al., (2006) [44]	Trust Relations in High Reliability Organizations	Nuclear/Oil and Gas
5	Harvey et al., (2016) [45]	Applying HRO and resilience engineering to construction: Barriers	Construction
6	Hopkins, (2007) [27]	And opportunities	Research
7	La Porte, (1996) [46]	The Problem of Defining High Reliability Organizations	Research
8	Lekka et al., (2011) [37]	High Reliability Organizations: Unlikely, Demanding and At Risk	Oil and Gas
9	Olde et al., (2014) [39]	The successes and challenges of implementing high reliability principles: A case study of a UK oil refinery	Construction
10	Panagiotis et al., (2009) [40]	High reliability organizing at the boundary of the CM domain	Construction
11	Pillay, (2014) [23]	Safety as an Emergent Property: Investigation into the Work	Construction
12	Samuels, (2010) [47]	Practices of High Reliability Framing Crews	Health care
13	Saunders, (2015) [40]	Progressing Zero Harm: a Review of Theory and Applications for Advancing Health and Safety Management in Construction	Construction
14	Weick et al., (2008) [30]	The Application of High Reliability Theory to Promote Pain Management	Research
15	Youngberg, (2004) [41]	Toward High Reliability Project Organizing in Safety-Critical Projects	Health care

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