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An analysis of the expected net benefit of adopting Proactive Behavior Based Safety in the construction industry

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An analysis of the expected net benefit of adopting Proactive Behavior Based Safety in the construction industry

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Abstract

All over the world, construction is a major employer and contributor to economic development. Especially Hong Kong's construction industry has experienced a rapid growth which contributed to a vast transportation network and urban infrastructure. (CLB, 2019) The high frequency of occupational injuries and fatalities in Hong Kong but also all around the globe highlight that workers in the construction industry are exposed to many hazards. (Choudhry R. M., 2014) In this thesis, the construction industries of Hong Kong and Romania are analyzed in more detail. It shall be used to reveal the hazards, risks, and challenges of occupational health and safety management in construction. Accidents occur due to unsafe conditions and mainly unsafe acts. (Abdelhamid & Everett, 2000) For the thesis, unsafe acts are of more research interest as their reduction will lead to fewer near misses and accidents. In the risk management part, the two concepts of Behavior Based Safety (BBS) and Proactive Behavior Based Safety (PBBS) will be introduced. International studies suggest improvement of health and safety in construction through BBS. However, due to construction sites' dynamic, complexity, mobility, and altering nature, the long-term benefits of BBS may be difficult to achieve. (Skowron & Sobocinski, 2018) PBBS is a more recent concept and assists workers in detecting hazards and dangerous areas through proactive warning signals. PBBS represents a promising approach especially for large enterprises in Hong Kong's construction industry to reduce risks and fatal consequences caused by working at heights and moving objects. (Li, Lu, Shu-Chien, Gray, & Huang, 2015) It is probably less suitable for small and medium-sized Romanian companies due to its costs.

Abstrakt (Danish)

Overalt i verden er byggeri en vigtig arbejdsgiver og bidrager til økonomisk udvikling. Især Hongkongs byggebranche har oplevet en hurtig vækst, som bidrog til et stort transportnetværk og byinfrastruktur. (CLB, 2019) Den høje hyppighed af arbejdsskader og dødsfald i Hongkong, men også over hele kloden, fremhæver, at arbejdere i byggebranchen udsættes for mange farer. (Choudhry R. M., 2014)) I denne afhandling analyseres byggeindustrien i Hong Kong og Rumænien mere detaljeret. Det skal bruges til at afsløre farerne, risiciene og udfordringerne ved arbejdsmiljøledelse inden for byggeri. Ulykker opstår på grund af usikre forhold og hovedsageligt usikre handlinger. (Abdelhamid & Everett, 2000) For afhandlingen er usikre handlinger af mere forskningsinteresse, da deres reduktion vil føre til færre næsten uheld og ulykker. I risikostyringsdelen introduceres de to begreber Behavior Based Safety (BBS) og Proactive Behavior Based Safety (PBBS). Internationale undersøgelser antyder forbedring af sundhed og sikkerhed i byggeri gennem BBS. På grund af byggepladsers dynamiske, kompleksitet, mobilitet og ændrede karakter kan de langsigtede fordele ved BBS imidlertid være vanskelige at opnå. (Skowron & Sobocinski, 2018) PBBS er et nyere koncept og hjælper arbejdstagere med at opdage farer og farlige områder gennem proaktive advarselssignaler. PBBS repræsenterer en lovende tilgang især for store virksomheder i Hongkongs byggebranche for at reducere risici og fatale konsekvenser forårsaget af arbejde i højder og bevægelige genstande. (Li, Lu, Shu-Chien, Gray, & Huang, 2015) Det er sandsynligvis mindre velegnet til små og mellemstore rumænske virksomheder på grund af dets omkostninger.

Acknowledgments

Many people have helped us in writing this thesis. Both authors would like to thank the supervisors of this project, Brooks Kaiser and José Guadalupe Rangel Ramirez. They contributed a lot to the work and the authors are grateful for their comments, feedback, and recommendations throughout the process.

We also want to thank our loved families and friends who have been supporting us along the way.

I want to dedicate this thesis to Lasey Thatcher because she gave me the inspiration and motivation to enroll in this Master's program. Her kind words helped me to pursue graduation. The offered course content of Aalborg University Esbjerg and Southern Denmark University has been rich and especially working with simulations was great. For me, being a student at AAU Esbjerg has been a challenging but joyful experience. Finally, I can say that I found a passion for Risk and Safety Management. (Friedrich)

Preface

This paper is written as a master's thesis of 30 ECTS points during the 4th semester of the master's program Risk and Safety Management at Aalborg University Esbjerg. The thesis was written during the period of 1st September 2020 until 8th January 2021. This thesis aims to fulfill the academic requirements to obtain a Master of Technology in Risk and Safety Management.

A lot of time, effort, and large sums of money are spent on improving safety. They frequently focus on issues in the management system or attempt to fix problems through technical solutions. There are some risks, however, which are very tough to manage because they appear resilient to efforts trying to eliminate them. Workers' unsafe acts or unsafe behaviors are some of the most crucial challenges that might hinder the effectiveness of safety programs. (Abdelhamid & Everett, 2000) (Choudry & Fang, 2008) This thesis offers a comprehensive study about accidents, construction hazards, such as risks, and suggests two behavior based concepts to improve occupational health and safety in the construction industry.

Friedrich Charles Eduard Lüdtke

Mads Høgh Henriksen

Readers´ guide

The academic structure of the thesis is illustrated in figure 1. The structure is influenced by the ISO:31000 - Risk Management framework. (ISO, 2018a)

For the reader, it is recommended to read *Appendix 1 - Glossary* chapter before reading the report itself. The glossary list includes relevant terms used in the thesis and will thereby set a baseline for how the authors understand and use them in the thesis. Appendixes include more information that should be included from a qualitative point of view.

Figure 1 – Academic structure of the thesis
Source: Authors

The following guidelines will apply:

1) All citations are stated in *cursive* and marked with citation (“…”) marks.
2) Acronyms are stated after the first time the word is used, e.g. Behavior Based Safety, hereafter only the acronym (here: BBS) will be used.
3) Figures are numbered, briefly explained, and refer to their source of origin.
4) All sources are referenced with the American Psychological Association citation style (APA), which usually includes a link to the source, date, name, author, etc.

Acronyms

ALRAP	As Low as Reasonably Practical
AR	Accident Rate
BBS	Behavior Based Safety
CLB	China Labour Bulletin
COP	Code of Practice
CVPL	Construction Virtual Prototyping Laboratory
ESAW	European Statistics on Accidents at Work
EU	European Union
FMECA	Failure mode, effects, and criticality analysis
FFH	Falls from heights
FR	Fatality Rate
GPD	Gross Domestic Product
HAVS	Hand-Arm Vibration Syndrome
HKSAR	Hong Kong Special Administrative Region
HSE	Health and Safety Executive
IEEE	Institute of Electrical and Electronics Engineers
IR	Incidence Rate
ISO	International Organization for Standardization
NGO	Non-Governmental Organization
OSHA	Occupational Safety and Health Administration
PBBS	Proactive Behavior Based Safety
PCMS	Proactive Construction Management System
PFAS	Personal Fall Arrest Systems
PPE	Personal Protective Equipment
PTW	Permit-to-Work
RTLS	Real-Time Location System
SAR	Special Administrative Region
SI	Safety Index
SDA	Social Dialogue Act
SSoW	Safe Systems of Work
TOA	Time of Arrival
VCS	Virtual Construction Simulation System
WHSC	Workplace Health and Safety Committee
WPAN	Wireless Personal Area Network

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1. Introduction

Thanks to the hard work of millions of construction workers all over the world, it is possible to accommodate the increasingly growing and aging population in sometimes ever taller and larger buildings. It has been estimated that daily about 13.000 new buildings between now and 2050 need to be built for an expected population of seven billion people living in cities and about ten billion worldwide in 2050. (Bertollini, 2019) Moreover, an increasing number of aging buildings must be maintained and modernized. In 2018, 11,4 trillion US$ were spent worldwide on construction. (Statista, 2020) In 2030, this number is expected to rise to 17,5 trillion US$ for global construction expenses. (Valente, 2019) In a report published by the consulting firm McKinsey, it was calculated that the construction sector grows only 1% annually. Compared to the world average of 2,8%, construction lacks 1,8%-points towards the average growth for all sectors worldwide, which indicates that there are possibilities in the construction sector for further economic gain. (McKinsey&Company, 2017)

What is *construction*? Construction includes commercial projects in building and civil engineering. Building applies to houses, factories, offices, shops, schools, hospitals, power plants, railway stations, etc. Civil engineering involves all other built structures in the environment, for example, roads, tunnels, bridges, railways, dams, canals, and docks. (Kulkarni, 2007) Construction works are temporary, one-off endeavors with unique features such as long period, complicated processes, abominable environment, advanced technologies, financial intensity, dynamic and transitory organization structures. (Zou, Zhang, & Wang, 2007) The construction industry produces real estate, investments, or capital goods. For the local community, town, region, state, or country, the construction industry presents a necessary and strategic sector for employment, development, sustainability, and growth of the economy. (Kulkarni, 2007) (Shafique & Rafiq, 2019) (Shao, Hu, Chen, Liu, & He, 2019) Construction works and projects, or simply construction, are very labor intensive but employment is permanently temporary. In many countries, the construction industry pays higher wages than, for example, manufacturing, which attracts a lot of skilled and unskilled migrants and foreigners. (Kulkarni, 2007) (Choudry & Fang, 2008)

Despite many advantages, the construction industry poses major hazards and negative consequences for the environment and for those who work in construction. There is no such industry with a high frequency of injuries, accidents, permanent disabilities, occupational illnesses, and fatalities than in construction. (Shao, Hu, Chen, Liu, & He, 2019) (Zhang & Fang, 2012) The International Labor Organization (ILO), an agency of the United Nations, provides the following information:

- *"at least 60.000 fatal accidents occur each year at construction sites all over the world. This is the equivalent of one death every ten minutes*

- *one out of every six fatal workplace accidents takes place at a construction site*
- *in industrialized countries, 25-40% of all fatal workplace accidents occur at construction sites*
- *in certain countries 30% of construction workers suffer back-aches, pains, and muscular-skeletal problems; and*
- *according to the fourth European survey of work conditions, 35% of all construction workers affirm that their work entails a health risk".* (Aires, Gámez, & Gibb, 2009) (ILO, 2020b)

Table 1 gives an overview of the situations in several countries, as reported by their respective statistic agencies for 2017. The term *construction workers* include all workers in the construction industry, except in the case of Hong Kong where *construction workers* include manual site workers only. (Labour Department, 2018)

Country or region	**Year**	**Number of fatal accidents in construction**	**Fatality rate [a]**	**Proportions of fatal construction accidents in all fatal industrial accidents (%)**	**Ranking of fatal construction accidents in all fatal industrial accidents (by number)**	**Ranking of fatal construction accidents in all fatal industrial accidents (by fatality rate)**
Hong Kong [b]	2017	22	18,5	9,69	First	First
U.S. [c]	2017	965	12,2	18,75	Second	Fifth
Japan [d]	2017	323	N/A	33,0	First	N/A
Australia [e]	2017	30	2,7	15,79	Third	Fourth
EU (28) [f]	2017	733	6,25	20,6	First	N/A

[a] Fatality rate: number of fatal accidents/100.000 construction workers;

Table 1 – Fatal accidents in the construction industry by country or region in 2017
Sources: [b] (Labour Department, 2018), [c] (BLS, 2019), [d] (ILO, 2020c) (JISHA, 2019), [e] (Safe Work Australia, 2018), [f] (Eurostat, 2020d)

In the United States in 2017, construction had the second largest number of fatal accidents, although its fatality rate ranked fifth behind the industries of *Agriculture, forestry, fishing and hunting*; *Transportation and warehousing*; and *Mining, quarrying*, and *Oil and gas extraction*. (BLS, 2019) In Japan, construction had the largest amount of all industrial fatalities in 2017. (ILO, 2020c) Also in Australia, construction was ranked as one of the top three industries with most people dying at work. (Safe Work Australia, 2018) Within the European Union (EU28), every fifth of all fatal accidents at work took place within the construction sector, also with construction being the industry with most incidents overall. (Eurostat, 2020d) Due to its highest fatality rate among all other listed economies, the Chinas Special Administrative Region (SAR) Hong Kong appears to be the worst performer. (Labour Department, 2018)

1.1 Establishing the context

The purpose of risk and safety management in construction, generally, is to plan, monitor, and control those measures needed to prevent risk exposure. Nobody wants to get hurt at work, but the management of occupational health and safety is challenging because there are vast hazards and risks inherited in construction. (Jeong, 1998) (Shafique & Rafiq, 2019)

Each country is required to develop its own legislation because there are truly no global laws governing health and safety in construction. However, most countries agree on the same basic approach: the risk of health and safety rests with the employer. Employers must protect their employees from any kind of work-related harm because they provide the workplace, machinery, equipment, and processes. The employer is responsible to control chemical, physical, and biological substances and agents, provide safe procedures, Personal Protective Equipment (PPE), and safe equipment, such as overseeing and monitoring the work. The employer must ensure that the risk of accidents or adverse effects on health is prevented. They should "*where the nature of the operations in their undertakings warrants it, be required to set out in writing their policy and arrangements in the field of occupational safety and health, and the various responsibilities exercised under these arrangements, and to bring this information to the notice of every worker, in a language or medium the worker readily understands*." (ILO, 2004) (RRC International, 2019)

Employees are responsible for their own health and safety. They must think and act in a meaningful and safety positive manner to prevent accidents, harm, injuries, such as death for themselves and others. This includes, for example, to wear adequate Personal Protective Equipment (PPE) at all times while being on the job to avoid, minimize, or reduce exposure to workplace hazards. Employees must follow the rules and procedures required by the employer or other governing party to prevent injuries and accidents. (ILO, 2004) (RRC International, 2019)

If a worker is involved in an occupational accident, there will monetary losses for the employer. Direct costs, which are measurable costs arising directly from the accident, can include compensation pays to the injured workers, repair of equipment and property, medical costs, legal costs, etc. Some of the direct costs can be estimated and insured, whereas criminal fines, production delays, and downtime, loss of raw material, overtime to make up production, recruiting new employees, or loss of business reputation cannot be insured and are harder to predict and determine. Moreover, employers are required to conduct investigation processes to identify immediately (obvious) causes to prevent the same accident or a similar type of accident from occurring in a similar location. They should also identify the underlying (root) causes to plan and implement remedial actions. In some countries and regions around the world, certain specified accidents must also be reported to the relevant authority by statute law. (RRC International, 2019)

The Accident Cost Iceberg proposed by Bird in 1974 states that the extent of hidden costs can be much higher than the costs directly related to the accident itself. This is mostly because uninsured costs are much more than the insured costs. Most hidden costs are "*penalties, fines imposed on the organization, the amount of productive time spent by the safety officer and safety and health committees doing investigation and interviewing witness, the time lost on productivity and outputs, loss of sales and potential customers, damages to the machines or equipment, cost of idle time, repair and set up costs, loss of man hours, cost incurred to hire replacement workers, documentation cost, etc.*" (Lop, Mamter, Kamar, & Norazlin, 2014)

1.1.1 Definitions of accident, near-miss, and undesired circumstances

The Health and Safety Executive UK, Great Britain's government agency responsible for the encouragement, regulation, and monitoring occupational health and safety, differentiates adverse events at the workplace in accidents and incidents. (HSE UK, 2020a)

An accident is, generally, an unplanned, unwanted event that results in injury, damage, or loss. The consequences of an accident can result in work-related death (fatality); major injury/ill health ("*fractures, amputations, loss of sight, a burn or penetrating, injury to the eye, any injury or acute illness resulting in unconsciousness, requiring resuscitation or requiring admittance to hospital for more than 24 hours*"); serious injury/ill health ("*where the person affected is unfit to carry out his or her normal work for more than three consecutive days"*); minor injury ("*all other injuries, where the injured person is unfit for his or her normal work for less than three days*"); such as damage only ("*damage to property, equipment, the environment or production losses*"). (HSE UK, 2014b)

Incidents refer to near misses and undesired conditions. (HSE UK, 2014a) Near misses are unplanned, unwanted events that did not cause harm but had the potential to do so. For example, a worker uses a defective machine and nearly cuts into his finger. Although the worker did not suffer from an actual injury, management must prevent this near miss because the same practice might result in a more severe incident the next time. Workers should always be encouraged and supported by supervisors and management to report near misses by standard practice, whereas management should keep a good record of such to take reasonable actions and arrangements for their prevention. (RRC International, 2019)

"*Undesired circumstances are a set of conditions or circumstances that have the potential to cause injury or ill health*." They result in near misses and accidents. Therefore, the worksite should be inspected for undesired circumstances frequently to avoid near misses and accidents. An example would be an untrained worker carrying out high-risk work (e.g. operating a crane). (HSE UK, 2014a)

Figure 2 presents the terms of an accident, near miss, and undesired circumstance in a graphic way.

Accident **Near miss** **Undesired circumstance**

Figure 2 - Accident, Near miss, and Undesired circumstance
Source: (HSE UK, 2014b)

1.1.2 Theory of accidents

Research in accident causation theory was pioneered by Herbert William Heinrich (1886 –1962), who discussed the interaction between man and machine, the relationship between severity and frequency, the reasons for unsafe acts, the management role in accident prevention, the costs associated with accidents, and most importantly the effect of safety on efficiency in his book *Industrial Accident Prevention, A Scientific Approach* in 1931. One of the most famous theories developed by Heinrich was the domino theory model of causation. In this domino theory, an accident is described as one of five factors in a sequence that lead to an injury. The name domino theory was genuinely suitable because the conduct of the factors was like the collapsing of dominoes when disrupted: when one falls, the others will collapse too. Heinrich used the following five dominos in his model: ancestry and social environment, fault of the person, unsafe act and/or mechanical or physical hazard, accidents, and injury. (Marsden, 2017) (Abdelhamid & Everett, 2000) The model proposed that through inherited or acquired undesirable attributes, individuals may submit unsafe acts or cause the presence of unsafe conditions that can be mechanical or physical hazards that might lead to harmful accidents. In this theory, people are the fundamental problem behind most accidents; and management – having the ability - is responsible for the prevention of accidents. While some of Heinrich's understandings and theories were later criticized for oversimplifying the control of human behavior in causing accidents, his work was the foundation for many others. (Abdelhamid & Everett, 2000)

The accident triangle also acknowledged as Heinrich's triangle or Bird's triangle is also a theory of occupational accident prevention. The accident triangle shows a relationship between serious accidents, minor accidents, and near misses. The model suggests that if the number of minor accidents is reduced, then there will be an equivalent decrease in the number of serious accidents. (Marsden, 2020) Unsafe behaviors or unsafe acts can be defined as any activity done by employees that is not as per se as the prescribed safety standard or practice. Unsafe behaviors will not automatically result to cause accidents but increase the risk. For example, a construction worker could decide to take off his safety-harness while performing work-at-heights (five meters above the ground) because it might be uncomfortable, and he enjoys being considered a "tough man" by others. This behavior is against the rules and the safe system of work (SSoW) as stated by the employer and industry legislation, strictly prohibited, and simply unwise. Suddenly, the construction worker loses grip and hold, and falls from height to the ground made of concrete. When we reached the ground, there are severe internal injuries and the final consequence is death. By doing so, the construction workers' unsafe behavior (not wearing a safety harness while working at heights) causes severe consequences for himself, but perhaps to others, damage to equipment as well, and convey losses to the employer.

The relationship was first developed by Heinrich in 1931 as he studied more than 75.000 accident reports from an insurance company's file as well as records held by individual industry sites. From this data, he proposed a relationship of one major injury accident to 29 minor injury accidents, to 300 no-injury accidents. He concluded that, by reducing the number of minor accidents, industrial companies would see a correlating fall in the number of major accidents. Heinrich´s work theory was refined by Frank E. Bird in 1966 based on roughly 1,7 million accident files from almost 300 companies. According to Bird, one serious injury accident relates to 10 minor injuries (first aid only) accidents, 30 damage-causing accidents, to 600 near misses with no injury or damage. (Marsden, 2020) In 2003, a study conducted by Conoco Phillips Marine developed the accident triangle one step further. It was found that for every fatality, there are about 300.000 unsafe acts. These studies are often combined to form what is the so-called accident triangle or safety pyramid. (Canfora & Ottmann, 2018)

Although the explicit figures are arguable, and perhaps industry-dependent, the main conclusion is distinct: when the number of unsafe acts is large enough, it will eventually result in a fatality or major accident. The accident triangle is illustrated in figure 3.

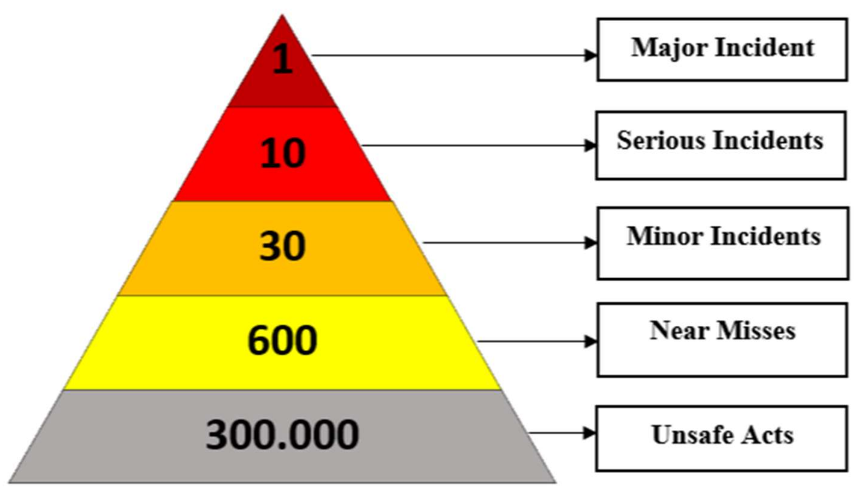


Figure 3 - Accident triangle
Source: (Avatara Software, 2020), graph made by authors

Another principal researcher of safety management was Dan Petersen (1932 – 2007). In his book *Technique of Safety Management,* Petersen introduced his non-domino-based approach in 1978. According to Petersen's multiple causation theory, accidents are caused mainly due to many contributing factors, causes, and sub causes which combine randomly to result in accidents. Hence, these factors should be targeted in the investigation of accidents. One example to describe Petersen's theory is a typical accident scenario of a man falling off a defective stepladder. Peterson argued that by just using investigation forms, only one act (climbing a defective ladder) and/or one condition (a defective ladder) would be recognized. When using the domino theory, the root cause of the problem would probably be the faulty supervisor's investigation. However, Peterson pointed out that by using multiple causation questions, also the surrounding factors to the accident must be considered. Suitable questions to the stepladder accident could be: *why* was the defective ladder not found during normal inspections; *why* did the supervisor tolerate its use; *whether* the injured worker was aware that he/she should not use the ladder; *whether* the worker was competent and accurately trained; *whether* the workers was reminded that the ladder was deficient; *whether* the supervisor inspected the task first. (Abdelhamid & Everett, 2000)

Petersen advised that the root causes of occupational accidents are often due to a lack of the management system in terms of management policies, work procedures, supervision, effectiveness, training, etc. These answers should reveal the opportunities for permanent improvement of inspection procedures, training, a better description of responsibilities, and pre-work planning and preparation by supervisors. If the mechanisms of how unsafe behaviors can happen are understood, then based on this understanding, workers and managers can be equipped with specific preparations that will significantly control unsafe behaviors and reduce on-site accidents. (Abdelhamid & Everett, 2000)

2. Research methodology

The research for this thesis has been carried out on the widely and commonly used research engine Google. First, “grey” literature was read, then more meaningful pieces of information were collected. Once a trend of interest was identified, the use of the more specific and specialized research engine Google Scholar was performed to refine the previous research. The used information is stated with its source and refers to the research paper, production sources, statistical data, and previous reports.

Using a deductive approach, the literature review and investigation were supported with basic but sufficient use of related data to identify and understand risks in the construction industry in Hong Kong and Romania. Later, the research moved on to more specialized databases such as the database of the Aalborg University library. The collected literature of interest was then examined by abstract to be read. If the paper was found to be meaningful for the thesis work, it was then selected to be part of the sources. The flow to refine the literature is shown in figure 4:

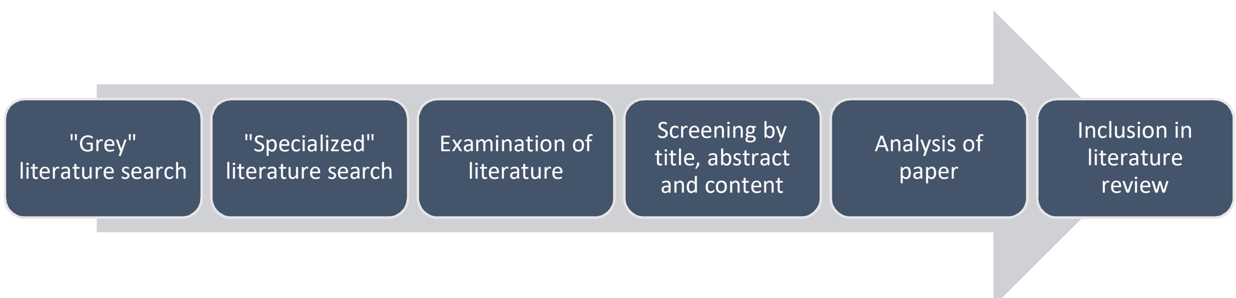


Figure 4 - Literature review flow
Source: Authors

There is a lot of good literature with the interest of managing health and safety in the construction industry. A lot of quantitative studies, including surveys and questionnaires, were conducted with construction workers, contractors, and construction companies and published in recent years. This information was helpful to identify issues and problems associated with construction sites, the construction industry, the subcontracting system, working conditions, and managing workplace safety in general.

Nevertheless, one of the biggest challenges of the writing process was to find good, reliable, and free available sources of data especially for accidents in the construction of Hong Kong because of language barriers. The authors are not able to write or read the Chinese language, therefore, only English sources or specific Chinese sources (that could be translated through translation software) are used.

The articles “Market control: Understanding China’s construction industry” from Wei Zhao and “A culture of violence: the labor subcontracting system and collective action by construction workers in post-socialist

China" from Pun Ngai and Lu Huilin both describe the root causes of mainland Chinas current challenges and problems in managing the construction industry. (Zhao, 2018) (Ngai & Huilin, 2010)

There are already a lot of articles addressing the construction industry of China and the SAR Hong Kong. However, the literature review did not precisely indicate to which extent social conditions and problems associated with the subcontracting system in mainland China and Hong Kong are similar. The authors identified that the educational requirements for working in construction are similar, laws and regulations are different. The scope of the thesis did not allow to indicate and compare all the differences between mainland China and Hong Kong.

Much of the information found in Romania were from European websites, as they stored much of the statistics used in the report on Romania and Europe. Many articles and data involving Romania are based on general surveys involving all European countries altogether. There is a tendency of generalizing developing countries into the same category and therefore the article didn't describe Romania itself, but developing countries in general - which Romania is defined as. E.g. an article about Qatar (Amber Mehmood, 2018), where the study is based on the Qatar construction sector, though it can be compared to Romania, as they have similar conditions and the article references, that the study itself can be compared to other developing countries.

Though many articles describe Romania as having similar education as the remaining countries in Europe, some differences between e.g. Denmark and Romania can be seen. These differences are seen in statistics in figures 8 and 9 on non-fatal and fatal occupational accidents respectively and are identified to be because of culture and financial differences as well as more years of safety implementation. Even though Romanian laws and regulations claim to set high standards of reporting and safety of the country, studies contradict these claims such as (Worker-participation, 2016).

For the risk identification, the authors used the methods of expert elicitation, scientific journal articles (Abdelhamid & Everett, 2000) (Fitzgerald, Chen, Qu, & Sheff, 2013) (Choudry & Fang, 2008) , such as (RRC International, 2019). (RRC International, 2019) is a study text to acquire the NEBOSH International General Certificate in Occupational Health and Safety, published and written by RRC International, UK's leading international provider of health & safety and environmental management business training. (rrc.co.uk, 2020) NEBOSH is a UK-recognized certificate awarding organization for the management of health and safety which also received Approved Awarding Body Status from the Scottish Qualifications Authority (SQA) Accreditation in 2009. (nebosh.org.uk, 2020) Other hazards were found in the texts of (OSHA U.S., 2016) (OSHA Europe, 2007) (Census and Statistics Department, 2019) Another interesting article that focuses on construction risks is "Understanding the key risks in construction projects in China" by Zou, Zhang, and Wang. The article provides an interesting overview of key risks obtained through a postal questionnaire survey of construction practitioners supported by research to indicate risks that "*significantly influence the delivery of construction projects*". Out of 85 risk factors, 25 key risks were identified and categorized into risks related to clients, risks related to designers, risks related to contractors, risks related to subcontractors/suppliers, risk related to government, and external issues that have a significant impact on cost, time, quality, safety, and environment. (Zou, Zhang, & Wang, 2007) This source for general knowledge.

For the risk analysis and evaluation, probabilistic annual data were obtained from the statistical data published by e.g. the Labour Department Hong Kong. However, the trust and reliability of the Chinese official sources and figures are in doubt. Many argue that the official data might be lacking. (CLB, 2019). (Fang, Xie, Huang, & Li, 2004) Hence, there is a lack of authentic field data. Information from China Labour Bulletin (CLB), a non-governmental organization based in Hong Kong, was used to obtain insight information about current issues concerning subcontracting and workplace safety in the Chinese construction industry. CLB supports and engages actively with the workers' movement in China. CLB also highlights that the official data and figures regarding workplace accidents in Hong Kong only demonstrate a generalized picture of occupational health and safety as it lacks crucial details about the nature and origin of workplace hazards, the most at-risk industries, and the most common causes of death and injury. "*This lack of transparency prevents the public from assessing and understanding the real problem areas in work safety in China*". (CLB, 2020a) For Romania and Europe, data from Eurostat (a directorate of the European Commission) was prioritized for the data analysis.

For risk management, the thesis authors attempted several times to get in touch with the inventors of the PBBS via email to obtain more insights into the program of PCMS. Unfortunately, they never received any form of response. Therefore, the perspective has been changed to analyze the method of Behavior Based Safety in more detail to obtain better insights into Proactive Behavior Based Safety's background. The information of (Li, Lu, Shu-Chien, Gray, & Huang, 2015) was used to understand, describe, and analyze the chances and risks associated with PBBS and PCMS. This work has been fundamental for many aspects of the risk management chapter and most of the work that is found in the thesis.

2.1 Problem formulation

This thesis aims to meet the academic graduation criteria for obtaining the Master of Technology in Risk and Safety Management at Aalborg University Esbjerg.

In construction, there are many risks for humans and the environment and many aspects possibly urge for improvement. Construction employers and other powerful stakeholders have moral, financial, and legal responsibilities for their workplaces, processes, and work equipment and must reduce risks to acceptable levels where risks cannot be eliminated and prevented. (RRC International, 2019) However, there can be different barriers present in the safety management system that limits the effectiveness of safety practices and procedures that are formulated by stakeholders for protecting and overseeing workers' health and safety. The perhaps most fundamental barrier is human behavior itself. Humans are naturally prone to make mistakes and especially working in construction demands people to be trained, educated, skilled, and equipped with information, so they can carry out their job safely.

The interest of this thesis is to enhance knowledge in risk assessment and risk management for the sake of accident prevention in the construction industry. The perspective of this thesis is to gain more insight into the causes of unsafe behaviors and to analyze which human factors need to be addressed so risks can be minimized or eliminated. After the identified risks in construction are analyzed and evaluated, reasonable risk treatment possibilities in terms of Behavior Based Safety (BBS) and Proactive Behavior Based Safety (PBBS) will be introduced. Many studies are discussing the effectiveness of BBS in construction, however, PBBS is a relatively young concept and seems to be a beneficial addition to BBS. The main research question of the thesis is, therefore: “What is the expected net benefit of implementing Proactive Behavior Based Safety in the construction industry?”

Hong Kong was chosen for analysis because of its high record of injuries, accidents, and fatalities. Romania was selected as the best fit for comparison due to its high record of fatalities among European countries.

2.2 Problem delimitation

The scope of the thesis does not allow to provide too many details about each singular subject that is part of the content.

The chapter system identification shall be used to understand the status quo in Hong Kong and Europe in terms of legislation regarding occupational health and safety, safety management systems, and social problems which are indicated by research. It is out of scope to make a comprehensive comparison between the two economies.

The chapter risk assessment is structured into risk identification, risk analysis, and risk evaluation. Together these chapters shall provide more insights about the hazards and risks present in the construction work for construction workers. Here, the focus will be on construction accidents and injuries. The construction industry in Hong Kong will be analyzed in more detail to identify which factors are contributing to its very high record of occupational fatalities and injuries.

The risk management chapter will introduce two effective solution tools, namely BBS and PBBS. BBS advantages and disadvantages will be explained in more detail to identify why PBBS might provide better results. However, only one article for PBBS has been published yet, therefore, the trustworthiness can be questioned.

3. System identification

This chapter lays the foundation to understand the issues within the construction industry in Hong Kong and Europe in more detail. The following passages will guide the reader towards problems and safety management in the construction industry of Hong Kong and Romania.

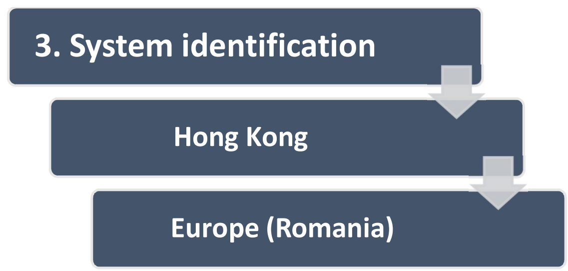


Figure 5 - System identification chapter outline
Source: Authors

3.1 Construction in Hong Kong

For the reader *Appendix 2 - Chinas transformation of the construction industry* can be useful to obtain more insights and for understanding how construction became a major industry in mainland China which affected Hong Kong to some extent. It was not fit into the actual content of the thesis mostly due to its comprehensiveness.

The probably most astonishing example of constructional development can be found in China. Within only 40 years, major cities like Shanghai, Hong Kong, Beijing, Taipei, and Guangzhou were established and Chinas construction industry contributed to massive economic growth. (CLB, 2019) (Ngai & Huilin, 2010)Even today, construction still accounts for 25% of the nationwide GDP and about 55,6 million people working in the construction sector in mainland China as of 2019. (Statista, 2019) (Shao, Hu, Chen, Liu, & He, 2019) In 2018, mainland China recorded 3.541 industrial accidents in construction which relate to 36% of all industrial related accidents, making construction officially the most dangerous industrial sector since 2013. (CLB, 2019) A similar situation is present in Hong Kong.

Hong Kong is a special administrative region (SAR) of China. The United Kingdom ended the administration for the colony of Hong Kong and returned control of the territory to China in July 1997. Hong Kong sustains separate governing and economic systems from that of mainland China under the principle of "one country, two systems". (Britannica, 2020) Hong Kong ranks fourth on the UN Human Development Index and is a highly developed territory with some residents having the highest life expectancies in the world. (UN HDRO, 2019) (CIA US, 2020) Hong Kong has been a global financial center over decades and its construction industry is a booming sector with the largest number of skyscrapers of any city in the world and several mega projects especially in transportation projects. (CTBUH , 2020) One of the most astonishing engineering examples is the Hong Kong-Zhuhai-Macau Bridge which opened in October 2018. The bridge connects the Lantau Island of Hong Kong with the Macau SAR via a 55-kilometer bridge and tunnel system that includes three cable-stayed bridges, an undersea tunnel, and several artificial islands. The bridge is the longest sea-crossing and the longest open-sea fixed link in the world, enabling vehicles to drive between Hong Kong and Macau/Zhuhai in about one hour, a journey that took over four hours in the past. (urban-hub.com, 2019)

Of the estimated 7,451 million inhabitants of Hong Kong, approximately 3,979 million were employed in 2018. (censtatd.gov.hk, 2020) Of all employees in 2018, 361.100 are estimated to work in the construction industry which accounts for 9,07% of Hong Kong's entire people in employment. (Census and Statistics Department, 2019) About 79% of all manual workers in construction were employed in big companies with at least 100 workers in 2018. In the same year, the median hourly wage for construction workers was 96.7 HK$ while the official median was 48.0 working hours weekly. (Census and Statistics Department, 2019)

3.1.1 Legal responsibility of overseeing health and safety in Hong Kong

All policies and practices in Hong Kong must be based on the provisions of the *Basic Law of the Hong Kong Special Administrative Region of the People's Republic of China*. The *Basic Law* is a national law of mainland China that serves as the constitution of the Hong Kong Special Administrative Region (HKSAR). The Labour Department, as a branch of the Department of Secretary for Labour and Welfare, is responsible for issues concerning occupational health and safety in Hong Kong and has four key interest areas, namely Employment Services, Labour Relations, Safety and Health at Work, and Employee Rights and Benefits. The tasks of the Labour Department include the implementation of new plans and policies, preparation of development programs, regulation of the construction markets and construction institutions (e.g. construction companies and contractors), and monitoring of health and safety in construction. (Chen, Cao, & Chow, 2012)

The Labour Department hires safety auditors annually to conduct safety audits. They are supposed to carry out site inspections on regular basis to evaluate the compliance of safety regulations covering general administration, site orderliness and housekeeping, scaffolding, excavation, shoring, formwork, protective clothing, dangerous openings, use of electricity, material hoists, external hoisting lifts, tower cranes and other construction tools and equipment. (Development Bureau, 1999)

The main legislation related to occupational safety and health consists of three main parts, namely *Boilers and Pressure Vessels Ordinance (*Chapter 56*)* which is composed of one subsidiary regulation and two orders; *Factories and Industrial Undertakings Ordinance* (Chapter 59) with 30 subsidiary legislation; and *Occupational Safety and Health Ordinance* (Chapter 509) which is composed of two subsidiary legislations. (Chen, Cao, & Chow, 2012) The framework chart of the legal system of occupational health and safety in Hong Kong is illustrated in figure 6.

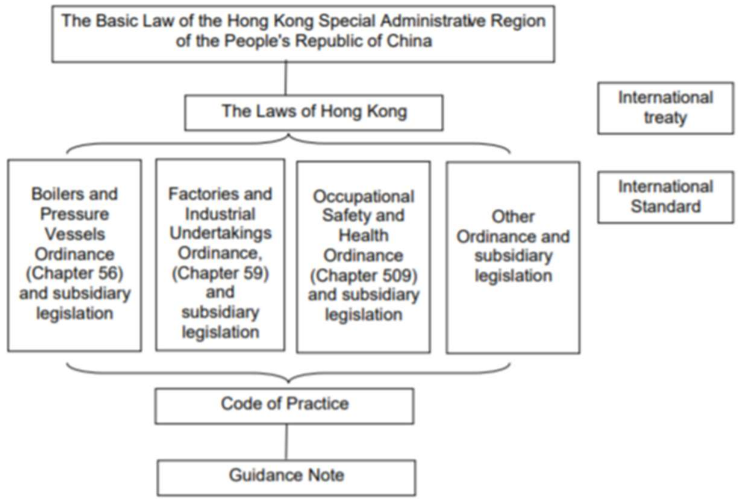


Figure 6 - OSH system in Hong Kong
Source: (Chen, Cao, & Chow, 2012)

In 1995, the Government of Hong Kong conducted a comprehensive review of industrial safety to determine Hong Kong's long-term safety plans and strategies. "*To achieve high standards of safety and health at work, the review concluded that Hong Kong enterprises must embrace self-regulation and safety management. The Government should provide a framework within which self-regulation was to be achieved through a company system of safety management."* Under the Factories and Industrial Undertakings Ordinance of November 1999, "*proprietors or contractors of certain industrial undertakings are required to develop, implement and maintain in respect of the undertakings a safety management system which contains several key process elements. They are also required to have the system regularly audited or reviewed*". (Labour Department, 2002)

The Code of Practice (COP) aims to provide practical guidance for proprietors and contractors of relevant industrial undertakings to comply with legal requirements. It has a special legal status: "*Although failure to observe any guidance given in this COP is not in itself an offense, that failure may be taken by a court in criminal proceedings as a relevant factor in determining whether or not a person has breached any of the provisions of the Safety Management Regulation to which the guidance relates*". (Labour Department, 2002) Besides, the provisions and requirements stated in the Guidance Notes could be obeyed with of one's own accord, and it does not have the same important legal status as the COP. (Chen, Cao, & Chow, 2012)

At the construction company level, the *Factories and Industrial Undertakings (Safety Officers and Safety Supervisors) Regulations* stipulate that construction sites with 50 to 200 employees must have at least one safety officer, from 201 to 700 employees at least two safety officers, from 701 to 1200 at least three and above 1200 employees at least four safety officers who are mainly responsible for the health and safety of employees, machinery, equipment, and processes. Moreover, employers are required to undertake adequate supervision, control, and monitoring of workplaces and workers to enhance safety and to notify the government if violations of the statutory legislation should occur. (Development Bureau, 1999)

(Chen, Cao, & Chow, 2012) reviewed the legal system of health and safety at work and the supervisory organization in mainland China and Hong Kong. The management of occupational health and safety, safety production, fire safety, dangerous goods, the boilers, and pressure vessels appear to be similar in both jurisdictions.

3.1.2 Education and skill requirements for working in construction in mainland China and Hong Kong

Mainland Chinas formal education is based on a three-level system and is similar compared to counterparts in western countries with both general and vocational education. Children start with the primary school which takes six years, followed by secondary education which takes three years in junior school and three years in high school. Tertiary education includes undergraduate and graduate programs which can take three or four years for undergraduate studies and usually two years for a master's degree for postgraduate studies. Vocational education or training, which prepares to take up employment as e.g. technician or skilled craft in general, can start for some as early they completed primary school. (Youjie & Fox, 2001)

Vocational schools in mainland China can be divided into two main categories. There are construction operative schools and construction engineering schools, and both require usually that students have received at least junior middle school education. The courses offered in construction operative schools are mostly practical and site operation oriented. After a three-year study period, graduates can get a job as a skilled craft or work as an operative on a construction site. The most common operative trades include carpenters, stonemasons, bricklayers, plasterers, painters, asphalt tanking workers, steel bar fabricators & fixers, structural steelwork fabricators & erectors, concrete placing workers, welders, plumbers, pipefitters, air conditioning ductwork fabricators, and electricians. (Youjie & Fox, 2001)

Students of the construction engineering schools obtain more knowledge about science, engineering, humanities, and management than in construction operative schools. The study time requires three to four years and after completing their studies, graduates can seek employment as site supervisors or staff with technical or managerial responsibilities. They can also take the national competition examination after graduating to obtain a university degree for widening their employment options. Moreover, there are many possibilities for graduates of both vocational schools to attain short-term training programs to acquire more specific insights about construction safety, quality inspection, fire prevention, construction law, labor law, etc. (Youjie & Fox, 2001)

At the township, town, and country level, the government established also their construction operatives and training centers in the early 1990s. At their own cost, the facilities are intended to make their construction workers competitive in obtaining construction contracts especially for state-owned enterprise projects in metropolitan areas and city centers. Students can obtain training either full or part-time. The schools are under the management and joint supervision of the provincial construction commission and the Ministry of Housing and Urban-Rural Development. Other training centers are rather market-orientated and recover the expenses of training and education by imposing costs to the employer. (Youjie & Fox, 2001)

In 2006 the State Administration for Work Safety (which functions have been merged into the new national Emergency Management Department in 2018) released a set of safety requirements for the construction industry. (CLB, 2018b) People working in construction and other site personnel are required to receive at least one day of safety training before their work. The objective of this training is to briefly instruct employees about safety duties, hazard identification, accident prevention, and other things that are important to be aware of when working in construction. After delegates pass a short evaluation, they are "legally" allowed to work on a construction site. Construction workers shall "*rigidly observe the rules and regulations concerning product safety and the operational rules of the entities concerned, obey their administration, and correctly wear and use personal protective equipment; accept education and training in production safety, be equipped with the knowledge of production safety necessary for their work to improve their skills in production safety and enable themselves to prevent from accidents and handle emergencies. Any employee who finds out any potential accidents or other insecure elements shall report immediately to the person in charge of the on-spot administration of production safety or the person-in-charge of the entity concerned. The person who receives the report shall handle them in good time.*" (Chen, Cao, & Chow, 2012) (Zheng, Xiang, Song, & Wang, 2010)

Following, on annual basis at least eight hours of training must be attended. The workers are then assessed by a competent and certified specialist for health and safety. (Youjie & Fox, 2001)

In Hong Kong, the education system is very similar to the United Kingdom. Children are required to attend school from the age of six until completion of secondary education, generally at age of 18. After graduating from secondary schooling, all students must pass a public examination to be awarded the Hong Kong Diploma of Secondary Education. (Britannica, 2020) Like in mainland China, there are different apprenticeship training programs and trades to choose to become a skilled craft in construction. The minimum requirement to work on a construction site is one mandatory safety training course under several occupational safety and health legislation administered by the Labour Department. Those who pass the evaluation at the end are awarded a "Green Card" as proof of evidence. (Choudhry, Fang, & Ahmed, 2008) It is unknown how the basic safety training program is evaluated in practice. (Zheng, Xiang, Song, & Wang, 2010)

3.1.3 Hong Kong occupational injury reporting and claim for compensation

Hong Kong's occupational injury insurance policy describes a "work-related injury" as "*accidental injuries suffered, due to work activities, during work hours and within the workplace*". In 2011, this definition was extended to contain also incidents happening outside of the work premises, for example, while traveling to or from work, workers dying during work or within 48 hours after work, such as workers who suffer from any kind of occupational illnesses or accidentally injure themselves. (Conaty, 2017)

The statistics of industrial accidents in Hong Kong are compiled by the Occupational Safety and Health Branch of the Labour Department. To identify the occupational injuries, source records, worker's compensation records, and employer's accident reports are used. Information indicating occupational fatalities is obtained from various sources including death certificates, workers' compensation reports, agency administrative reports, and data published from the Census and Statistics Department. (Jeong, 1998) (Labour Department, 2019) Under the *Employees' Compensation Ordinal* of 1953, employers must report occupational accidents and injuries which resulted in death or work incapacity for over three days to restore the victims' position and punish those ill-performed contractors. Legislation as such erected an ex-ante "contract" between workers and employers in which the employers commit to bear a specified amount of money for all accidents arising within their responsibilities of employment. (Li & Poon, 2009) The *Employees' Compensation Ordinal* states clearly the amount of compensation to be paid in cases of permanent total incapacity due to work. It differentiates between three categories depending on the age of the employees:

1. Employees who are under the age of 40 will be compensated with HK$344.000 or 96 months of earnings whichever is higher;
2. Employees who are over 40 years of age but under 56 years of age at the time of the accident are eligible to receive HK$ 344.000 or 72 months of earnings whichever is higher;
3. Employees who are 56 or above are entitled to receive HK$344.000 or 48 months earning whichever is higher. (Li & Poon, 2009)

Notably, these categories do not mean that the amount of monthly earnings for calculating compensation is unrestricted. The compensation estimations are based on monthly earnings of a maximum of HK$21.000. The total compensation amount awarded for a victim is decided by judges in court and is supposed to provide the remedy to the victim as close as possible to the status had the accident not occurred. The judge would decide the percentage of liability that was borne by the contractors and/or subcontractors, after determining the whole amount to be compensated. Had there been no prior agreement on the percentage of each defendant's liability on construction injuries, the court also decides the percentage out of which each party should pay. Moreover, judges might also compensate the claimants under the item such as loss of society, retirement benefit, etc. The panel of judges might also withhold a sum of money which had been received by the victim and their corresponding responsibilities for their carelessness. (Li & Poon, 2009)
According to a study conducted by (Lipscomb, Dement, McDougall, & Kalat, 1999), compensation claim incidences were highest for back/shoulders, fingers, and leg/knee. In Hong Kong, claimants must provide

evidence in form of a medical assessment report for compensation purposes. It indicates which part of the body suffers from injury and the corresponding percentage of body impairment. Mechanism of injury was highest for limbs, cases accounted for half of the cases. The other common injuries are the head, back, eye, fingers, or toes. (Li & Poon, 2009) The mechanism of injury refers to the way a physical injury occurred (e.g. fall from a height, struck by vehicles, etc.) and is used to evaluate the forces involved in trauma and, thus, the potential severity for injuries. (Medical Dictionary, 2009) Head injuries have the highest chance to be compensated with a larger sum of money. Among all cases involving head injuries, about 47% received more than HK$1,5 million, followed by eye, then shoulder injuries. The results generally reflect the seriousness of the injury has a great influence on the amount of compensation when the level is decided by judges. (Li & Poon, 2009) (Lipscomb, Dement, McDougall, & Kalat, 1999)

3.2 The subcontracting system in construction Hong Kong

In Hong Kong, it is generally accepted and common practice that construction enterprises outsource the work to other contractors and several subcontractors. Multilayer subcontracting involves subdividing work into a range of trades (e.g. laboring, scaffolding, roofing, ductwork, pipework, electrical and control works, testing, and commissioning, etc.) and assigning the task to each trade with specific skills. Rather than due to specialization, subcontracting is to increase the organization's efficiency of manpower, cope with variable and fragmented work demands, and minimize costs. (Yik & Lai, 2008)

The following example shall be used to further understand the construction subcontracting system in Hong Kong. Given the example of building a theatre, the project is first published by a property developer (who was responsible for land reclamation) to a selected number of design institutes. Design competitions are often used by property developers for residential buildings, large-sized public buildings, such as railway stations, museums, theaters, exhibition centers, memorials, government buildings, etc. Once a design institute has won, and all design details have been accepted, the property developer chooses a way to implement the project. The property developer could, for example, publish the project for competitive bidding to all qualified bidders who are big construction companies with a good reputation in the industry. Other options available are selective bidding, negotiating contracts, and government appointment. In very rare cases, the government may select one or more construction companies to accomplish construction projects which are of special social or political value, or unique nature. (Ngai & Huilin, 2010)

The construction companies (main contractors) will offer their services by estimating preliminary costs and try to win the bid. If a construction company was won, it will most likely limit its responsibilities to project management and equipment arrangement while multiple subcontractor businesses are hired for providing raw materials and the workforce. They may publish some project parts for bidding to find the “best” subcontractor or have already contracted with subcontractors from previous projects. Subcontractors are willing to tender for all kinds of jobs and projects, creating intense competition on the market. Hence, it is not untypical that subcontracting firms will even borrow money from the banks or creditors to start the project on behalf of the client. (Tam, Zeng, & Deng, 2004) (Yik & Lai, 2008)

Subcontractors can benefit from further subcontracting if it will lead to lower costs than possessing a full-fledged construction crew to deal with all kinds of work. Other advantages are reduced vulnerability towards business fluctuations, greater flexibility in adjusting the workforce to meet work demands, and fewer costs for personnel management and legal obligations to workers. Furthermore, the financial risk for upfront capital investments can be shifted to the lower-tier subcontractors through contracts. Smaller subcontractors who cannot bid for subcontract work directly will be willing to become a lower-tier subcontractor because they will make more profit as if they become an employee of a subcontractor. Subcontractors are normally paid from the upstream subcontractor on a monthly or fortnightly basis but wage arrears or even withhold of payment can happen. (Yik & Lai, 2008)

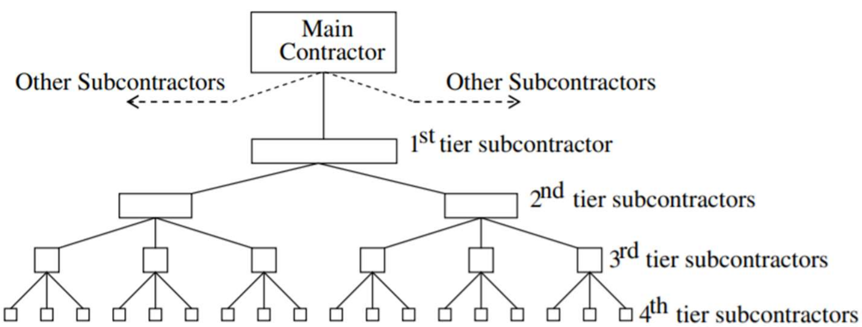


Figure 7 - Subcontracting chain
Source: (Yik & Lai, 2008)

In our example, the hired labor contractor may have claimed to set up a labor service company to recruit workers for the job but instead, they rely on labor-supply subcontractors to hire the workforce, manage the daily division of work, and the payment of wages. The labor-supply subcontractor could be further dependent on labor-use facilitators scouting for people willing to work in rural areas of mainland China. Because of the relatively high rate of unemployment and poverty in rural areas of mainland China, there is usually a high interest in work. Although they know from friends or relatives that working in construction in dangerous, jobs is attractive because the average pay is higher than working in manufacturing or service industries. (Ngai & Huilin, 2010) (Tam, Zeng, & Deng, 2004) In mainland China many young people coming from rural areas try to earn and save as much money as they can to buy a residence or to quit their job in construction and make a living through agriculture. Such incentives and the perspective of escaping from poverty seem to be motivation enough to compensate for the known risks and hardship of labor present in the construction industry. (Youjie & Fox, 2001) The labor wage rates depend on whether a worker is skilled, semi-skilled, or unskilled. (Yik & Lai, 2008)

For young people holding urban resident status, working in construction is very unattractive. Construction is considered a 3D job - Difficult, Dirty, and Dangerous. In an opinion poll made by the China Academy of Social Sciences in July and August 1999, a sample of 2.599 young people (older than 16) with urban resident status in 63 cities in mainland China ranked construction as the lowest of 69 selected occupations in which they consider a career in. (Youjie & Fox, 2001)

Back on the construction site of a theater, there could be hundreds of workers organized in multiple, small subcontracting teams with the same, similar, or different tasks. As recent studies revealed, a clear majority of people getting hired as construction laborers lack education, competency, discipline, skills, and safety training which are essential to work safely and prevent injuries and accidents at work. Although construction companies and contractors are aware of this matter, there is usually a high demand for unskilled laborers because they are cheap and essential for the fast success of the project. In many cases, unskilled workers receive only a short-term contract (if they get a contract at all) while a small number of skilled workers are directly employed by the contractor or construction company to mitigate the risk of bad or lacking quality. (Zhao, 2018) Skilled construction workers are usually administrative, professional, technical, and clerical staff with some years of experience, and/or with some sort of vocational education from a construction operative or engineering school. (Youjie & Fox, 2001)

3.3 Fundamental problems in Hong Kong

There are many problems in the construction industry of Hong Kong. It is argued that multilayer subcontracting is considered as one of the main causes of poor construction quality, an excessive amount of rework, and bad construction site safety in Hong Kong. (Yik & Lai, 2008)

3.3.1 Funding problems

The subcontracting system is riddled with corruption, misappropriation of funds, and disruption of capital flows. Several construction projects are very speculative and are undertaken without any guarantee of funding but promise high returns of profit for the developer, lenders, and individual contractors who are mainly concerned with their own interests and profits. (CLB, 2019) In many cases, labor contractors must take out loans just to secure the work and to compensate for building materials and working equipment. Other contractors might even operate without access to a credit facility. This so-called “capital contracting” is a common practice in the construction industry and involves passing the financial risk down to the production chain. Should the flow of capital dry up, quality fails to meet standards and requires additional work or repairs, or subcontractors simply claim to have no money, workers are at high risk of wage arrears, payment at a substantially lower rate or never receiving any payments. (Ngai & Huilin, 2010) (Yik & Lai, 2008) Low-tier subcontractors must carry the biggest financial risks that result from project funding problems done by superior construction companies. (Zou, Zhang, & Wang, 2007)

3.3.2 Lack of worker contracts

Another issue is that some construction workers have never seen or signed any official document stating their employment relationship or other formal labor agreement. (Fitzgerald, Chen, Qu, & Sheff, 2013) This issue is especially severe in mainland China. Without a labor contract, workers' chances in seeking help from the authorities, claiming for their rights in court, or even attempt prosecution, are very limited and in vain because they are not able to prove the employment relationship with their contractor or construction firm. Thus, construction workers have no proper evidence. (CLB, 2014) Besides, managers can employ the workers at any time and control the workers according to their demands. Should the manager be unsatisfied with the skills and abilities of the employee, the worker will not be hired in the next project or laid off directly. For every new project, workers are "re-employed" and wages are negotiated according to the market situation and financial assets of the subcontractor or company. Workers are trapped in a passive position. (Zhao, 2018) If contracts are issued, however, they can lack wage rates, working hours, and rest periods. Concepts of overtime and overtime payments, such as holidays, are sometimes non-existing in the industry. Apart from the winter period, a 13- to 14-hour day can be the norm and can last from sunrise until dusk. Workers suffer often under the hardship of long and at times irregular working hours but most of them avoid complaining because they worry that too many complaints will lead to not be hired for the next project, thus, unemployment, hunger, and misery. (Ngai & Huilin, 2010) (Zhao, 2018) (CLB, 2018a)

3.3.3 Workers accommodation

Construction companies often spare investments for the repair and maintenance of workers' accommodation or dormitories on site. Many people living facilities are dirty, shabby, crowded, and prone to mosquitoes, rats, and other pests. They are neither well-ventilated during the hot summer, nor well-heated during the cold winter which significantly increases the risk of diseases and illness for workers. However, the terms and conditions of work vary from site to site. Generally, there are much better in major cities like Beijing, Shanghai, Tianjin, and Shenzhen in China. (Zhao, 2018) (Ngai & Huilin, 2010) (Youjie & Fox, 2001)

3.3.4 Wage arrears

When wage arrears occur, and workers express their anger towards their responsible labor contractor, the labor contractor can claim that the problem originates from the higher-level labor contractor. The responsible labor contractor may also be unsatisfied and unpaid and might even join the workers to seek clarity from the superior labor contractor (who will probably not be any better off but trying to accuse his superior contractor). This dispute could range up the subcontracting chain until it reaches the main contractor who admits that there has been a funding deficit, or no money is left. (CLB, 2019) It was also revealed that some disputes in mainland China and Hong Kong can last for months and companies eventually refuse to have an employment relationship with workers and not pay at all. (Ngai & Huilin, 2010) To avoid intense conflicts in funding shortfalls, some labor contractors choose to prioritize the "fringe workers" in paying limited wages to lessen the uncertainty of "core worker" leaving the site. (Zhao, 2018) Past incidents have also shown that the tension between subcontractors and workers caused by unpaid wages can even trigger violent acts of verbal disagreements or intensify to fights between hired gangs. In other cases, it can lead workers to threaten committing suicide, damage building parts with axes and sledgehammers, or strike. (Ngai & Huilin, 2010)

The issues in Hong Kong's construction industry are not new and have attracted a lot of attention from legislators, administrators, trade unions, judicial officials, and the media for many years. Whenever the media uncovers a dispute and makes it public, the local authorities allocate lots of administrative efforts to take counteractive actions and punish the guilty parties and business owners if possible. But as long as the media "does not blow the whistle", too less or nothing is done when the same issue appears elsewhere, leaving the general impression of government officials being too busy with fighting the fire instead of directing meaningful efforts towards preventive actions, on how to avoid the fire starting in the first place. (CLB, 2019)

3.4 Construction accidents and fatalities in Hong Kong

As formerly elaborated, construction workers in Hong Kong are more likely than any other occupation to suffer from violations of basic labor rights. Regarding occupational health and safety, construction workers are more likely to be injured, involved in any kind of workplace accident, or suffer from work-related illnesses. (CLB, 2019) Notably, Hong Kong's construction industry has been recognized as one of the most dangerous industries for decades because of its high number of occupational injuries, accidents, and deaths. (Shafique & Rafiq, 2019) (Lingard & Rowlinson, 1997)

To see if the trend of occupational accidents in construction Hong Kong has improved or deteriorated during recent years, the annual number and rate of industrial accidents in construction Hong Kong from 2009 until 2019 are examined. The data of both the number of industrial accidents and the accident rate were obtained from official figures published by the Labour Department Hong Kong and a journal article by (Zhoue, Shen, Xu, & Zhou, 2019) containing previous figures of the Labour Department. (Labour Department, 2020)
The accident rate may be more useful than the total of industrial accidents because the total of accidents does not consider the steadily increasing number of employees in this sector whereas the industrial accident rate does. The industrial accident rate (IAR) sets the number of workplace accidents in relation to the number of workers employed in the sector (frequency) and is calculated as indicated by the Labour Department Hong Kong. (Labour Department, 2020)

$$\text{Accident rate (AR)} = \frac{\text{Total number of industrial accidents}}{\text{Total number of employed workers}} \times 100.000$$

Industrial accidents include all types of injuries and deaths arising from industrial activities in industrial undertakings as defined under the *Factories and Industrial Undertakings Ordinance*. (Labour Department, 2020) Figure 8 shows the number of industrial accidents and the accident rate in the construction of Hong Kong from 2009 to 2019.

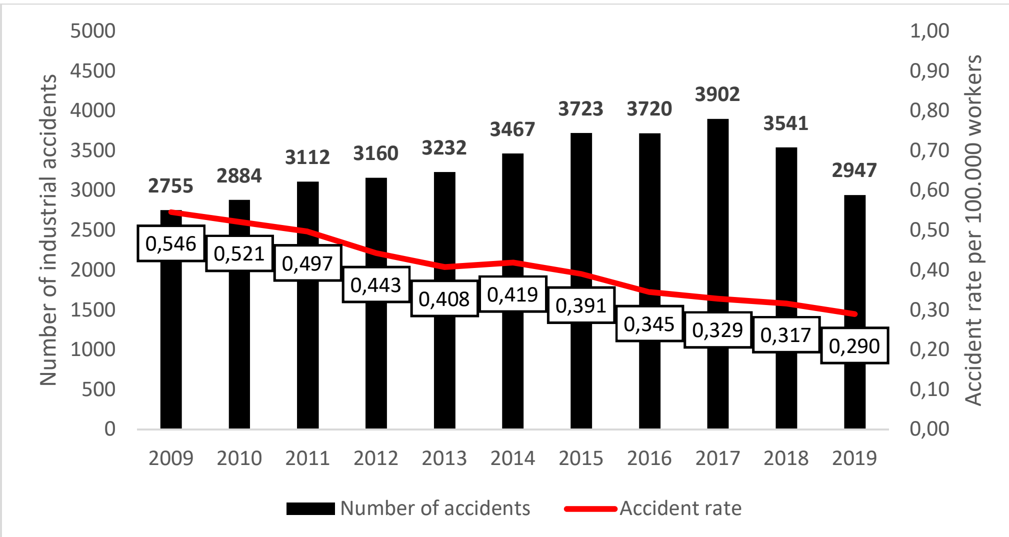


Figure 8 - Number of industrial accidents and accident rate in construction Hong Kong from 2009 to 2019
Source: (Labour Department, 2020), graph made by authors

From 2009 to 2017, the reported number of industrial accidents increased by almost 42%. The number of reported accidents peaked in 2017 with 3.902 industrial accidents only in construction and then declined. The industrial accident rate per 100.000 workers, however, shows a continuous decline of industrial accidents. Although the frequency of industrial accidents overall increased, the accident rate decreased. One explanation for the decreasing accident rate is that the number of employees working in construction in Hong Kong increased from 2009 to 2019. According to the accident rate, safety seems to improve overall which is positive news. (Labour Department, 2020)

One other useful indicator is the number of industrial fatalities represented by the Fatality Rate (FR). The FR measures the relation of total occupational deaths that occurred due to accidents or injuries in construction and considers the total amount of persons employed in the same sector (frequency). The FR is calculated as indicated by the Labour Department. (Labour Department, 2020)

$$\text{Fatality rate (FR)} = \frac{\text{Total number of fatal accidents}}{\text{Total number of employed workers}} \times 1.000$$

Figure 9 shows the number of fatalities and the trend of the fatality rates of construction in Hong Kong from 2009 to 2019.

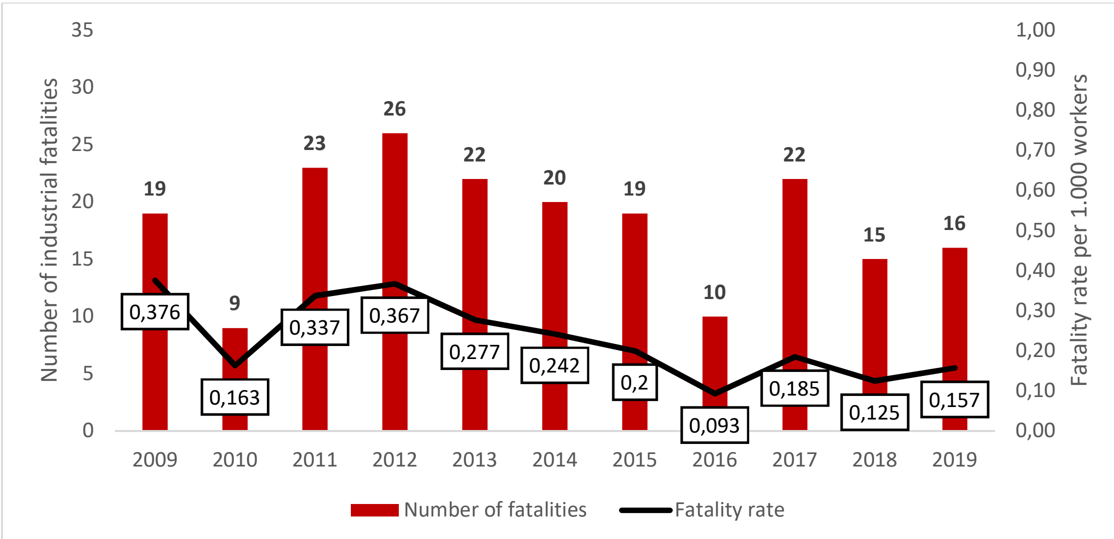


Figure 9 - Number of industrial fatalities and fatality rate in construction Hong Kong from 2009 to 2019
Source: (Labour Department, 2020), graph made by authors

The greatest amount of occupational fatalities in construction occurred in 2012 with 26 deaths. When the fatality rates of 2009, 2011, and 2012 are compared to the numbers of 2013 until 2019, it can be concluded that fewer workers died at work which suggests improvement of occupational health and safety.

In conclusion, when safety is measured according to the rate of non-fatal and fatal accidents, Hong Kong's construction industry has improved during recent years. Nevertheless, as the figures show, it is far from acceptable.

Tasked authorities seem to lack the capacity to judge whether Hong Kong's extensive legislation and several construction management policies laws have the desired effect in practice. Some claim that government bureaus in authority for workplace safety are understaffed and often too busy with filing detailed and exhaustive investigation reports on accidents that occur within their jurisdiction. Thus, they have too little time or incentives to conduct routine workplace inspections. However, when workplace safety inspections occur, e.g. in form of an accident investigation, construction companies are often well-prepared and can occasionally convince inspectors to turn a blind eye to safety violations with gifts or other advantages. If they cannot, and the business is cited for a violation, business owners will try to implement the most crucial follow-up action without making any substantive changes to their worksite. Therefore, accidents are likely to reoccur in hazardous workplaces that had either just "passed" an inspection or had been cited for the violation but taken too few actions. Moreover, the construction industry has a bad reputation for cover-up accidents and deaths, especially in remote areas with not many witnesses, because large scale incents (involving more than 30 deaths) can lead to heavy fines and the possibility of imprisonment. (CLB, 2020a)

3.5 Construction in European countries

The construction industry is also of great strategic importance for many countries in Europe. Construction is the greatest industrial employer in Europe, representing 7.5% of Europe's whole employment and 28.1% of industrial employment in the European Union (EU) in 2019. (efbww, 2020a) (European Commission, 2020a) The construction sector includes building companies, public works, demolition, and maintenance, and contributed to about 9% of the Gross Domestic Product (GDP) in the EU in 2019. (Aires, Gámez, & Gibb, 2009) (European Commission, 2016) (European Commission, 2020a)

Historically, Europe has been one of the front runners in every sector throughout the last two centuries with the industrial revolution starting in the late 18th century in Britain and spreading to other parts of the western world during the 19th century. With the industrial revolution, much profit came through the increased productivity but also increased injuries from the new machines taking over, which should be handled by workers. Throughout the 1900's many European countries started to focus on occupational safety and reducing injuries to their workers and have shaped the industrial world that we see in Europe today. (Britannica, 2019)

3.5.1 Constructions unions in Europe

Today two big construction trade unions exist in the world consisting of many small unions across countries from all over the world. The first unions saw their light in the 18th century in the United Kingdom for protecting labor rights and representing skilled workers in their occupation. Later with the industrial revolution in the 19th-century unions shifted from focusing on single, skilled workers to be industrial unions with both factory workers and children in focus which pushed unions in rapid development to what we know of today.

The Building and Wood Worker's International (BWI) consists of 351 trade unions across 127 countries with a total of 12 million members. (BWI, 2020) The second large trade union federation has business in Europe only, namely the European Federation of Building and Woodworkers (EFBWW). The EFBWW consists of 76 affiliate unions across 34 countries in Europe and represents two million workers with both federations' main purpose to defend the rights of employees in the construction sector and the freedom of speech for construction workers. (efbww, 2020b)

Labor rules and regulations have been influenced by trade unions throughout history and today, regulations from European Directives ensures labor conditions to be acceptable through, for example, a guarantee of 28 days of paid holiday (Directive 2003/88/EC or Working Time Directive), prohibiting discrimination at work (Directive 2000/78/EC) and minimum wage, etc. (EUR-Lex, 2020)

In Romania, there are five large confederations of trade unions, each with more affiliated federations. They hold approximately between 32.8% to 50% of workers in Romania and the union density is relatively high. In specific industries of Romania, such as construction, union density can hold almost 85% of workers. However, a *Social Dialogue Act* from 2011 removed legislation for negotiation at the national level, which covered minimum terms and conditions for employees in all of Romania. (worker-participation, 2016) Other legislations abolished in 2011 include industry agreements where half of the industry's employers are required to be represented by an association, otherwise the industry agreements are not binding. Even though the same *Social Dialogue Act* (SDA) states that agreements made between unions and companies cannot contain worse conditions than those agreed upon at the national level. Moreover, according to the SDA statement, in cases where unions have much influence, e.g. bigger companies, the agreements between unions and companies provides significant improvements to the general agreements made on the national level, while unions with less power are having a hard time reaching agreements improving the national standards. (worker-participation, 2016)

3.5.2 The legislative framework for occupational health and safety in the EU

One of the principal objectives of the European Union (EU) is to assure the European worker's increasingly safe work conditions and that workplaces are free of injuries, accidents, and ill-health. To put these objectives into practice, the EU issues directives regarding occupational health and safety to all member states. (Bianchini, Donini, Pellegrini, & Saccani, 2017) The most important law which introduces safety provisions and guidelines is *Directive 1989/391/EEC*. It is also considered as the "framework directive" because it is mainly concerned with the prevention of work-related risks, elimination of accident factors through risk assessments, creation of protection- and prevention measures under which employers should create opportunities of informing, consultation, balanced participation and training of employees. The directive applies to both public and private enterprises in the EU. (Aires, Gámez, & Gibb, 2009)

The European Agency for Safety and Health at Work coordinates actions at both EU and national level. The Directorate-General for Employment, Social Affairs, and Inclusion are responsible for regulations at the EU level. (Aires, Gámez, & Gibb, 2009)

3.5.3 Construction accidents in European countries

As same as in Hong Kong and mainland China, over the past years, the construction industry in Europe has accounted for most of the occupational injuries and accidents within all industries. To indicate how European countries have been performing during recent years, the statistics of the EU database Eurostat were used to obtain information about accidents and injuries in construction. This refers to tables hsw_n2_01 and hsw_n2_02. (Eurostat, 2020) The annual total of reported accidents in construction for each (major) European country was collected from 2009 until 2017. Some countries are missing because their data was not available in Eurostat. Then, the average or the arithmetic mean of the obtained data regarding annual construction for non-fatal and fatal accidents between 2009 and 2017 was calculated in Microsoft Excel 2016 and illustrated as two diagrams. The results are figures 10 and 11. Notably, blue colors in the figures refer to the countries that are members of the EU in 2019. (Eurostat, 2020) (Britannica, 2019)

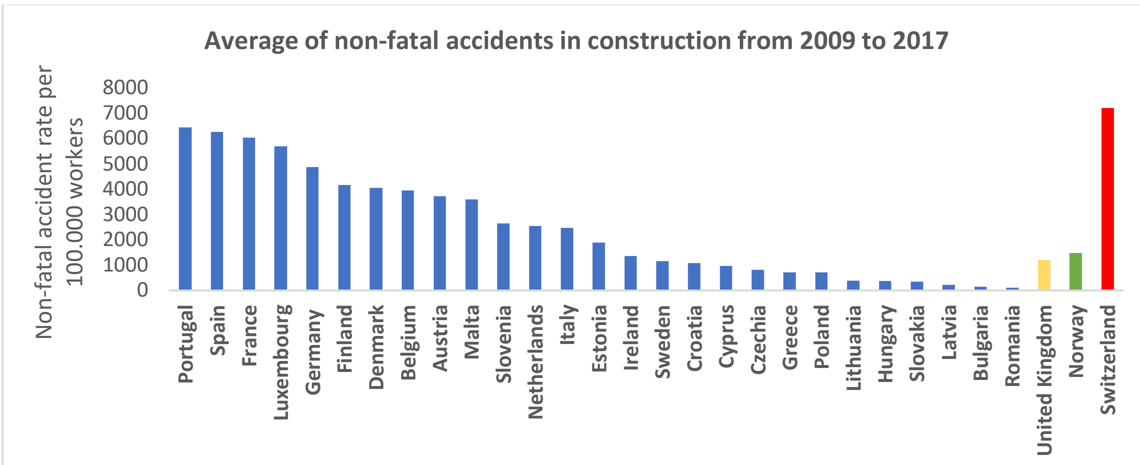


Figure 10 - Non-fatal accidents average in Europe from 2009 to 2017
Source: (Eurostat, 2020), (hsw_n2_01), graph made by authors

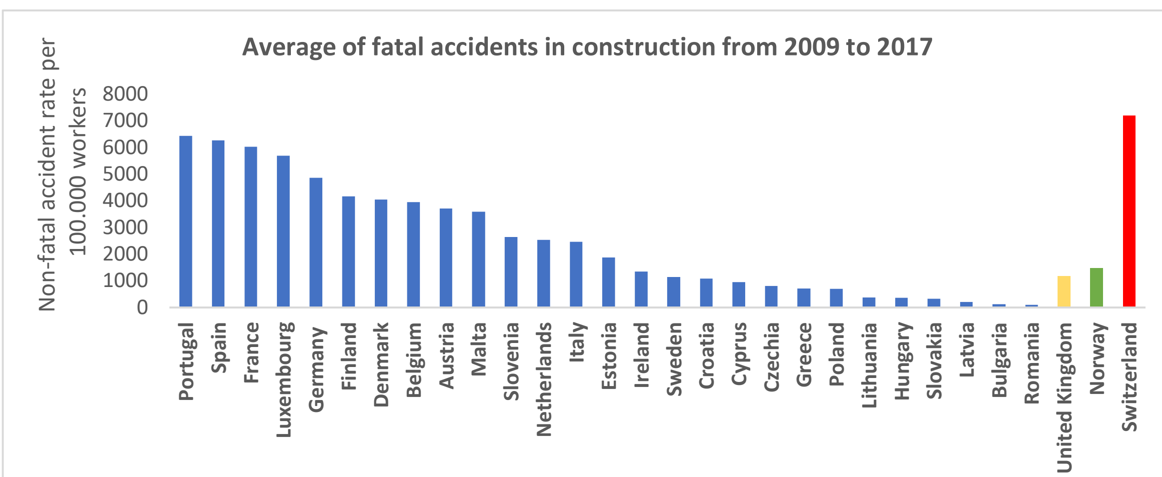


Figure 11 - Fatal accident rate average in Europe from 2009 to 2017
Source: (Eurostat, 2020), (hsw_n2_02), graph made by authors

There is a clear difference between European countries regarding non-fatal and fatal accidents. Within the category of non-fatal construction accidents, EU countries like Portugal, France, and Spain top the charts with approximately 6.000 accidents per 100.000 workers, but comparing those numbers to their fatal accidents, their statistics perform better compared to other countries. Malta and Romania have the highest fatal rates per 100.000 workers of all the EU-countries. Notably, there is a tendency for countries with high economic levels and a high level of industrialization to have the most non-fatal accidents, but they have fewer fatal accidents. (Cioca, 2018)

Bulgaria and Romania present countries with a very low non-fatal accident average during the period 2009 to 2017. Apparently, according to their fatality rate average, Romania and Bulgaria are in the top four as they have approximately 13 and 16 fatal accidents per 100.000 workers respectively.

A lot of fatalities is the opposite of what we see in general for developed countries. With both countries moving from least non-fatal accidents to high on the charts suggests that both countries have a trend of not reporting non-fatal accidents. This may be because of under-reporting from the construction companies when accidents occur that are non-fatal. Contrary to the non-fatal accidents, the fatalities are harder to hide, thus, seeing the very low non-fatal accidents from Romania and other eastern European countries also being on the low end of reports. The tendency of not reporting an accident changes the statistics and the perspective of the countries with a low non-fatal accident rate. Therefore, the fatal-accident chart is used as a reference for countries that urge improvement in risk and safety management. An example is Romania as the country has low non-fatal accidents on average but a high fatal accident rate. Malta can be misleading in statistical charts due to its low population of roughly 438.000 people in 2017. (worldometers, 2021) The focus is, therefore, on Romania rather than on countries that perform better in accident statistics. (Cioca, 2018)

3.6 Construction in Romania

The country of Romania is in the eastern part of Europe and had an economic growth of 3,5% in 2020. (Institutul National De Statistica, 2020) Romania has been part of the EU since January 2007. (EU, 2020) The country can be considered as a developing country with a high potential both in safety and in economics. (International Monetary Fund, 2020) With an estimated number of 19,3 million inhabitants, Romania is the 61^{st} most populated country in the world and ranks 54^{th} place in GDP per capita. (Institutul National De Statistica, 2020)

According to Romania's construction turnover, the industry has also grown by 19,8% from 2010 to 2016. This indicates that the construction market in Romania is increasing and developing towards western standards and, thus, the insurance rate of the country is also growing, according to historic tendencies. (European Commission, 2018)

3.6.1 Occupational health and safety in Romania

Over many years EU policies have focused on improving the social dialogue between workers and their supervisors on which changes are required to make the workplace a safer place. Romania adopted *European law 319* on workplace health and safety on the 4th of July 2006 along with many governmental decisions. Stating that workers should have a minimum level of education of high-school graduation and 40-hour training on workplace health and safety to be employed in the construction sector. The Workplace Health and Safety Committee (WHSC) is a committee of construction workers with further courses and education. THE WHSC consults with health and safety representatives and government officials to discuss and improve safety on behalf of the workers. (Frunzaru, 2016)

Romanian construction companies must participate at WHSC meetings every three months to discuss and be updated about legislative industry inputs and changes. Though Romanian companies often do not participate in these committees, as the representative workers, part of WHSC, often are very busy and unable to answer what questions other workers bring to the committee due to pressure of time. Because of this, meetings end up in a vague discussion without a focus point and no conclusion. Among other employees had no idea the WHSC existed and was to hold meetings every quarter as a minimum, even though required by law. (Frunzaru, 2016)

3.6.2 Romania's high fatal injury rate

While statistics from figure 10 show a low non-fatal injury rate of Romania, the fatal injury rate from figure 11 reveals the truth of a country with bad conditions in health and safety. Although legislations have been catering to these problems, unsafe work practices among workers rather than the working conditions of Romanian construction sites are considered as a root cause. (Sonya Meekel, 2011)

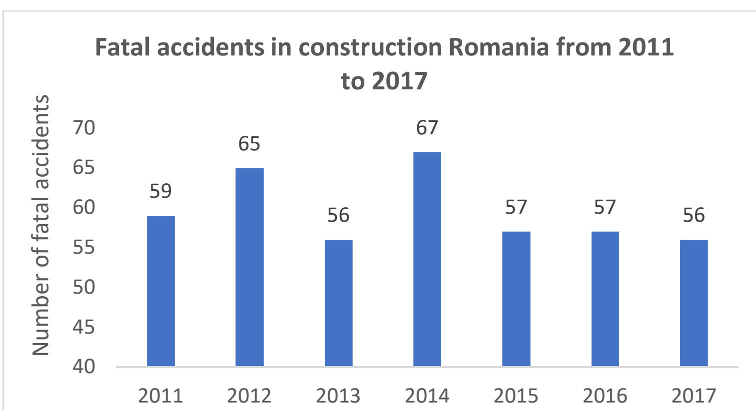


Figure 12 - Fatal accidents in the construction Romania from 2011 to 2017
Source: (Eurostat, 2020), (hsw_n2_02), graph made by authors

Figure 12 shows the number of fatal accidents registered in Romania between 2011 to 2017. With a spike in fatal accidents in 2012 and 2014. The changes are hard to notice as the fatal accident rate is stable from 2011 to 2017 and only decreased by approximately 3.

Two of the main influencers on health and safety in Romania are time and budget. Workers are pressured into taking the shortest and cheapest solution and compensating for everything else, including health and safety, to reduce the price cost. This results in construction workers' poor individual work, sometimes ignorance, and a raised work pressure because of time and budget restrictions, as 86% of interviewed construction workers have seen an increase in external pressures in the last 5 years, and 75 % of those believing the change is driven by cost. Rushing schedules and accelerating past safety problems are the root cause of Romanian injuries as productiveness among workers have a higher priority than safety. (Sonya Meekel, 2011)

Another widespread problem in the construction sector is the culture of masculinity and toughness among construction workers. as no one wants to be the weakest link of their colleagues and no emotions shall be shown when injuries occur, and often short-cuts or even ignorance towards safety procedures, limit the effectivity of health and safety legislation, safer equipment and safe systems of work.

Training courses and further education is what brought e.g. Danish and German construction sectors to increase safety, productivity, and neglect masculinity. Accepting that safety is more important, and reputation is not reduced by considering hazards. (Sonya Meekel, 2011)

3.6.3 Under-reporting of construction accidents

The reason behind the tendency of under-reporting non-fatal accidents is due to a poorly established reporting system in underdeveloped countries. A non-binding legal obligation system makes employers avoid reporting accidents if they are not fatal as it can have high negative economic consequences for the company if it is reported to authorities. Non-obligations make employers not report non-fatalities because safety poses costs while the companies seem to "gain nothing" for maintaining a high standard of occupational health and safety. Moreover, not reporting incidents avoid situations with both shareholders and government left unpleased with the company's health standards, as the statistics look good. (Joanne Linnerooth-Bayer, 2009)

The problem with under-reporting only is a problem assumed especially in low-mid income countries in Europe and less likely in economies with higher health and safety standards as e.g. Germany and Denmark. According to figure 11, Romania is at the bottom of the chart, indicating that they have the highest rate of fatal accidents on average. And because of this, Romania has probably the biggest improvement margin and most need for safety enhancements in Europe.

Germany and Denmark, for example, have still a relatively high fatal injury rate in construction on average, however, these countries have an insurance-based accident reporting system in which workers receive financial compensation for an accident that happened at work from their insurance company, not from their employers. The main difference between developed countries in western Europe and low-mid income countries like Romania is that the countries' legislation requires construction companies to compensate for the injured workers themselves is assumed to be the reason for the under-reported problem of the Romanian rate of incidents. As they save the insurance costs, but still must compensate occupants if they are injured. Western Europe is exposed to less financial risks when reporting work injuries because they will receive financial support provided by having insurance. In Romania, however, such a system does not exist, and triggers Romanian employers to not report "what they cannot hide". (Joanne Linnerooth-Bayer, 2009)

4. Risk assessment

This chapter is used to identify, analyze, and evaluate the risks in construction in more detail.

Risk assessment is an evolving process that provides useful information about risks and sources of hazards. It supports the risk managers, decision-makers, such as stakeholders to decide on acceptable risk levels and the implementation of strategies and countermeasures to reduce the likelihood or severity of risks. During risk management, the chosen strategies and countermeasures shall be monitored and reviewed to further control the sources of risks. (Stroie, 2011)

According to the ISO (International Organization for Standardization) risk management principles, a proper risk assessment consists of risk identification, risk analysis, and risk evaluation. (ISO, 2009) (ISO, 2018a) Figure 13 represents this process more graphically.

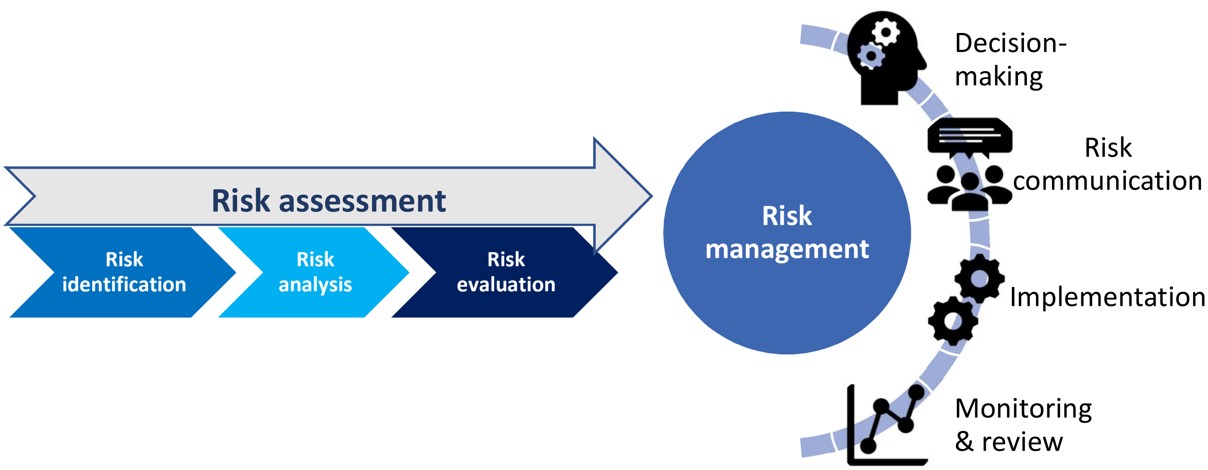


Figure 13 – Risk assessment and management process
Source: Authors

The purpose of the risk assessment, generally, is to ensure that hazards are eliminated, if possible, or risks minimized to acceptable levels by the application of correct and relevant standards. It should be suitable and sufficient which means that it must be good enough to satisfy legislation and prevent predictable injuries and losses from occurring. (RRC International, 2019) According to (RRC International, 2019), it consists of five steps:

1. Identify the hazards
2. Identify the people at risk
3. Evaluate the risk and decide on precautions (through likelihood, severity, and risk rating)
4. Record the significant findings and implement them
5. Review and update as necessary

4.1 Definitions

4.1.1 Definition of uncertainty and risk

To understand the assessment and management of risks, it is important to explain what is meant by the term *risk*. Among researchers, there is no agreed definition for risk and there are vast concepts of how to explain what is a risk. (Aven & Renn, 2009) Therefore, it is important to indicate how the authors understand the risks in this thesis.

The classic definition of risk refers to the calculable part of uncertainty, for which it is possible to estimate the occurrence probability and the magnitude of damage or loss. Uncertainty is not an unknown risk. Uncertainty is the opposite of certainty and exists where imperfect or unknown information is present. It is also defined as the unknown unknowns that we cannot reasonably estimate, measure, and predict. Whatever is completely unknown, cannot be prevented from occurring because fundamental knowledge is not provided. (Aven & Renn, 2009) (Aven, 2010)

According to (Aven, 2010), the classic definition of risk is a measure, or outcome, of the probability and severity of negative consequences:

$$Risk = Probability \times Severity$$

Negative events and risks are part of our daily lives and there are only rare things that pose completely no risk, thus, we not able to avoid but to choose between risks. (Kaplan & Garrick, 1981) Risk can affect only one person, but it can also harm more people, the environment, processes, systems, organizations, industries, and governments depending on its severity. (Aven, 2010) Risk is assumed as a deviation from the desired level and has usually a negative outcome, but can also be positive. (Dziadosz & Rejment, 2015)

Another definition is the quantitative definition of risk by (Kaplan & Garrick, 1981), as risk is the outcome of probability *and* consequence, divergent from the classic definition of risk as to the outcome probability *times* consequence. This mainly because the classic definition may be deceptive. "*In the case of a single scenario, the probability times consequence viewpoint would equate a low-probability high-damage scenario with a high-probability low-damage scenario- clearly not the same thing at all."* (Kaplan & Garrick, 1981) When analyzing risks, we attempt to foresee the consequences of our actions or inactions that influence the future to some degree. The goal of the risk analysis is, therefore, to answer the following three questions:

i. "*What can happen? (i.e. What can go wrong?)*
ii. *How likely is it that that will happen?*
iii. *If it does happen, what are the consequences?*" (Kaplan & Garrick, 1981)

For responding to these questions, a list of outcomes or "scenarios" may be useful, as recommended in figure 14.

Scenario	Likelihood	Consequence
s_1	p_1	x_1
s_2	p_2	x_2
⋮	⋮	⋮
s_N	p_N	x_N

Figure 14 - Scenario list
Source: (Kaplan & Garrick, 1981)

"If the table contains all the scenarios we can think of, we can say the table is the answer to the question and therefore is the risk. More formally, using braces, {}, to denote "set of" we can say that the risk, R, "is" the set of triplets. (Kaplan & Garrick, 1981)

$$R = \{< s_i, p_i, x_i >\}, \quad i = 1, 2, ..., N.$$

In terms of the classic definition of risk, risk equals the expected value of damage even if multiple scenarios are considered. This view might lead to the conclusion that risk is the mean of the risk curve, which is a visual depiction of the risk between probability and losses. From the perspective of (Kaplan & Garrick, 1981), however, the risk is not the mean, but the curve itself. "*A single number is not a big enough concept to communicate the idea of risk. It takes a whole curve.*" (Kaplan & Garrick, 1981)

The probability is a statistical measure of uncertainty about future events and consequences. There are different concepts of probability, depending on how probability is defined and measured. One concept is the frequency concept of probability, also known as the objective measure of probability. Should previous information or data be available about the occurrence of outcomes or events, the probability is defined as the proportion of times an outcome occurs if the same condition is repeated over the long haul again and again. Generally, if a situation is repeated many times (M), and if an outcome (X), occurs (m) times, then the probability can be measured by

$$P(X) = \frac{m}{M}.$$

However, if there should be no evidence of the same or similar past situations, the concept of subjective probability can be used. The subjective probability is seen through the eyes of an assessor or an individual's personal view about the chance of an outcome to occur. The subjective probability is based on some background information, knowledge, experience, and can be very individualistic. The probability of the risk can be expressed as a percentage or decimal value between 0 (for statistically not occurring) and 1 (for one hundred percent certainly occurring). (Ahuja, 2017) (Aven, 2010) The goal of risk management should be to estimate the probability of risks as best as possible, so their impacts are measured right. Moreover, according to the definition of risk, the considered event must be to some extent certain only then it can be measured through probability. (Aven & Renn, 2009)

The severity of risk is a measure for quantifying risks. The severity refers to "*intensity, size, extension, scope and other potential measures of magnitude, and affects something that humans value (lives, the environment, money, etc.)"*. Through severity, risks can be ranked, for example, between low, medium, and high, and estimated in monetary values. It is important to note that the severity is just a way of describing the consequences. (Aven, 2010)

Considering the example of a person who is playing roulette in a casino and expects to win a great amount of money because he or she bets everything on only one number – all in or nothing. The bet and probable loss of 5€ have relatively low severity because 5€ have only little buying power compared to the loss of 50€, meaning a medium severity because this amount of money is more valuable than 5€. A high severity would be if the person bets and loses 500€. Losing 500€ can be described as an impact with a high severity because of its consequences. Unless the person has a relatively high income, losing 500€ can result in great difficulties in paying for essential goods or services like the apartment rent, groceries, or the electricity bill for example. Therefore, losing 5€ is only a low risk, while losing 50€ presents a medium risk. A high risk would be if the person bets and loses 500€ in the bet. (Aven & Renn, 2009)

Another example of severity is the degree of an injury experienced by a worker in a construction task. The worker operates a defective machine and suffers from a minor injury - a cut in the finger. The worker might require first-aid because of the depth of the wound and work needs to be stopped. This process could slow-down progress, cause small delays, and low costs for the employer. This kind of event has certainly happened before and is relatively easy to manage, therefore has a low severity. If the worker loses his small finger, the severity can be estimated as medium. Work needs to be stopped, first-aid must be provided, and the worker needs to take time off to recover. For the employer, this incident will require more administrative effort because it needs to be reported at least to management and requires investigation of how it could happen (also to prevent it from happening again). A high severity would be if the person loses his hand which leads to a great loss of blood, removes basic movement capability, and although the worker did not die, his quality of life is reduced through this accident. For the worker, the quite severe consequences will require weeks of recovering in the hospital and at home, perhaps unemployment. For the employer, this could result in high compensation costs, sick pay, fines, costly legal complications in court, prosecution, and stop of business if more accidents like this occur. (RRC International, 2019)

4.1.2 Definition of hazard

As previously explained, a risk is a chance that something negative will probably cause harm or loss. A hazard can be understood as a source of harm. It can be events, substances, or conditions that can result in damage to health, life, property, the environment, or any other interests of value. (Aven, 2010) (Kaplan & Garrick, 1981) For example, we imagine a person who is swimming in a small pool. The swimming pool is in a bad condition and there is too much chemical chloride in the water. The consequence of skin contact with too much chloride will negatively affect the health and physical condition of the person. A very high concentration of chloride imposes a health risk for the person swimming because it may lead to dehydration, kidney damage and/or acidosis (condition when there is too much acid in the blood system), and even death. High levels of chloride can also cause short- or long-term symptoms of skin irritations, diarrhea, nausea, dizziness, weight loss, vomiting, and general weakness (fatigue). Low levels of chloride might cause the risks of heart failure and lung diseases. (Pfortmueller, 2018) (medlineplus.gov, 2020) Hence, the person in our example is exposed to many risks while the source of the risks mostly caused by mainly one hazard, namely too high levels of chloride in the pool. Hazards can be classified based on their energy source, origin, or effect. Hazards classified by their effect are health hazards, safety hazards, economic hazards, and environmental hazards. (RRC International, 2019)

Health hazards distress the health of exposed persons through measurable changes in the body indicated by the development of signs and symptoms, or non-measurable, indicated by subjective symptoms. Health hazards typically lead to an acute or chronic illness as consequence (e.g. asbestos, dust, carbon dioxide). (RRC International, 2019) (ISO, 2009) Safety hazards may be created by ergonomic tasks and requirements associated with the work of a person (e.g. repetitive manual handling, heavy lifting). The distress the safety of individuals and people, typically causing an injury or fatality (incident). Economic hazards can financially impact the success of a project (e.g. a disaster causing the collapse of the stock market). Environmental hazards affect the environment, principally the natural environment and ecosystems. Higher than natural levels of radiation can, for example, originate from building elements that are made of concrete and similar materials. (Kowalik, Logon, Rybak, Ubsyz, & Wojtowicz, 2019)

4.2 Risk identification in construction

The fundament of risk management is risk identification. Quite often, construction projects fail to achieve their goals of time, quality, budget, and safety. Negative consequences can include economic loss, personal injury, death, physical damage, time, and cost overrun. There are many factors of the environment, resources, manpower and management that come into play, which makes risk identification a challenging but necessary part of the construction lifecycle. (Alkaissy, Arashpour, Baabak, Hosseini, & Bai, 2019) (Suraji, Duff, & Peckitt, 2001)

At the stage of risk identification, it shall be identified which hazards and factors are likely to affect one part or even the whole sequence of the project or system. For the risk assessment, it is the first step to detect the potential hazards and risks associated with the construction project. (Zou, Zhang, & Wang, 2007) Some of the common risk identification methods are the following:

- Brainstorming (expert elicitation),
- Delphic technique,
- Use of checklists,
- Experts' evaluation,
- Internal and external audit in a company,
- Periodic document reviews (Dziadosz & Rejment, 2015)

An overview of project risks that are can negatively affect the construction process or construction site can be found in *Appendix 3 – Project risk identification in construction*. The project risks were gathered through research and supported by the expert elicitation of the thesis authors. The list is not final and exhaustive. Many other risks are likely to create loss and other negative consequences but require further study and research.

For example, construction designers could fail to provide correct measurements which might lead to changes and adjustments, and result in loss of productivity, higher costs, poor quality, etc. Financial and economic risks, generally, might affect the availability and flow of monetary resources and goods. A frequent risk experienced by contractors is overspending the budget. In a tender process, the contractor must estimate the budget and prepare a quotation to get hired for a construction project. The actual project cost might well overrun the initial budget because of different reasons. While executing the contract (especially a fixed price contract), contractors must be aware of changing conditions in and outside the workplace because they can negatively impact the project costs. (Yan & Liu, 2020) Political (or legal) risks include inter alia that the country peace might be under threat because of e.g. civil war, the economic stability of the country (which could be also a financial risk), such as chaining regulations and presentative officials. Laws have a great impact on the construction project. The work must not always be stopped but regulations, policies, practices, procedures, or other requirements can likely demand that certain activities could be stopped until the activity complies with the present legislation. (Oetzel & Miklian, 2017) Construction-related risks are more interesting for this thesis because they create negative consequences and awful conditions at work. They affect mainly workers, machinery, equipment, and property, but can also distress other parts or stakeholders of the construction project (e.g. investors, contractors, insurance companies, the public). When site conditions pose hazards (e.g. caused by bad housekeeping), injuries are more likely to occur. This is also true for lacking utilities on-site or safety equipment (e.g. lack of easy-accessible and reliable safety harnesses for conduction work at heights). (Tam, Zeng, & Deng, 2004) (Zou, Zhang, & Wang, 2007) Construction has a high intensity of labor; thus, human behavior has a great influence on workplace safety. This will be explained in more detail at a later stage. If workers ignore safety procedures, they put themselves in greater danger and may risk the lives of others which can cause near-misses and accidents. Moreover, insufficient management (e.g. lack of supervision, monitoring, or worker consultation) can lead to inefficient processes and can increase the likelihood of incidents and accidents, thus, delays, different types of costs, etc. However, threats can also be created by the failure of equipment. A defective harness, for example, might fail to prevent and mitigate a fall from heights. (Zhang & Fang, 2013) Environmental risks are to some extent impossible to avoid and prevent, and their management is challenging. Very bad weather (e.g. a storm, heavy rain) could result in a stop of work, while natural disasters and other emergencies (e.g. an earthquake, the breakout of fire, the explosion of a nuclear factory, a tsunami) are more dangerous. Finally, diseases (e.g. COVID-19) and pollution (e.g. the amount of carbon dioxide in the air) can also have negative impacts on workers' health and safety during the construction process. (RRC International, 2019)

4.3 Construction related hazard identification (HAZID)

Many hazards can affect the project and the actual construction process. (Zou, Zhang, & Wang, 2007) describe the process of construction as very difficult because projects are "*long-period*, *complicated processes, abominable environment, financial intensity, and dynamic organization structures, and such organizational and technological complexity generates enormous risks*." Construction is fully different from the manufacturing industry, for example, which is a static work setting with mostly stationary employees working in fabrication sceneries. The construction industry is regarded as a dangerous industry with a lot of injuries due to three characteristics: decentralization, mobility, and dynamic. The meaning of decentralization is that the employees are separated by sites and although regulations and plans are available, they still must make decisions by themselves when facing specific problems. Mobility implies that construction employees move among positions, construction sites, and companies more often as compared to other industries. There is also more dynamic in construction, which refers to constantly changing structures and processes, such as labor. Because of these characteristics, safety performance is more relevant to human factors. Moreover, the dynamic of the workforce on construction sites may be very complex and might improve much slower than that in many other industrial settings, especially under the labor subcontracting system. (Lee, 1993) (Choudry & Fang, 2008) (Khosravi, et al., 2015)

For the risk identification of construction-related risks, the qualitative method of HAZID is used because it creates a great overview of the hazards, causes, and consequences but also considers what can or should be done to eliminate or minimize the impact of the hazard. The HAZID consists of the five columns Cause, Prevention (proactive), Hazard, Mitigation (reactive), such as Consequences. (cholarisk, 2020)

Causes refer to the source of origin of the hazard. Many of the causes were identified by expert elicitation and with help of (RRC International, 2019), (Abdelhamid & Everett, 2000), (OSHA Europe, 2007), (Choudry & Fang, 2008), (Fitzgerald, Chen, Qu, & Sheff, 2013), (OSHA U.S., 2016), such as (Census and Statistics Department, 2019).

Prevention measures are effective, proactive controls that should protect workers from hazards. They aim to avoid or reduce hazards; thereby minimizing or eliminating risks of injuries, illnesses, and incidents. They are proactive and aim to lower the probability and/or severity of the hazard from occurring. When hazards are eliminated they will not occur. (OSHA, 2020a) The preventive controls in the HAZID should refer to the causes of hazards so it is more obvious which actions are recommended to prevent the occurrence. However, because some causes can be prevented by the same or very similar controls, the order of the prevention controls does not always refer to the causes in the HAZID precisely, also due to layout limitations in Microsoft Word 2016. According to (OSHA, 2020a), effective preventive control strategies should always be identified through worker consultation because workers are the best source of information about the conditions that create hazards and workers might provide insights into how they can be controlled. Options for controlling hazards should be based on the "hierarchy of controls" which is also of great use for the risk management process. (RRC International, 2019) The hierarchy of controls will be further explained in subchapter *5.1.1 Control of risks through the hierarchy of controls*.

Hazards refer to threats or something that has mostly negative consequences for the workers and the construction company. The identification of hazards and risks, generally, can be found in internal information sources of the operating organization. It is worth to investigate accident records, medical records, risk assessments, maintenance records and reports, safety representative inspections, audits records, safety committee meeting minutes, meeting protocols, etc. Otherwise, national legislation, approved codes of practice, standards published by the International Organization for Standardization (ISO), manufacturers information, research papers, journals, magazines, etc. are of great help for external information. Another more specific hazard identification method is task analysis. Task analysis allows detecting hazards before the work starts and divides the work tasks into component steps. For each component step, associated hazards should be further analyzed, and individual control measures introduced. (RRC International, 2019) Finally, it is also recommended to review safety logs of the company or from recognized safety organizations like OSHA, HSE, or other official bodies of the government with relation to occupational health and safety. (OSHA U.S., 2016) (RRC International, 2019)

Depending on the scope of the hazard identification, there could be many more hazards to be identified which could affect the environment, the public, or other stakeholders but this requires further research and investigation. The HAZID considers only the "most common" and frequent hazards that are likely to be found on construction sites in general. The HAZID will also be limited in hazards that cause negative consequences for construction workers who are directly or indirectly affected by the hazards on construction sites. The hazards will be classified by their effects on physical, safety, chemical, biological, ergonomic, and psychological hazards.

Mitigation strategies are any sustained actions taken to reduce the impact of the hazard. Mitigation is reactive, because the occurrence of the hazard is already known, and the source or cause of the hazards cannot be eliminated, thus, it will have negative consequences. Mitigation helps to minimize the severity or likelihood. Mitigation strategies also require further monitor and review after the actions were taken. (nh.gov, 2020)

Consequences are the undesired events and outcomes if the hazard occurs. The thorough identification of consequences is of great importance to predict the probability and indicate the severity. Some hazards may be more destructive than others and might require higher alert and prioritizing. The consequence analysis also helps to estimate costs resulting from the hazard scenarios. Hazard scenarios may address the questions of *who, what where, when, why,* and *how*. Thus, it provides a transitional product that expresses the condition and the consequences that will be further assessed during the risk analysis. (RRC International, 2019) (OSHA U.S., 2016)

Figure 15 presents the HAZID.

Cause	Prevention (Proactive)	Hazard	Mitigation (Reactive)	Consequences
Physical hazards				
Bad housekeeping (e.g. cables and wires)	Procedures for clean-up, proper housekeeping, and tidy-ness	**Slip, trip, or falls**	Personal Protective Equipment	**Minor injuries Fractures Broken bones Head injuries Trauma Death**
Objects on the floor	Protective footwear		Maintenance and inspection	
Poor lighting in the workplace	Provide suitable lightning			
Unsuitable floor coverings	Use of slip-resistant surfaces		Safety training and information	
Damaged or uneven floor surfaces	Personal Protection Equipment			
Contaminated floor surfaces (e.g. due to oil)	Clear and visible safety barriers		Behavioral controls (e.g. through supervision, cameras, CCTV)	
	Safe work practices			
Loose floor surfaces (e.g. due to clutter, debris, etc.)	Clear signage of high-risk areas		Use of safety signs	
Work with electricity or electrical components	Avoid work with electricity	**Electricity**	Personal Protective Equipment	**Electrical shock Arcing Secondary effects (any sort of injury that results indirectly from receiving an electric shock, e.g. falls, cuts, bruises, and broken bones) Fire Loss of muscular control Burns Respiratory arrest Ventricular fibrillation Death**
	Earthing		Residual current devices	
	Isolation of supply		Reduced and Low-Voltage systems	
	Double insulation		Inspection and Maintenance	
	Formal visual inspection, testing, records of inspection and testing		User checks	
	Personal Protective Equipment			
Use of electrical equipment in wet environments	Safe work practices		Competent persons	
Improper connections	Fire protective arrangements and emergency procedures			
Work near overhead power lines	Safe system of work (e.g. Permit-to-work)		Safety training and information	
Contact with underground power cables	Protection of conductors			
Work on the main electricity supplies	Fuses and miniature circuit breakers		Supervision	
Electrical outlets or switches	Avoid overloading in outlets			
Pinched or pierced wire insulation	Proper equipment inspection		Protective measures against fire	
Construction machines	Acoustic heaven	**Noise**	Personal Protective Equipment	**Temporary reduction in hearing sensitivity Noise-Induced Hearing Loss (NIHL)**

			Safety training and information	**Tinnitus** **Inability to hear/ Deafness** **Stress effects** **Difficulty concentrating and an increase in errors**
Use of construction tools	Hearing Protection		Damping, silencing	
Combustion engines	Modifying the process		Health surveillance	
Use of vibrating construction machinery and tools	Reducing the vibration at source - elimination	**Vibration**	Interrupt pathway from source to receiver – isolation	**Hand-Arm Vibration Syndrome (HAVS)** **Nerve** **Muscle weakening**
			Personal Protective Equipment	
			Limiting the duration of exposure	
			Safety training and information	
Alpha particles (e.g. smoke detectors)	Radiation exposure should be eliminated as far as is reasonably practicable	**Radiation**	Safety training and information	Acute effects: **Sickness** **Diarrhea** **Hair loss** **Anemia** Chronic effects: **Cancer** **Genetic mutations** **Birth defects** **Death**
Beta particles (e.g. science labs and thickness gauges)				
Gamma-rays (e.g. from industrial radiography for non-destructive testing of metal and welds)			Personal Protective Equipment	
	Exposure should be reduced to the lowest level reasonably practicable		Health surveillance	
Working exposed to different and changing temperatures	Avoid working in the heat	**Heat**	Sun cream	**Fatigue** **Minor injuries** **Burns** **Heat strokes** **Skin cancer** **Death**
Working exposed to sunlight	Protected work environments from heat and sunlight		Building shelter	
Working in a confined space	Use of proper ventilation		Proper ventilation	
Hot work	Safe work practices		Shift work	
Working in hot environments			Adequate rest time	
Working without ventilation	Personal Protective Equipment		Health surveillance	
Working in hot conditions			Safety training and information	
Faulty equipment	Routinely inspection and testing of facilities, machinery, and equipment	**Fire**	Fire alarms	

Hot work	Safe systems of work (e.g. Permit-to-Work)		Safety training and information	**Minor injuries** **Fractures** **Broken Bones** **Burns** **Fire blasts** **Explosions** **Inhalation of smoke** **Respiratory diseases** **Unconsciousness** **Cancer** **Collapse of structures** **Death**
Work with electricity	Safe work practices		Personal Protective Equipment	
Work with combustible materials	Safety training and information		Enclosure	
	Fire risk assessments			
Working with combustible chemicals	Control of combustible and flammable materials		Emergency and rescue arrangements	
Cooking and heating appliances	Supervision		Emergency drills	
Mechanical heat			Regular inspection and testing for firefighting equipment	
Deliberate ignition	Security arrangements			
Smoking	Prohibition of smoking in areas where the risk of fire exists		Sprinklers	
	Safe disposal of smoking materials in the designated outdoor smoking areas		Appointed first-aid personal	
Working exposed to rain	Avoid working in bad weather	**Weather**	Increase visibility through adequate lightning	Cold and wet weather: **Dehydration** **Numbness** **Shivering** **Frostbite** **Immersion foot** **Hypothermia** **Death** Hot and dry weather: **Dehydration** **Fatigue** **Heat strokes** **Sunburn** **Skin cancer** **Death**
Working exposed to snow				
Working exposed to fog	Protection and shelter		Personal Protective Equipment	
Working exposed to ice				
Working exposed to very high humidity or very low humidity			Frequent breaks and rest times	
Working exposed to wind				
Working exposed to storm	Personal Protective Equipment			
Working exposed to high temperatures or very low temperatures				
Working exposed to the high exposure of sunlight			Monitoring of weather conditions	
Working at night				
Safety hazards				
Malfunction of work equipment	Proper and regular inspection of equipment with checklists		Safety training and information	

	Safe work practices	**Work equipment**	Two-Hand controls, Hold-to-Run controls	**Minor injuries** **Cuts** **Fractures** **Burns** **Dislocation** **Broken bones** **Death**
Breakdown of work equipment	Fixed, interlocked, adjustable, and self-adjusting guards on construction tools and machines		Supervision	
	Use of sensitive protective equipment (trip devices)		Regular inspection and maintenance	
Improper use of work equipment	Use of protective appliances		Emergency stop controls	
	Proper instruction and supervision			
Poor maintenance of vehicles	Drivers training and information	**Vehicles and moving machine parts**	Traffic control	**Struck by vehicles** **Fall of loads** **Collapse or toppling of equipment** **Falls from height** **Obstruction in a traffic route** **Death**
Poor securing of loads	Ensuring safe parking and storage to avoid obstruction		Safety training and information	
Interfering of workers or pedestrians with vehicles	Routine inspections and maintenance		Personal Protective Equipment	
Working on elevated platforms, high buildings, etc.	Avoid working at height	**Work at height**	Safety training and information	**Falling from heights** **Falling of objects** **Dropping of objects** **Minor injuries** **Fractures** **Broken bones** **Head injuries** **Trauma** **Death**
Unstable or poorly maintained access equipment	Prevent materials from falling using physical safeguards, such as toe boards and brick guards		Proper instructions and supervision	
Deterioration of materials	Use of physical safeguards to prevent falling objects from hitting people below		Personal Protective Equipment	
Unprotected edges	Use of safety equipment (e.g. safety harness, fall arrest)			
Weather	Use of suspended access equipment		Emergency rescue training	
Bad housekeeping	Safe work practices			
Falling materials	Use of scaffolds, ladders, step ladders, mobile elevating work platforms, mobile tower scaffolds, etc.		Proper housekeeping and tidiness	
	Avoid working in confined space		Safety training and information	
	Safe System of Work for entry and egress		Use of proper ventilation	

Working in enclosed areas	Safe system of work (e.g. Permit-to-Work)	**Work in confined space**	Supervision	**Fire** **Explosion** **Loss of consciousness or asphyxiation arising from gas, fumes, vapors** **Lack of oxygen** **Drowning** **Asphyxiation** **Loss of consciousness because of increased body temperature** **Death**
	Safe work practices		Frequent breaks and rest times outside confined spaces	
	Stand-by person			
	Use of proper ventilation		Fire prevention measures and alarms	
Restricted ventilation	Reduce combustible and flammable materials			
	Isolation and lock-off of in-feeds and out-feeds		Efficient communication methods to be used inside the confined space	
	Isolation and lock-off of electrical and mechanical hazards			
Difficulties in access/egress	Efficient communication methods to be used inside the confined space		Safe and quick access and egress methods	
	Suitable lightning			
Working exposed to gases, fumes, vapors	Suitability of individuals in terms of body size and psychology (e.g. not claustrophobic)		Emergency and rescue arrangements and training	
	Gas testing			
	Removal of residues			
Working alone	Avoid lone working	**Lone working**	Safety training and information	**Being the victim of violence** **Unconsciousness** **Any type of injuries and ill health due to falling, confined space, etc.**
	Procedures for logging workers' locations when lone working		Arrangements for remote supervision (e.g. cameras, CCTV)	
	Lone workers alarm systems to raise the alarm		Use of mobile phones, radios or other communication channels	
	Safety training and information		Emergency and rescue arrangements and training	
Chemical hazards				
Work, processes, or exposure to substances hazardous to health that can be inhaled, swallowed, digested, and/or absorbed by the skin	Elimination or substitution of hazard	**Solids** **Dust** **Fumes** **Gases** **Mists**	Reduce exposure time	Acute effects: **Minor injuries** **Burns, Nausea** **Sickness** **Diarrhea** **Hair loss** **Anemia**
			Safety training and information	
	Change of process		Personal Protective Equipment	

	Respiratory Protective Equipment	**Vapors** **Liquids** **Fibers** **Smoke**	Dilution ventilation	Chronic effects: **Gradual progressive, irreversible damage to organs, bones, nerves, and body parts** **Cancer** **Genetic mutations** **Birth defects** **Death**
	Enclose or segregation of hazard		Health surveillance, including biological monitoring	
Biological hazards				
Work, processes, or exposure to biological agents that can be inhaled, swallowed, digested, and/or absorbed by the skin	Elimination or substitution	**Fungi** **Bacteria** **Viruses**	Reduce exposure time	**Diseases** **Sickness** **Diarrhea** **Organ damage** **Death**
	Personal Protective Equipment			
	Personal hygiene		Reduce the dose of exposure	
	Change of process		Safety training and information	
	Respiratory Protective Equipment		Health surveillance, including biological monitoring	
	Enclose or segregation			
Ergonomic hazards				
Very repetitive movements of relatively small loads	Good handling technique	**Manual handling**	Personal Protective Equipment	**Back injuries** **Tendon and ligament injuries** **Muscle injuries** **Hernias** **Chronic soft-tissue injuries (WRULDs)** **Cuts** **Fractures** **Burns** **Dislocation** **Broken bones**
On-off movements of very large and heavy items	Lifting devices		Rest times and shift work	
Lone working	Working in teams (also to reduce the workload and duration of work)		Maintenance and inspection of tools and equipment	
			Supervision	
Working in awkward postures	Safe work practices		Safety training and information	
Work in cramped spaces				
Psychological hazards				
Lone working	Zero-tolerance policy and prosecution of offenders		Safety training and information	**Stress** **Fatigue**
Working under time-pressure	Security staff		Diffusing aggression	

Dealing with people under the influence of drugs and alcohol	CCTV cameras	**Work-related violence, racism, sexual harassment, mobbing, mental ill-health, etc.**	Screens between staff and public	**Inability to concentrate Insomnia Being extra alert (Hypervigilance) Post-Traumatic-Stress-Disorder (PTSD) Depression Anxiety Increased aggression potential**
Working with violent people	Security doors between public areas and staff areas		Panic alarms	
Working overtime	Pleasant environment		Reporting and storing of past incident records	
Mental illness	Worker consultation and support		Worker consultation and support	
Use and/or abuse of alcohol and other drugs (e.g. cocaine, crack, ecstasy, ketamine, crystal meth, etc.)	Rules restricting access to alcohol during working hours	**Substance abuse at work**	Arrangements for workers to have access to rehabilitation and treatment programs	**Late attendance Increased absenteeism Reduction in quality of work Reduced situation awareness Reduction in work rate Dishonesty Theft Potentially to fund a habit Irritability and mood swings Deterioration in working relationships Organ damage Death**
	Statutory legal requirements prohibiting to be under the influence of drugs and alcohol		Disciplinary procedures for those who refuse assistance refuses to be tested or fails a test	
	Non-statutory requirements prohibiting workers from being under the influence of drugs that have been set by the employer		Provision of information, instruction, and training to workers, supervisors, and managers	
	Arrangements for any random drugs and alcohol testing		Arrangements for any random drugs and alcohol testing	

Figure 15 - HAZID of construction processes
Source: Authors

4.3.1 Occupational diseases in construction

According to WHO, occupational diseases are contracted *"primarily as a result of an exposure to risk factors arising from work activity*". They can have several causes and factors in the work environment that may need to be considered in combination with other risk factors, to prevent or mitigate the risk. (WHO, 2020)
Occupational diseases can have devastating, sometimes lethal, consequences for construction workers. Companies usually need to pay compensation costs if they are found as the source of harm or cause of death. Diseases often lead to too much pain for the worker, stop of work, unemployment, medical treatment costs, and generally lower quality of life. (RRC International, 2019) Some of the most common occupational diseases in construction are listed below:

- Asbestos-related injuries, such as mesothelioma and other cancers
- Respiratory Ailments, especially asthma/COPD
- Noise-indicated hear loss (NIHL)
- Repetitive stress injuries
- Back, neck, and knee injuries (HSE, 2020d) (van der Molen, de Vries, Stocks, Warning, & Frings-Dresen, 2016)

Workers who do a lot of the activities like curbing, paving, block-cutting; stone masonry, stone floor laying; demolition; and chasing out/re-pointing, have a high chance of being diagnosed with respiratory problems, with the main cause being exposure to dust and respirable crystalline silica resulting in the disease silicosis. Other prevalent respiratory diseases amongst construction workers are COPD (Chronic Obstructive Pulmonary Disease) and asthma. (HSE, 2020d) Researchers who observed and analyzed the reported annual incidences in the construction sector in the Netherlands for five years found out that especially hearing loss and work-related contact dermatitis (a disease which can cause symptoms of itchy, dry skin or a rash on swollen, reddened skin) significantly increased. The annual incidences in work-related repetitive strain complaints, back complaints, arthrosis, distress/burnout, and asthma/COPD did not change significantly in their study. (van der Molen, de Vries, Stocks, Warning, & Frings-Dresen, 2016) (mayoclinic.org, 2019)

4.3.2 Occupational diseases in Hong Kong

According to figures from the (Labour Department, 2020) for all industries in Hong Kong, occupations related to construction have the highest risk of contracting occupational diseases during or after employment. From 2011 to 2019, occupational deafness, silicosis, and tenosynovitis of the hand or forearm always ranked always in the top three. The reported numbers are shown in table 2.

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019
Disease	Number of confirmed occupational diseases								
Occupational deafness (including monaural hearing loss)	157	99	65	78	133	184	177	275	308
Silicosis	63	44	51	68	56	43	54	59	52
Tenosynovitis of the hand or forearm	70	69	38	64	31	63	39	39	35

Table 2 - Occupational diseases in Hong Kong from 2011 to 2019
Sources: (Labour Department, 2012), (Labour Department, 2013), (Labour Department, 2014), (Labour Department, 2015), (Labour Department, 2016), (Labour Department, 2017), (Labour Department, 2018), (Labour Department, 2019), (Labour Department, 2020)

4.4 Stakeholder analysis of health and safety in construction

The second step of the risk assessment is to identify the people at risk - which will be done by conducting a stakeholder analysis. Conducting a stakeholder analysis for occupational health and safety on construction sites is beneficial because it helps to identify who is affected in changing and unpredictable environments, such as to indicate who has probably a lot of power to improve the conditions. (Aapaoja & Haapasalo, 2014)

A stakeholder can be defined as a person (e.g. an employee, customer, or citizen) or group of people who are somehow interested, involved, have some aspect of rights or ownership, or responsibilities in an organization, business, project, society, etc. (Dictionary Cambridge, 2020) Some stakeholders will always have divergent interests because of their objectives and socio-cultural backgrounds but also their contribution of knowledge or support can differ, such as their power of influence and ability to catalyze changes can differ. Power relates to the probability that one stakeholder can execute his or her own will regardless of resistance from other stakeholders. Power might also be explained in the degree to which managers give priority to competing stakeholder claims. The different levels of power of stakeholders will possibly be caused by their ability to mobilize social and political efforts, or, to add or remove resources from a project. (Aapaoja & Haapasalo, 2014) In construction, each stakeholder has specific requirements concerning the project, which creates ultimate conflicts with others. Especially the project managers need to consider and satisfy a variety of stakeholders, which include the end-users, the clients, investors, costumers, designers, the government, employers, and employees. One conflict, for example, could be that the project manager must coordinate many functions at the same time but only a small budget for health and safety is available. Thus, the management is challenged in how to ensure efficiency and productivity without taking too much risk of exposing workers to hazards. (Aapaoja & Haapasalo, 2014)

Figure 16 presents a general stakeholder analysis considering persons or groups that have an interest, are passively affected or affect actively the management of occupational health and safety on construction sites.

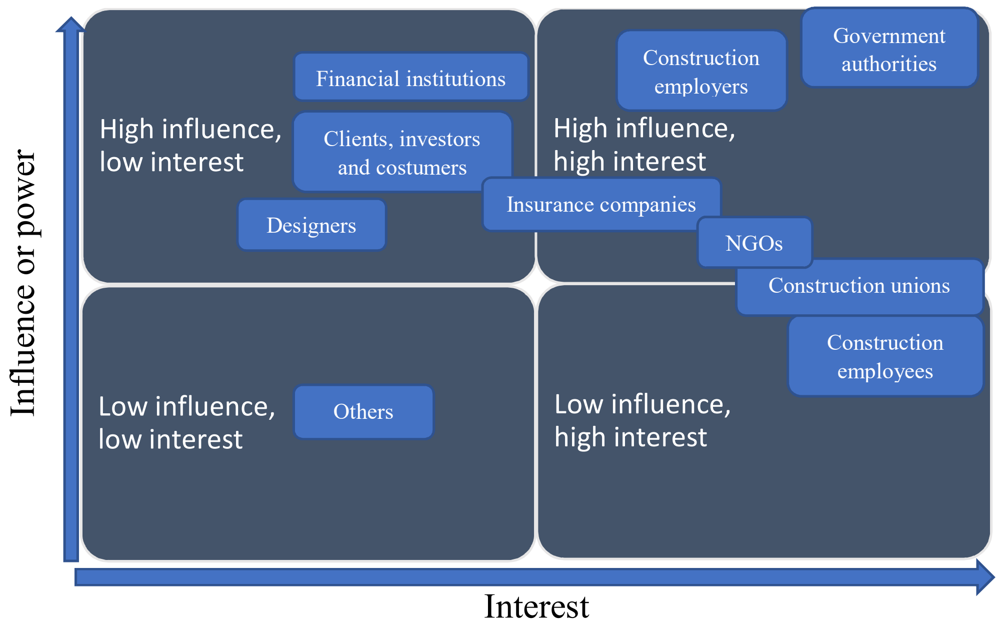


Figure 16 - Stakeholders with interest in health and safety management in the construction industry
Source: Authors

Construction employees: Every employee is responsible and accountable for his or her own health and safety. Workers' attitudes, norms, beliefs, and actions should reflect that workers think and behave with care to protect their own life and promote the safety and well-being of others. This includes they follow the safety procedures formulated by their employer, wear PPE, warn others in situations of danger, handle operations as required by the safety procedures, and consult with the employer when they are unsure about the safe operation of a task, where hazards are identified, where safety measures are not in place or fail, and to report unsafe behavior, near-misses, and incidents of others so that safety for everyone can be ensured and improved. Workers must be competent, trained in safety and the task-at-hand, be instructed and aware about the hazards and risks inherent in their work and workplace so they have the chance to work safely without causing harm to themselves and others. (ILO, 2020a) (RRC International, 2019) For the construction industry, workers are the most important element because without workers there would be no work done. They are the backbone and human capital of construction employers. From a legal, moral, and financial point of view, their health and safety must always be protected by the construction employers. (RRC International, 2019) They have high interest but not so much power.

Construction employers: They are the employers of construction workers. Construction employers have a moral duty which relates to ethical and responsible behaviors especially towards their employees in health and safety. Those who earn a wage with construction work should not be put at risk by suffering from illness and injuries. (RRC International, 2019) Construction employers pay insurance for the health and safety of their workers in terms of medical insurance and hospitalization, such as for building safety insurance, capital item insurances, etc. (Lop, Mamter, Kamar, & Norazlin, 2014)
In workplaces where safety management is effectively implemented, incidents are less likely to occur. If companies, contractors, subcontractors, and suppliers fail to eliminate, substitute, or provide safe workplaces, machinery, equipment, process, etc., there can be several financial impacts. If incidents happen more often and become public, the employer can be at risk during external audits and might lose their certifications for providing work and operation. Losing reputation will possibly lead to fewer customers and clients which puts the business under more risk and pressure. Therefore, workers' health and safety should be the main priority of any employer. (osha.europa.eu, 2001) (RRC International, 2019) On construction sites, there are typically many different contractors and subcontractors present simultaneously who require sufficient risk assessments, good channels of risk communication, such as good coordination of work and change. They should support an approach toward zero incidents. Construction employers have contracts with clients, investors, and customers. (RRC International, 2019) Employers have a lot of power since they own the processes, procedures, and operations.

Clients, investors, and costumers: They can be described as the decision-makers or people with a lot of power and influence when it comes to the planning and process of construction projects. Through construction projects, clients and investors want to acquire a good return-on-investment and need to comply with the contracts of their employers, who await payment. Therefore, they have a high interest in having the project finished according to the timeline because otherwise there could be financial consequences. This could motivate them to keep up the pressure towards other stakeholders and prioritize profit over safety. Clients, investors, and customers should have a high interest in health in safety because construction accidents result in time loss and efforts spend on an investigation, and may require drastic process adjustments and changes. Such interruptions halt the progress and might increase the risk of delay for the project. Besides, a high number of accidents seek the attention of the media and government. This may lead to increased administrative effort, complications, and financial burdens for clients, investors and customers, and employers. (Zou, Zhang, & Wang, 2007)

Designers: Designers are tasked with the fundamental creation of the project. They make drawings and need to consider the clients' demands and wishes. It is of great importance that structures, and materials are safe, and pose no risk to health for workers and other stakeholders. If the construction design is lacking or measurements are incorrect, they are not only in danger of losing reputation and possible projects in the future, they can also become fined, prosecuted, and put in prison. Therefore, designers should only propose materials and constituents in their structures that pose the least harm to workers and the environment (e.g. using asbestos for building poses a high risk for workers and the environment). (Li, Zuo, Cai, & Zillante, 2018)

Construction union(s): The world's largest national trade union is the All-China Federation of Trade Unions (ACFTU) with an estimated 300 million members and one million full-time officials. The ACFTU is also China's only legally mandated union. The ACFTU helps to improve working conditions, pay, and has the power to discuss other labor-related issues with high-up government officials or management of companies. However, there have been disputes about whether ACFTU is one hundred percent an independent trade union or even a trade union at all. (Taylor & Li, 2007) The ACFTU is organized according to the hierarchy of local and regional union federations and classified as a "mass organization" that is supposed to benefit the interests of the Communist Party and local government bodies rather than its members and workers. (CLB, 2020b) Their power is hard to estimate.

Insurance companies: Insurance companies have a moderate to high interest in health and safety and moderate power. Insurance companies must compensate a certain amount of money in the event of losses. They depend on the existence and calculation of risks for their businesses. Insurance companies collect, analyze and evaluate risks to decide what is the right coverage and pricing for their insurance products, for example, life or personal insurance for workers, property insurance for construction machines and equipment, fire insurance, liability insurance against property damage or to compensate for the loss of personal, guarantee insurance against damage arising due to dishonesty, disappearance, and disloyalty of employees or second party, and social insurance. (iedunote.com, 2017) When accidents occur more frequently, it means that insurance companies must meet higher liabilities and obligations in the form of higher monetary compensation for things that can be insured. In the long term, this could result in insurance companies increasing their membership fees or even narrowing their product portfolio to condense their losses. (RRC International, 2019)

Financial institutions: Financial institutions include commercial and retail banks, credit unions, commercial and private savings/loan associations, and mortgage firms that have relatively high power. They ensure the availability and flow of monetary resources for the contractor and want to have a high return on investment. The greater the limit or restriction of financial funds, the less money is available for protection against hazards or safety equipment in general. When safety is not prioritized, and safety barriers are lacking, it can significantly increase the probability, but also the severity of risks. The lost time due to accidents and investigation procedures can cause the risks of project delays, cost overruns, and even breach of contract. This might result in reduced opportunities for the employer, contractor, or client to acquire money, but also legal enforcements, intensification of contracts terms and conditions, and more complications with the financial institutions. For example, a creditor with a good reputation in the industry could formulate safety boundaries of unacceptable accidents to be recorded by the main contractor in the loan contract. When the main contractor is unlucky, there will be more serious accidents than previously agreed on. Following, the creditor might not only lose interest in the funding of the project but could result also in legal steps against the contractor and claims for compensation. Some of the undesirable consequences could be punishment in form of a fine, formal enforcement action, or even imprisonment in court. (RRC International, 2019)

Government authorities: Governmental authorities include ministries, local and public authorities/representatives, and other bodies exercising executive, legislative, judicial, regulatory, or administrative functions. (lawinsider, 2020a) They discuss and set constraints for the management of health and safety through legislation, policies, standards, and codes to protect employees' fundamental rights. The government has a lot of power because they can order changes in the industry, supervise the construction companies, prohibit certain activities of stakeholders, increase worker rights, and issue orders to change construction housing, etc. They should also have a high interest in health and safety on construction sites because people expect the government to protect them from harm and violation of working conditions through the employers on construction sites and in general. (Li & Poon, 2009)

Others: They refer to all other stakeholders (e.g. other industries, external economy, NGOs, competing or supporting companies in and outside of the country) who have a moderate interest in management safety but low influence. For example, a private company in Hong Kong that specializes in creating a special industrial paint could be liable for a high number of fatalities in construction, therefore, they need to pay close attention to safety trends and changes in the industry. Because of different roles and responsibilities, it is difficult to assess their power and interest.

4.6 Risk analysis of construction Hong Kong

The risk analysis stage helps to determine the importance of identified risks and lays the foundation to professionally communicate risks to stakeholders who can be affected by the event of a risk. Risk analysis's main purpose is to estimate the probability of risk occurrence and calculate their severity *when* risks occur. Thus, their possible impact can be calculated which supports decision-making and stakeholders to prioritize actions against risks. Commonly, it can be differentiated between qualitative and quantitative risk analysis. (Stroie, 2011) (Dziadosz & Rejment, 2015)

Qualitative risk analysis is by nature usually more subjective than quantitative risk analysis methods. The method of qualitative risk analysis does not use statistical values to evaluate the risk in an organization. Instead, relative values are used as data entries for the value of a potential loss. Frequently used terms include, for example, low/medium/high, numbers like 1,2,3, or rare, unlikely, moderate, likely, very likely and refer to the probability of risk occurrence and their consequences. (Stroie, 2011)

Compared to methods of qualitative risk analysis, quantitative risk analysis is a more objective approach. Quantitative risk analysis is used to identify risks by evaluating verifiable data to analyze the effect of risk, e.g. in terms of cost overruns, resource consumption, scope, delays, and deviations from planning for the project. (Wood, 2019) This information can be critical to detecting the main areas that are exposed to the risk and create an efficient and effective risk response that addresses also the underlying causes of risk. (Curtis & Carey, 2012) (Altenbach, 1995) Using probabilistic methods and the probability theory, some of the most frequent techniques for quantitative risk analysis are: (Dziadosz & Rejment, 2015) (Cynthia, 2020)

- sensitivity analysis,
- multi-criteria decision-making methods,
- decision trees, event trees
- Expected Monetary Value analysis
- methods of operations research and econometrics (e.g. the game theory).

The risk analysis will be based on data of non-fatal and fatal injuries in the construction of Hong Kong from 2011 to 2018. Accidents, injuries, and fatalities are considered awful conditions for construction stakeholders because such lead to harm for construction workers, sometimes even to multiple loss of human life. For the construction employers, they can lead to high monetary expenses, fines, prosecution, and could increase the attention of media and governmental authorities. (RRC International, 2019)

4.6.1 Occupational injuries and fatalities in construction Hong Kong

The following data was obtained from the Occupational Safety and Health Statistics Bulletin (Issue No. 10-19) and archived Occupational Safety and Health Statistics (2009 - 2018) of the Labour Department, the safety branch of the Government of Special Administrative Region Hong Kong. (Labour Department, 2015)

In December 2011, there were 62.635 manual workers registered in the construction industry of Hong Kong. This number increased by about 79% to 111.849 manual workers employed in construction as of December 2018. (Labour Department, 2019) "*Manual workers at a construction site are people either directly employed by the main contractor or being called upon by sub-contractors or gangers to work in the construction site on the survey reference date. They include skilled, semi-skilled, and general workers. Professional and administrative personnel such as architects, engineers, surveyors, contract managers, site agents, clerks of works, technicians, site foremen, and general clerical staff are excluded. For sites under the charge of Government departments, manual workers in some 40 selected major occupations at the skilled and semi-*

skilled levels […] are covered in the administrative returns furnished by the respective Government departments." (censtatd.gov.hk, 2020) Following, manual workers will be considered as construction workers.

Figure 17 shows the number of construction workers, the number of industrial injuries, such as fatalities in the construction industry of Hong Kong from 2009 to 2018. The figure was obtained from the Labour Department. (Labour Department, 2019)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
No. of Accidents 意外數目	2 755	2 884	3 112	3 160	3 232	3 467	3 723	3 720	3 902	3 541
No. of Fatalities 致命意外數目	19	9	23	24	22	20	19	10	22	14
Employment Size 受僱人數	50 501	55 341	62 635	71 295	79 303	82 795	95 103	107 799	118 674	111 849
Acc. rate/1 000 Workers 每1 000工人計的意外率	54.6	52.1	49.7	44.3	40.8	41.9	39.1	34.5	32.9	31.7
Fatality rate/1 000 Workers 每1 000工人計的致命意外率	0.376	0.163	0.367	0.337	0.277	0.242	0.200	0.093	0.185	0.125

Figure 17 - Number of construction workers, occupational injuries, and fatalities in Hong Kong from 2011 to 2018
Source: (Labour Department, 2019)

4.6.2 Type of accidents in construction Hong Kong from 2011 to 2018

The archived Occupational Safety and Health Statistics of the Labour Department classify occupational injuries and fatalities in different categories regarding the type of accident. "*Occupational injuries refer to injury cases in workplaces reported under the Employees' Compensation Ordinance, resulting in death or incapacity for work of over three days. Occupational injuries include reported cases outside the jurisdiction of the Occupational Safety and Health Ordinance, e.g. cases of natural diseases and cases that happened outside Hong Kong. Industrial accidents refer to injuries and deaths arising from industrial activities in industrial undertakings as defined under the Factories and Industrial Undertakings Ordinance*." (Labour Department, 2019) The information obtained from the Labour Department was supported by (Shafique & Rafiq, 2019), a journal article referring to the same sources. However, there is a slight deviation between the stated total number of fatalities according to the Labour Department and the actual number of fatalities as indicated by the type of accident. In 2012, the total number of fatalities should be 26 and not 24. In 2018, the total number of fatalities should be 15 and not 14. Therefore, the thesis authors continued to use the actual total number of fatalities (as the sum of all types of accident in the same year) for 2012 and 2018 in their figures and calculations.

All occupational injuries and fatal injuries were gathered to create table 3.

Type of accident	Occupational injuries								Fatal occupational injuries							
	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Fall of person from height	390	429	439	374	380	351	381	347	10	12	15	7	9	7	9	11
Slip, trip or fall on same level	649	738	801	882	950	1057	1086	960	0	0	0	0	0	0	0	0
Striking against fixed or stationary object	280	295	311	390	382	392	447	392	0	1	0	0	0	0	0	0
Striking against fixed or struck by moving object	552	551	612	646	584	586	549	493	3	2	2	2	1	1	3	0
Contact with electricity	6	17	10	12	8	7	9	10	2	7	0	2	3	2	0	1
Injured while lifting or carrying	606	525	490	453	677	626	724	710	0	0	0	0	0	0	0	0
Trapped in or between objects	106	114	137	205	160	158	147	157	1	1	0	2	1	0	3	1
Struck by falling object	73	56	50	68	110	111	113	91	3	2	2	5	3	0	1	0
*Others	556	527	482	543	612	572	658	566	4	1	3	2	2	0	6	2
Annual total	3.218	3.252	3.332	3573	3863	3860	4114	3726	23	26	22	20	19	10	22	15
*Others: include all accidents types other than those mentioned above in occupational safety and health statistics																

Table 3 - Overview of occupational injuries and fatalities according to the type of accident in the construction industry of Hong Kong from 2011 to 2018

Sources: (Shafique & Rafiq, 2019) & (Labour Department, 2019), table made by authors

4.6.3 Average distribution of accident types for occupational injuries and fatalities from 2011 to 2018

To analyze which types of accidents are the leading causes of construction injuries in Hong Kong, the average for all accident types was calculated in Microsoft Excel 2016 for both occupational injuries and fatalities between 2011 and 2018. The results are shown in figures 18 and 19. Moreover, some of the contributing factors leading to such injuries are stated below.

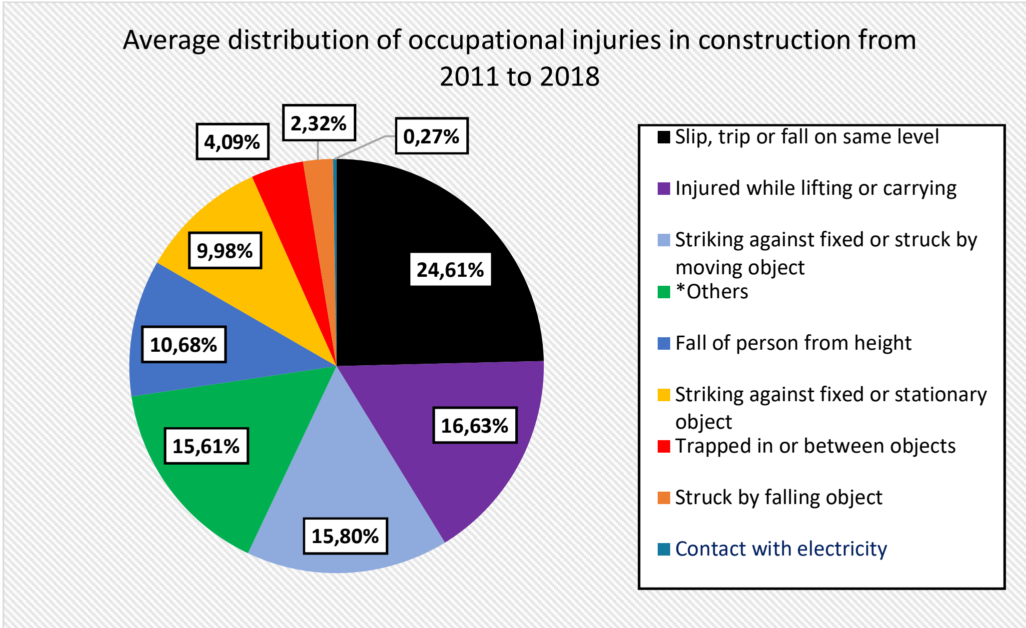


Figure 18 - Average distribution of occupational injuries in construction in Hong Kong from 2011 to 2018
Source: (Labour Department, 2019), (Shafique & Rafiq, 2019), graph made by authors

As shown in figure 18, the leading cause of all occupational injuries between 2011 and 2018 were slips, trips, or falls on the same level (24,61%).

In construction, generally, slips, trips, and falls can be caused through any kind of wet or slippery surface, uneven surface, due to debris, clutter or slick spots, obstacles due to insufficient housekeeping (e.g. tools, cables, rubbish), such as unsafe stairs or ladders. (safetyskills.com, 2017) (HSE UK, 2020c)

Accidents that are due to lifting or carrying (16,63%) are in second place. By nature, construction work involves a high degree of manual handling and laboring. Workers must lift, lower, push, pull, and carry sometimes heavy and unwieldy objects, loads, or materials, such as tools, machinery, and equipment. Common factors that increase the risk of injuries include the load being too heavy, too large, too difficult to grasp or unstable, the task being too repetitive, too strenuous or involving awkward postures or movements, and the working environment missing adequate space. In many instances, workers are also exposed to extreme temperatures or poor lighting. (HSE UK, 2020b) Manual handling can result in fatigue and leads typically to injuries of the back, neck, shoulders, arms, or other parts of the body. While cuts, bruises, fractures, etc. are usually less harmful and might require only a few days of recovery, damage to the musculoskeletal system of the body (muscles, tendons, ligaments, bones, joints, bursa, blood vessels, and nerves) has a greater severity because such injuries are more destructive and can even lead to some degree of disability. Injuries classified as ‘musculoskeletal disorders’ are often a consequence of regular and increasing stress, wear and tear through repetitive manual handling due to working in construction for several years. (OSHA Europe, 2007) Rework, the process of doing an operation at least one extra time due to quality deviations and non-conformance to project's requirements, has also a strong tendency to cause injuries in construction activities. This is because safety is situational, and workers can be distracted by ad hoc rework tasks while undertaking their routine project tasks. (Alkaissy, Arashpour, Baabak, Hosseini, & Bai, 2019)

Striking against fixed or being struck by moving objects are ranked third (15,80%). According to OSHA, two different types of events can be differentiated: "*When the impact alone creates the injury, the event is considered as Struck. On the other hand, when the injury is created more as a result of crushing injuries between objects, the event is considered as Caught.*" (OSHA, 2011)

According to (OSHA, 2011), struck-by hazards can be classified into four main categories: struck-by flying object; struck-by falling object, struck-by swinging object; or stuck-by rolling object. Flying object hazards are present when something has been thrown, hurled, or is propelled across space. Such occasions are usually created when a part of material splits up from a tool, machine, or other equipment, and results in injuries or fatality. A hazard can also be created when an object is ejected under power (e.g. a nail from a nail gun). Especially powder-actuated tools are mainly hazardous due to the force behind the fastener. These fasteners have enough power to go through different types of material like wood, concrete, steel, thus, they can certainly harm humans. Compressed air, commonly used to power tools and clean surfaces, can also be the source of flying object hazards. The risk of struck-by falling exits, whenever objects can fall from an elevated to a lower level and workers are at risk to be crushed, pinned or caught under a falling object or equipment. Hazards of a struck-by swinging object are caused when loads and materials are mechanically lifted or hoisted. When the load is raised, the materials may swing, twist, or turn. In many cases, workers do not expect sudden movement and they could be hit. Lifting operations using a crane contain high risk and are especially dangerous in windy conditions as the load will swing more and a wider area may be affected. (OSHA, 2011) In many cases accidents involving falling materials resulted from improper rigging. Rigging should be done only by competent and certified personal. Crane operations require extensive layout planning of the construction site, including the location of the crane, to minimize material movement over workers. Workers should have less exposure to objects passing overhead and must not be underneath a raised load. (Hinze, Huang, & Terry, 2005) Struck-by rolling hazards are caused through rolling, moving, or sliding objects. For example, a worker can be struck or run over by a moving vehicle. (OSHA, 2011)

For construction injuries, generally, it was revealed that working under a tight project schedule and time pressure, workers are more likely to take shortcuts and neglect existing safety procedures when trying to finish according to the timeline. (Choudry & Fang, 2008)

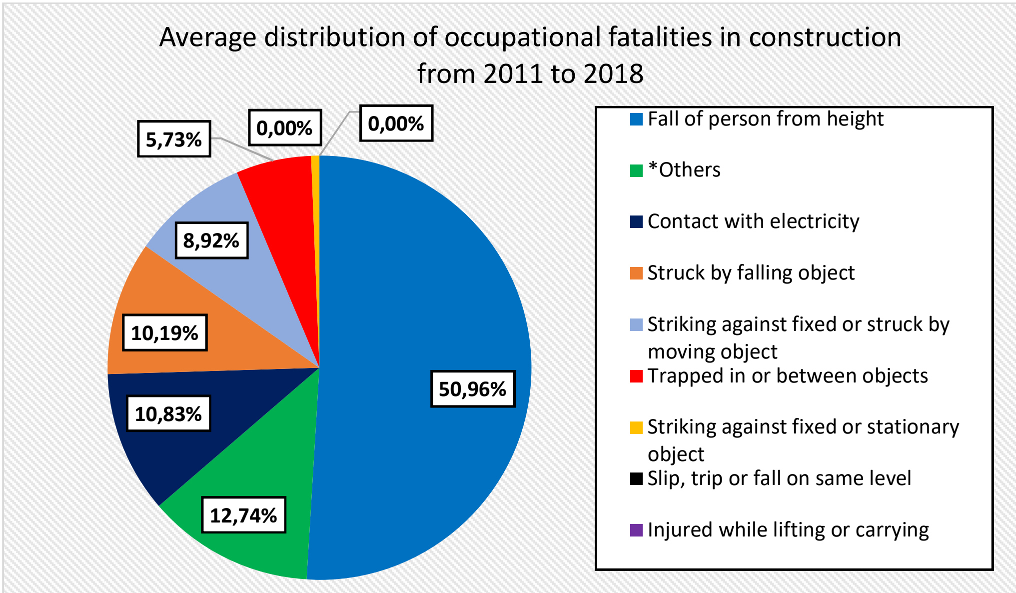


Figure 19 - Average distribution of occupational fatalities in construction in Hong Kong from 2011 to 2018
Source: (Labour Department, 2019), (Shafique & Rafiq, 2019) graph made by authors

Within fatal injuries, falls from height (FFH) are by far (50,96%) the most frequent accident type among all others in construction Hong Kong. FFHs are also the leading cause of serious and fatal injuries for construction employees globally. (Nadhim, Hon, Xia, Stewart, & Fang, 2016)

According to (HSE UK, 2014a), FFH is in many cases already considered as the cause of the accident when a person has fallen from any kind of elevated platform, from a ladder or a flat roof; from a fragile surface, or into an opening in a floor or a hole in the ground.

Although is there is a vast number of safety handbooks, guidelines, and laws stating that employees who carry out work at height must use safety harnesses, workers often behave differently, and especially scaffolders on construction sites in Hong Kong are often observed not using safety harnesses. Empirical results showed mostly "*the inconvenience and discomfort of using a safety harness, underestimating the risk of not using safety harnesses, negative pressures from gangmasters, foremen, and safety lines are causing the underlying motivation for deciding against the use of safety harnesses*". (Zhang & Fang, 2013) Construction workers performing work at heights are impacted by the platform/surface conditions in different ways. Firstly, equipment and agents create a contributing risk factor if they are in an improper position, lacking or defective. This refers mostly to scaffolds or ladders but can also include slippery or inclined surfaces, unprotected walkways, barriers, and safety guardrails because such are used to perform work-at-heights. Improperly erected scaffolds and unexpected modifications increase the likelihood of accidents. Secondly, some construction sites are sometimes operational for 24 hours. Workers are more prone to suffer from injuries when there is insufficient lightning or even illumination during night shifts because they are not able to see their

surroundings properly. Moreover, prolonged construction activities carried out on a ladder or scaffold with undependable design increases the risk of falling from heights by a great extent. (Nadhim, Hon, Xia, Stewart, & Fang, 2016)
Although other countries, including mainland China, have long removed the practice of using bamboo, Hong Kong is one of the last places where bamboo structures are still used for scaffolding. Bamboo is the fastest-growing plant on earth, and the use of bamboo in construction poses low costs and is sustainable. However, not all pieces are consistent, need to be tied together manually, and with increasing structure become more fickle, flexible, and bend, making construction workers performing work at heights more prone to accidents. (Wei, 2020)

As stated by the Labour Department, the accident type of *Others (12,74%) includes all accident types other than those mentioned in occupational safety and health statistics. (Labour Department, 2019) The thesis authors assume that this category could include injuries due to transportation accidents, exposure to hazardous substances to health, fire, etc.

In third place was dying through contact with electricity (10,83%). Electricity is a major hazard on construction sites and is commonly caused by working on electric currents of a machine, tool, or appliance, overhead powerlines, electric wiring, transformers, and related equipment. In very rare cases, death can also occur due to lightning. (Janicak, 2008) Many accidents involving contact with electricity are caused where employers have no written safety policy nor provide a safety training program for employees, such as when lockout-tagout programs and verification of energy isolation are either not present and/or neglected. (Zhao, Thabet, McCoy, & Kleiner, 2014) (Janicak, 2008)

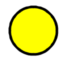
4.6.4 Event tree analysis of fatal and non-fatal injuries in construction Hong Kong

To enhance the risk analysis, an event tree was conducted. The event tree shall be used to calculate the probability of a worker suffering from an injury, generally, such as for the probabilities of suffering from one of the leading causes of non-fatal, such as fatal injuries.

Event trees are highly effective risk assessment tools and find broad application in many industries. Event and/or decision trees are used as a simple model that helps to discover, understand, and communicate the structure of problems with uncertainty. Event trees may be useful in the following situations: (Ostrom & Wilhelmsen, 2012) (Kamiński, Jakubczyk, & Szufel, 2018)

- "*several actions follow one another,*
- *the states of the world may differ based on the decisions that have already been made,*
- *some decisions may result in more accurate probability estimates of those states*."

The event tree is constructed using a directed graph from left to right, with a set of nodes that split into three disjoint sets:

- decision nodes - represented as 
- chance nodes - represented as 
- terminal nodes - represented as 

The leftmost node is the root node and is either one decision or chance. Two other main parameters that must be determined are the probabilities of events and the values. "*The probability of events is a specified state of the world obtains. As the possible states of the world within one reaction are in fact competing events, the sum of their probabilities must be equal to 1*." (GitHub Inc., 2020)

In our case, the event tree starts with a chance node of either an injury occurring or not (*Worker has injury?*). The consequences of near misses will not be further considered because not enough sufficient data was available in English language. However, it is still of great importance to consider near misses in practice because they are likely to lead to accidents and injuries in the future. (RRC International, 2019)

The possible outcomes of both events, injury or no injury, are mutually exclusive, so the outcome is either *Yes* or *No (including near miss)*. No injuries pose no harm for workers, no additional costs for the stakeholders, and have the contrary probability value of *injury.* The probabilities (*P*) of the events *Worker has injury* and *No injury (including near miss)* are calculated as follows:

$$P\ (Worker\ has\ injury) = \frac{\mu_{All\ Injuries_{2011-2018}}}{\mu_{Workers_{2011-2018}}}$$

$$P\left(No\ injury\ (including\ near\ miss)\right) = 1 - P\ (Worker\ has\ injury)$$

The used data was obtained from the statistics of the Labour Department Hong Kong as in table 3. The analysis does not consider accident events because one single accident did most likely lead to more than only a single injury or fatality. Therefore, the number of *All Injuries* is considered and refers to the sum of fatalities and injuries in the same industry and the same year. In 2011, for example, the number of *All Injuries* is calculated as:

$$n_{All\ Injuries_{2011}} = n_{Fatalities_{2011}} + n_{Occupational\ injuries_{2011}}$$

Moreover, to indicate the probability of a worker suffering from an injury or not, the annual average for workers and injuries from 2011 to 2018 was used:

$$\mu_{All\ injuries} = \frac{1}{8} \times \sum \left(n_{All\ injuries_{2011}} + n_{All\ injuries_{2012}} + \ldots + n_{All\ injuries_{2018}} \right)$$

$$\mu_{Workers} = \frac{1}{8} \times \sum \left(n_{Workers_{2011}} + n_{Workers_{2012}} + \ldots + n_{Workers_{2018}} \right)$$

If an injury occurs, there are two mutually exclusive chance nodes; either the injury is fatal (leads to death) or non-fatal (does not lead to death). The probabilities for fatal and non-fatal are calculated as follows:

$$P\ (fatal\ injury) = \frac{\mu_{Fatalities_{2011-2018}}}{\mu_{All\ injuries_{2011-2018}}}$$

$$P\ (non-fatal\ injury) = 1 - P\ (fatal\ injury)$$

with

$$\mu_{Fatalities} = \frac{1}{8} \times \sum \left(n_{Fatalities_{2011}} + n_{Fatalities_{2012}} + \ldots + n_{Fatalities_{2018}} \right)$$

The calculations were made according to comments and suggestions of one of the thesis supervisors. The reader can obtain the numbers used for the calculations made in Microsoft Excel 2016 in *Appendix 4 - Calculations for the event tree.*

For both fatal and non-fatal injuries, the top four leading causes are considered as identified in the previous subchapter. The remaining leading causes are summarizing as *All others*. Non-fatal injuries are further clustered according to their severity. Initially, they were moderate, severe, or major. However, to improve readability, only serious and major severities are stated. Because to less sufficient data on this matter was found, both probabilities are assumed to be 50%, so the probability of either a serious or major non-fatal injury is the same and does not influence the desired results. The severity indices on a logarithmic scale were assumed by the authors and especially the category of *Assets* requires future study (table 4). The author used this particular way to indicate the severity because it was found in a scientific article and was found to have a meaningful concept. (Kim, Kang, & Kim, 2015) Notably, it does not change the degree of severity if multiple descriptions are true at the same time. Because fatal injuries are always considered to cause death, they are not further clustered and have always the severity of *Catastrophic*.

Severity Index	Severity	Description			
		People	Assets	Environment	Reputation
1	Moderate	Slight injury	HK$ 100	Slight effect	Slight impact
2	Serious	Minor injury	HK$ 500	Minor effect	Minor impact
3	Major	Major injury	HK$ 1.000	Localized effect	Considerable impact
4	Catastrophic	Single fatality	HK$ 5.000	Major effect	National impact
5	Disastrous	Multiple fatalities	HK$ 10.000	Massive effect	International impact

Table 4 - Severity Index
Source: Authors

Finally, terminal nodes show the outcome of a sequence of actions/reactions from the root node. In theory, the terminal nodes are the endpoints where decisions can be made, and no events may occur afterward. (GitHub Inc., 2020) In our event tree, however, terminal nodes shall be used to determine the consequence of the risk.

The event tree is illustrated in figure 20.

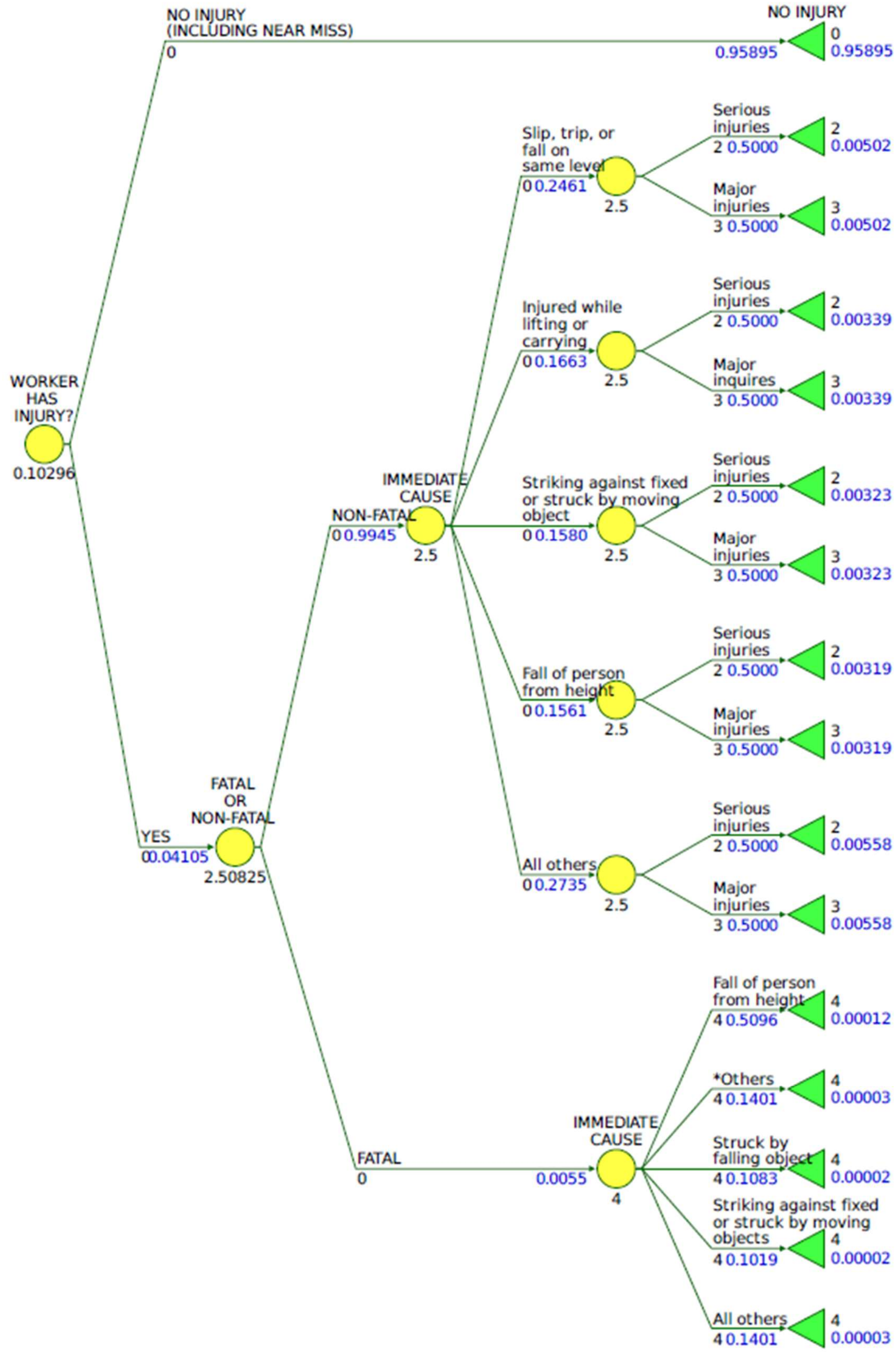


Figure 20 - Event tree of suffering from a fatal or non-fatal injury in construction Hong Kong from 2011 to 2018
Source: Authors, made with silverdecison.pl

A lot of information can be obtained from figure 20. Based on the record of construction injuries in Hong Kong and considering the size of the construction workforce each year, the probability of suffering from an occupational injury is 4,105% for one construction worker on average. The probability that the accident leads to a fatality is 0,55% and is 99,45% non-fatal but poses injuries.

4.6.5 Influence of age on accident proneness in Hong Kong

Research has different views on which age group is more accident-prone. While some state that rather young workers have higher chances of accidents due to lack of experience, others argue that the accident rate among older workers is not lower than for younger ones. (Li & Poon, 2009) (Miguel A Camino Lopez, 2018)

(Salminen, 2004) conducted a review of international literature to answer whether young workers have a higher risk of occupational injuries and whether the injuries of young workers (under the age of 25 years) are more likely to result in death than for older workers. The findings showed that young workers have a higher rate of non-fatal injuries. "*Most of the reviewed studies on fatal injuries indicated that young workers had a lower fatality rate than older workers. One explanation for this result is that young workers have a better impact resistance than older workers so that the same impact which could kill an old worker would only lead to injuries of a young worker but less often to death"*. Another advantage of young workers is also that they recover better from trauma than older workers. (Salminen, 2004)

(Li & Poon, 2009) reviewed Hong Kong court cases from 2004 to 2008. They revealed that most of the serious injuries are reported from people in the age group of 47-56 (accounting for 30 among the 101 court cases), whereas the age group of 27-36 and 17-26 account for 18 and 15 cases respectively. There were only seven cases in the age group of 57-67. The percentage of court cases especially for occupations in construction was highest in the age group of 17-26. In the construction industry of Hong Kong, trades like general and causal laborers suffered the most from serious injuries, followed by electrical technicians, painters, decorators, plasterers, carpenters, and scaffolders. (Li & Poon, 2009)

(Chiang, Wong, & Liang, 2018) did a comprehensive data analysis with descriptive statistics of fatal incidents of manual workers on construction sites in Hong Kong from a period between 2006 and 2015. As shown in figure 21, there were more construction deaths among older age groups, except for the group aged 60 or above.

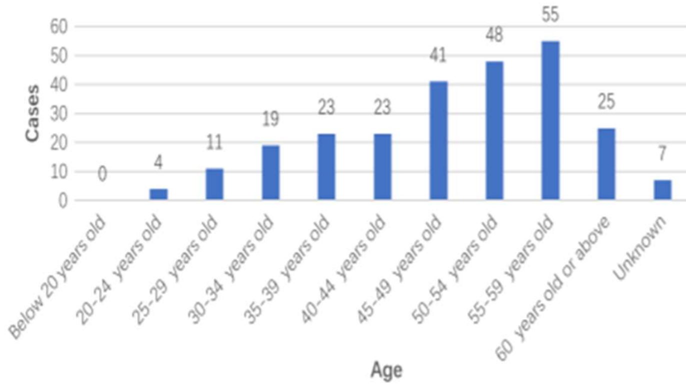


Figure 21 - Frequency distribution of fatal accidents by age in Hong Kong from 2006 to 2015
Source: (Chiang, Wong, & Liang, 2018)

This underlines that probably the decline in physical and psychosocial conditions leads to more deaths of aged workers. However, the number of cases of the age group 60 and above were less. This is perhaps because people usually retire at this age and those who continue, work fewer hours as it takes a longer time to recover from the strain and hardship of construction site duties. (Chiang, Wong, & Liang, 2018) Moreover, aged workers died also in relative terms. Figure 22 shows the proportion of the total fatalities to the total number of registered workers for each age group. The age groups of 45-49, 50-54, and 55-59 have higher fatality numbers in the chart, indicating that more people of the aging workforce are prone to site fatalities, especially between 45-59. It also seems that being more skillful and experienced does not protect against the demands of strenuous construction work. However, the relatively low ratio in the age group of 40-44 may indicate that workers in this age are physically strong enough to sustain the hardship of the work, and experienced enough to avoid injuries and accidents generally. (Chiang, Wong, & Liang, 2018)

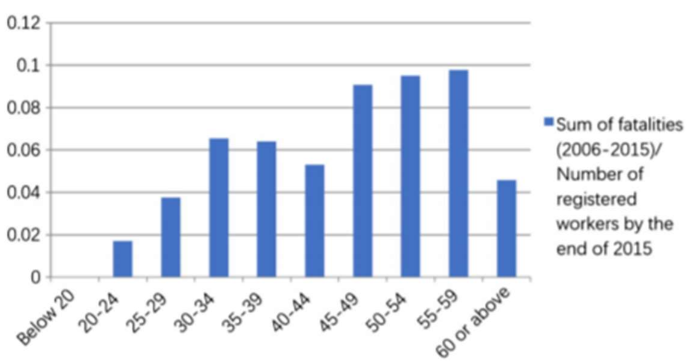


Figure 22 - Ratio of fatal accidents to registered workers by age in Hong Kong from 2006 to 2015
Source: (Chiang, Wong, & Liang, 2018)

4.6.6 Time of the day of construction accidents in Hong Kong

(Chiang, Wong, & Liang, 2018) further analyzed patterns of fatal cases. Construction workers in Hong Kong usually start work at 8:00, stop during a one-hour lunch-break at noon and another 30-min tea break at 15:15, and finish around 18:00. As shown in figure 23, most fatal accidents occurred in the late morning (10:01-11:00 am) and early afternoon (14:01-15:00).

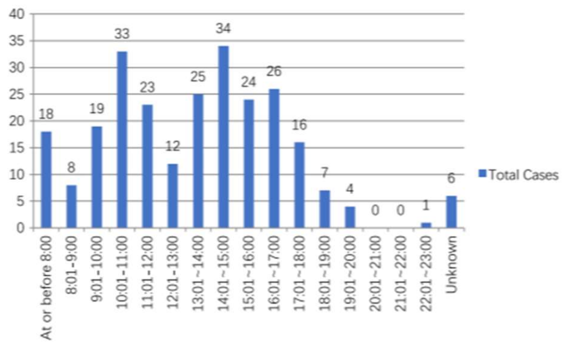


Figure 23 - Frequency distribution of fatal accidents by hour of the day from 2006 to 2015
Source: (Chiang, Wong, & Liang, 2018)

These periods are approximately two hours before and one hour after the lunch break. These findings are similar to the results of (Huang & Hinze, 2003), who analyzed accident data provided by OSHA between 1990 and 2001. According to their studies, most accidents occurred "*between 10:00 and 11:00 in the morning and between 13:00 and 14:00 in the afternoon*". The often-cited explanation for this is fatigue, which was analyzed in more depth by (Dongping, Zhongming, Mingzong, & Han, 2015) and (Zhang, Murphy, Fang, & Caban-Martinez, 2015) for construction workers in mainland China. Fatigue in construction is dangerous because it leads to decreased situation awareness during the work, such as mental fatigue, discomfort, and negative impact on the physical condition of the working day and night. (Chiang, Wong, & Liang, 2018) Generally, fatigue can be caused by a lack of sleep, stress, and exhaustion due to long working hours, overtime, and too much workload for the individual worker. (RRC International, 2019)

(Dembe, Erickson, Delbos, & Banks, 2005) found that the risk of suffering from occupational injuries are more likely when people work more than 40 hours weekly. Construction workers in Hong Kong exceed this mark regularly as they are normally required to work 48 hours per week on average. (Chiang, Wong, & Liang, 2018)

4.6.7 Day of the week & month of the year of construction incidents

Knowing which day of the week and which month of the year fatal incidents have occurred, can also be useful for accident prevention. On construction sites in Hong Kong from 2006 to 2015, most fatal incidents occurred on Mondays and Tuesdays likewise, the beginning of the 6-day workweek. Second place was Wednesdays and third place Fridays. Fatal accidents due to falling from heights (the leading cause of fatalities) occurred usually Mondays, Wednesdays, and Fridays. (Chiang, Wong, & Liang, 2018)

According to the distribution of fatal accidents by the month of the year, most workers died in July. The month of July has the longest sunshine, highest temperatures, most humidity, and highest daily global solar radiation in Hong Kong throughout the whole year. Construction workers working outdoors are exposed to heat which can increase the risk of heat stress and unpleasant working conditions. The months of August, September, October, and December indicate also high frequencies of fatalities. October and December are months with a lot of rainfall which increases the risk of slip, trip, or falls, such as falls from height due to wet and slippery surfaces. (Chiang, Wong, & Liang, 2018)

4.7 Root cause analysis of construction injuries and fatalities

Accidents happen due to immediate (direct) causes and root causes. The root causes of accidents, generally, can be understood as the things that lie behind the immediate causes and are caused by multiple interrelated factors. The underlying root causes for injuries and accidents are harder to identify than the immediate/leading causes, however, root causes must be considered to prevent further near-misses, undesired circumstances, and accidents in the future. It is very unlikely that just and exactly one root cause is responsible for one accident. Often, root causes are failures in the management system, such as:

- Failure to supervise workers
- Failure to provide appropriate training
- Lack of maintenance of equipment, structures, and machinery
- Inadequate checking or inspection
- Failure to carry out proper risk assessments (RRC International, 2019)

(Park, Kim, Han, & Hyun, 2020) analyzed fatal construction accidents in Korea. They collected 675 cases that were reported from 2007 to 2013 and determined the relationships between immediate and root causes. The direct causes of the analyzed accidents were clustered in unsafe conditions and unsafe acts and root causes were identified by the means of the Delphi method among seven construction experts. Results showed that the primary root cause leading to fatal accidents are "*lack of manager's safety consciousness*", followed by "*insufficient construction period*", and "*lack about education about safety*". Other relevant, but less frequent, root causes were "*shortage of safety management cost*", "*worker's excessive work*", and "*shortage of safety climate*". (Park, Kim, Han, & Hyun, 2020)

(Toole, 2002) surveyed design engineers, general contractors, and subcontractors in Pennsylvania, USA, to indicate the agreement on the site safety responsibilities that should be assumed by each of these groups.

According to his study, root causes of construction accidents were named as "*lack of proper training*, *deficient enforcement of safety*, *safety equipment not provided*, *unsafe methods or sequencing*, *unsafe site conditions*, not *using provided safety equipment*, p*oor attitude toward safety*", such as "*isolated, sudden deviation from prescribed behavior*". According to these findings, accidents mainly occurred due to "*lack of proper training*" and "*poor attitude toward safety*" of employees. (Toole, 2002)

In Hong Kong, a lack of education regarding safety at work is a great root cause of accidents. (Choudhry, 2014) (Li, Lu, Shu-Chien, Gray, & Huang, 2015) The majority of subcontracting firms are hired for temporary work and subcontractors are usually smaller and more financially insecure than larger subcontractors on-site. Many times, the small subcontractors do not have the withdrawal to educate their employees properly in safety training, which makes them automatically more vulnerable to risks. In addition to that, they often lack familiarity with an ever-changing crew. Language barriers of foreign workers and communication issues can deteriorate the problem. Moreover, workers are often time-pressured, make mistakes, and undertake unsafe acts in the middle of a job because they rush to complete a job on schedule. This is considered another major root cause of construction accidents. (Park, Kim, Han, & Hyun, 2020)

4.8 Analysis of unsafe acts

As previously explained, accidents are mainly caused by the subtle mix of unsafe acts and unsafe conditions. Unsafe conditions are easier to remove because they can be identified as who is responsible for them. Removing the risk of unsafe acts or unsafe behaviors is more challenging because it needs to be considered that there are internal and external influences shaping human behavior.

4.8.1 From human cognition to unsafe behaviors

One universal theory suggests that human behavior is caused by cognition and attitude. Cognition refers to the mental development of acquiring knowledge and understanding through thought, experience, and the senses and how we decide to act. (Fang, Zhao, & Zhang, 2016) Figure 24 shows a simplified cognitive model of how obtained information is processed resulting in action.

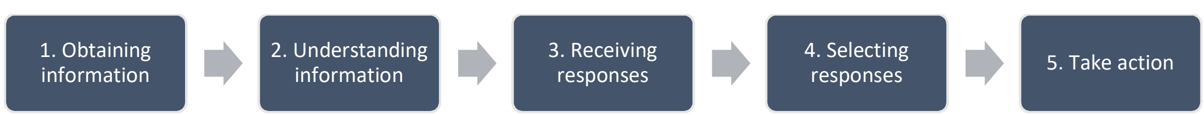


Figure 24 - Cognitive model
Source: (Fang, Zhao, & Zhang, 2016)

Perceived control refers to a person's perception of the ease or difficulty of executing a behavior. This concept also depends on two components: control belief and perceived power. For example, a scaffolder may believe

that working at heights without a safety harness will not lead to an incident because he or she did the same behavior multiple times in the past, and “nothing happened”. Following, the person is more likely to take the same risk again and again because it is perceived as not so risky. However, control belief and perceived power are often deceptive, so it is dangerous to neglect the safety procedures which are based on risk assessments, logic, and the scientific evidence of hazards present. (Fang, Zhao, & Zhang, 2016)
(Lombardi, Vermaab, Brennana, & Perry, 2009) analyzed why workers still decide to conduct unsafe behaviors when the hazards were already known. Findings revealed that worker individuals’ risk assessment, contextual factors, and social factors have a predominant influence in their decision-making.

Behavior attitude is mostly based on how a person thinks and feels intrinsically, such as the degree to which this behavior meets a person’s motivations. Three motivations may determine a workers’ attitude to the use of, for example, a safety harness: the motivation for safety, the motivation for convenience, and the motivation for comfort. Because of the motivation for safety, workers facing a fall hazard will evaluate the risks of all potential behaviors including safe behaviors and unsafe behaviors, and form a risk perception of each potential type of behavior. If a potential behavior is perceived to be of lower risk than others, this behavior can better satisfy the workers' motivation for safety and the worker will have a more positive attitude to this behavior. On construction sites, there is often a strange phenomenon. Although workers perceive a high risk of unsafe behavior, they still carry out this unsafe behavior which can be explained by the motivation for convenience. Workers want to complete their work in the least time and with the least effort; especially when they engage in work with high physical demands and tight deadlines. If a worker perceives an unsafe behavior more effortless, he or she may be eager to select it for convenience, even when the risk of unsafe behavior is not the lowest. In considering the use of PPE, the discomfort of using PPE is a barrier to its uptake. Since contractors generally purchase equipment only by price and durability with little consideration of usability, much PPE is difficult to use, which is an important barrier to its uptake by workers. A scaffolder who does not feel comfortable enough using a safety harness may elect against it. (Zhang & Fang, 2013)

A good and safety promoting attitude would be considering safety as something that can be achieved through individual and collective actions in the organization and it is something worth speaking up for. (RRC International, 2019) Likely actions (behaviors) arising from this state of mind would be to follow the rules and guidelines established by the employer, maintain good housekeeping, report near misses, help management to remove existing hazards and identifying new ones, act with respect and according to social norms, wear PPE, use equipment as prescribed, avoid alcohol and drugs at work, and consult with the employer when in doubt. (ECITB, 2019) In return, “good” behaviors will decrease unsafe acts and unsafe conditions, thus, injuries and accidents. “Bad” behaviors are more likely to arise when a worker has already a negative attitude towards safety. This does not always have to be so obvious, but over time, it can cause more frequent failures in identifying unsafe conditions that may have existed already before or developed after a worker has started an activity. If the worker fails to identify an unsafe condition, it means there was too little consideration of hazards, and the workers do not recognize the potential risks. If the worker identifies the unsafe condition, however, an evaluation must be made. The worker's decision is either to act safe and discontinue work until the unsafe condition is corrected or to take a chance of acting unsafely and continue working. Management should carefully examine the reasons behind failure to identify the unsafe condition or the decision to act unsafely after identifying an unsafe condition. (RRC International, 2019) Notably, some unsafe conditions may never be identified by a worker. Examples of such conditions are non-human-related events or conditions of human factor violations. Human factor violations are typically overexertion (repetitive movements, sudden motions, or prolonged effort), cumulative trauma disorders, fatigue, toxic poisoning, mental disorders, etc. Moreover, in many industries, particularly in construction, a worker may simply have no previous experience with the task being performed because he/she is "new". As revealed by many studies and especially by Heinrich, a major amount of accidents is caused because humans are naturally prone to make mistakes and errors. (Abdelhamid & Everett, 2000) (Winge, Albrechtsen, & Mostue, 2019)

4.8.2 Factors influencing unsafe behaviors and accidents on construction sites

(Khosravi, et al., 2015) investigated findings and results from 56 studies related to unsafe behaviors to discover the empirical factors influencing unsafe behaviors and accidents on construction sites. They are shown in figure 25 and will be further explained below.

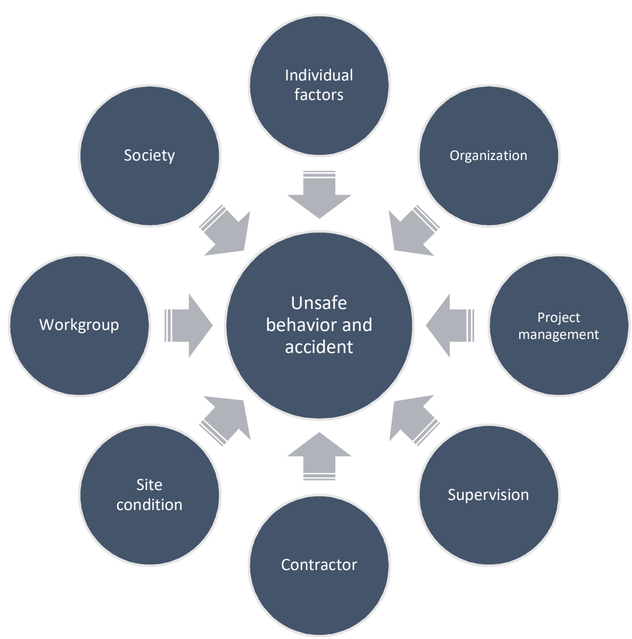


Figure 25 - Factor influencing unsafe behaviors and accidents on construction sites
Source: (Khosravi, et al., 2015), graphic made by authors

Individual factors: Many studies identified individual factors are one of the most important characteristics influencing unsafe behaviors and causing accidents. Individual factors can be understood as workers' capabilities, knowledge, and skills related to the work and task at hand, such as attitudes and motivation. Individual characteristics are unique for every worker and refer to health, fitness, age, physical condition, emotional stability/instability, and resistance to stress and fatigue. (Winge, Albrechtsen, & Mostue, 2019) (Khosravi, et al., 2015) Although the correlation of each characteristic requires future study, research showed that especially occupational stress directly influences safety behavior and, ultimately, the risk of being involved in construction accidents. (Winge, Albrechtsen, & Mostue, 2019)

Studies on stress and smoking showed that people who smoke report higher levels of stress compared to non-smokers which makes them technically more prone to accidents. Moreover, working stress can in some cases be linked to the frequent and regular consumption of caffeine. (Leung, Liang, & Olomolaiye, 2016) (Meliá & Becerril, 2009)

In 2006 a survey conducted by the Chartered Institute of Building of 847 construction workers in the UK identified that 68.2% of the construction employees suffered from stress, anxiety, or depression. In this survey, the respondents declared that particularly organizational factors related to the company and their supervisors, such as lack of feedback, poor communication, poor relations with superiors and inadequate ventilation, poor lighting, inadequate equipment, as the main sources of their stress. (Meliá & Becerril, 2009) Another survey among 1.732 UK construction workers conducted by the Health and Safety Executive UK found that merely 5% of the respondents stated to suffer from occupational stress, depression, or anxiety. However, 88% of the respondents described some level of stress. According to this survey, significant stressors for many workers were due to having too little time available for the tasks they were supposed to do, traveling or commuting, being responsible for the safety of others at work, long working hours, and laborers declared hazardous working conditions as too stressful. (Beswick, Rogers, Corbett, Binch, & Jackson, 2007) (Meliá & Becerril, 2009)

Employees who are older, married, or with more family members to support have usually more positive perceptions and attitudes towards safety compared to those who are younger, single, or with fewer family members to support. Increased social responsibilities may decline the propensity of risk-taking and increase the tendency to work more safely, better perception of the work environment, and more positive attitudes and beliefs towards safety. This tendency may stem from the recognition of one’s mortality that accompanies the maturing process. People who are older and more mature may not view the nature of the risk itself any differently, but they will assess the consequences of a mishap differently. (Fang, Chen, & Wong, 2006)

Education level is also an important influencing factor. Employees with education levels of primary school or lower have far less positive perceptions of safety than others. It is recommended that graduation from primary school and higher may be one of the fundamental criteria used for recruiting, or that those employees with education levels below primary school should obtain more safety training. (Fang, Chen, & Wong, 2006) Not only are people with a lot of safety training are more likely to know the right thing when in doubt, but they are also less likely to die in an emergency. (RRC International, 2019)

Construction is one of the sectors in which there are higher occurrences of use and abuse of alcohol, marijuana, cocaine, and other substances that are usually to some extent addictive or even illegal. Such substances are normally prohibited on-site because the primary concern is that the mental condition of a worker may be altered. Drinkers or users can have impaired judgment and situation awareness which increases the chance of injury for themselves and to fellow workers. Moreover, other bad manners like violence, disrespect, or carelessness can develop over time. Especially job stress, usage or addiction of co-workers, the availability of these substances at the worksite, and long phases spend apart from the family contribute to some extent to the alcohol and drug consumption in the industry. (Meliá & Becerril, 2009) (Fang, Chen, & Wong, 2006)

Organization: An organizations' health and safety culture are neither written down nor easily stated, thus, it is hard to grasp. It can be explained as a subtle mix of formal and informal rules, relationships, values, duties, etc., which put together, describe the distinctive "feel" of an organization. On one hand, this is about how the organization gets things done and the specific way of doing things. On another level, it is about how people perceive the organization in general. Inside the organization, no single person has the power to determine the culture of the organization. Instead, all staff working determine it collectively. (Fung I. W., Tam, Tung, & Man, 2005) (RRC International, 2019)

A positive safety culture indicates that the safety attitudes and values of the company are accepted by its employees, and employees are encouraged and promoted for safe behaviors. Most workers think and feel that health and safety are important, and they work safely because they want to, and not simply because they must. They will probably stay with their employer for a long time. Inside the organization, a strong health and safety policy is in place. Managers from top to bottom think about health and safety implications, demonstrate clear leadership, and show good example in their decisions and worker do likewise. (Fung I. W., Tam, Tung, & Man, 2005) (RRC International, 2019)

In a negative health and safety culture, however, clear direction and leadership from management are lacking and other priorities (like profit) may dictate their actions. Workers will think and feel that is not important to work safely and are encouraged for negative views, opinions, and behaviors. This may be because workers are poorly educated or see safety as an inference. Consequently, standards will be not understood or worked too, and workers' behavior will be poor, making them more prone to accidents and ill health. People will consider leaving the employer sooner or later. (Fung I. W., Tam, Tung, & Man, 2005) (RRC International, 2019)

Safety climate is usually regarded as more superficial than safety culture. Scholars have described the safety climate as an indicator of the overall safety culture of an organization. Safety climate is a "snapshot" of safety culture as the perceived value placed on safety in an organization at a particular point in time. Safety climate can also be understood as the "mood" of an organization, based on what workers feel and experience at a specific time. Dimensions of safety climate can differ from industry to industry and from district to district, hence, no universal set of safety climate factors exists. (enablon, 2017) (Teo & Feng, 2009)

The size of the company has generally a strong relationship with the occurrence of accidents. Especially small companies with only a few (less than 20) workers tend to undertake riskier work than large companies because the latter can better outsource and distribute the job and have usually better time planning and economic capability. In addition to that, small and medium-sized companies lean towards insufficient safety measures and standards, meaning that the quality or presence of e.g. PPE, Personal Fall Arrest Systems (PFAS), and safety belts/harnesses are often lacking, and workers receive too less or no safety training at all to avoid incidences. When sufficient resources for health and safety are made available, however, accidents can be avoided to a great extent. (Nadhim, Hon, Xia, Stewart, & Fang, 2016)

Site condition: Due to the nature of work, construction activities take place in fast altering and dynamic environments, under developing site conditions and outdoors. Some work tasks are riskier than others and especially outdoor activities exposed to frost, snow, heavy rain, extreme temperatures, excessive noise, and a lot of dust increase the probability of accidents. Occupations exposed the most to changing weather and high risk are roofing, carpentry, and scaffolding. Since it is impossible to change the weather, workers require modifications that consider the weather condition and forecast. (Nadhim, Hon, Xia, Stewart, & Fang, 2016)

Workgroup: Group norms are the accepted attitudes and ground rules about several things. Group norms can, for example, encourage a group of people to work efficiently and discourage behaviors that deter its efficiency. Because of human psychology, group members desire acceptance by others and the workgroup, so they are usually prone to conform to group norms and peer-pressure. (Jetten & Hornsey, 2013) A construction worker may not be fully accepted unless behaviors are respected by his co-workers. Therefore, workers will consider the attitudes of their co-workers towards health and safety. When deciding on behaviors, three kinds of co-workers' attitudes may be considered by a worker: (Zhang & Fang, 2013)

1. *Co-workers' attitudes to low efficiency caused by safe behaviors*. A lot of work on construction sites needs to be done in collaboration with other workers. If the work efficiency of one worker is lacking, the work of the others will be affected, and therefore, workers may not be willing to cooperate with co-workers having low work efficiency.
2. *Co-workers' attitudes to safety*. On construction sites, the workspace is limited. When carrying out work collaboratively, workers performing unsafe behaviors may not only hurt themselves and makes them prone to accidents, others are affected as well. Workers who follow the rules, work procedures,

and behave safely are normally considered as having a positive attitude towards health and safety and are more respected for such by others. Moreover, whether or not co-workers talk about safety or warn others in situations of danger and threat is also a way through which they judge co-workers' attitudes towards safety.

3. *Co-workers' view on the image of a person with unsafe behaviors*. Most people are concerned about their good image and a common phenomenon in construction is that workers want to be considered as a 'brave person'. (Zhang & Fang, 2013) Some workers on Chinese construction sites even behaved unsafely on purpose just to exhibit being 'tough guys' among their co-workers. (Choudry & Fang, 2008)

Some individuals will have more power and influence in a group and peer-pressure might lead to ignoring safety procedures, safe systems of work (SSoW), etc. One reason why safety initiatives may not immediately work is that the prevailing safety climate/culture does not support the behavior and therefore, more robust efforts may be needed to reframe attitudes toward safety generally. (Zhang & Fang, 2013)

Contractor: As already elaborated, on large Chinese construction sites there are many subcontractors with a tendency for contract tenders to be based on price, with only a slight budget for occupational health and safety arrangements and investments. (Khosravi, et al., 2015) Lacking capability or resources for occupational health and safety leads to more accidents and workers' injuries. (Nadhim, Hon, Xia, Stewart, & Fang, 2016) Constraints are created through the construction process/operation, construction management, and the subcontractor, and all their responses influence accident occurrence to a great extent. Constraints have a high probability to avert the attention of construction workers and may increase the probability of risks. (Suraji, Duff, & Peckitt, 2001)

Managers' evaluation of workers' performance determines workers' conditions and benefits such as salary, promotion, and work stability. People with fewer accidents have higher job satisfaction. Studies have also shown that there was a significant negative correlation between job satisfaction and the occurrence of unsafe acts. This means that job dissatisfaction can increase unsafe acts and unhappy people are more likely to be at risk of an accident. (Hossein, Motalebi, Zahra, Mahdieh, & Hamidreza, 2019) (Stoilkovska, Žileska, & Mijoski, 2015)

Supervision: The safer the response of supervisors, the fewer micro accidents are occurring and the less tension is experienced by workers. Conversely, the negative effect of supervisors' safety response on micro accidents will increase tension and stress. Some essential key principles for effective supervision are that the right people for the job are selected, training is provided where appropriate, and necessary skills and aptitude for supervisory activities (planning, communication, delegation, leadership, etc.) exist. Supervisors must have sufficient understanding and knowledge about hazards and their controls, and the skill and credibility to gain respect from their workers. Moreover, the performance of supervisors must be frequently measured, audited, and reviewed. Supervisors cannot be unsupervised. (Croner-i Ltd, 2020) Workers work more safely for a supervisor who is perceived as someone who respects and supports his workers and their contributions. (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

Project management: Different studies in the construction environment revealed, that safety leadership, management commitment, and support, management style, risk communication, competency, such as review, and feedback had a high negative association with unsafe behaviors and accidents. (Khosravi, et al., 2015) When construction projects schedules are tight, and the supervisor needs to accelerate tasks, it can generate pressure on workers' behaviors to finish a project on time. Therefore, workers are more willing to take shortcuts and ignore safety procedures but make they more prone to injuries. Studies indicated that this is especially true for FFHs and why most FFHs arise in the afternoon hours. (Nadhim, Hon, Xia, Stewart, & Fang, 2016) (Zhang & Fang, 2013)

Society: Some studies highlighted the influence of social factors on workers who undertake unsafe behaviors and accidents. (Suraji, Duff, & Peckitt, 2001) declared two reasons for the influence of society on construction safety. First, pressures from the social, economic, or political climate or environmental conditions can directly affect workers. As a result, these factors can distract them from their task, potentially leading to accidents and injuries. Second, the construction client is under several risk factors representing vulnerability for negative consequences, e.g., accidents, financial loss, crisis, social, and political pressures, during the conceptual development of a project. The response of the client can provide many of the constraints, within which other stakeholders (e.g. project management, design participants, and subcontractors) are likely to operate more unsafely. This cause-and-effect process can potentially intensify workers' constraints through unsuitable construction planning or unsuitable construction control procedures, leading to unsuitable site conditions, unsuitable worker behaviors, or unsuitable construction processes. (Suraji, Duff, & Peckitt, 2001) In a market-driven society, it is common for construction stakeholders to concentrate exclusively on completing projects to the required quality standard with the minimum time and cost. (Ng, Chen, & Skitmore, 2005) This condition is particularly concerning for construction stakeholders at the lower end of the subcontracting chain. Safety may be regarded as a secondary concern that can decrease the budget of employers for investments into safety but also accommodation. (Khosravi, et al., 2015)

4.9 Construction risk evaluation

This chapter will evaluate the risks introduced in the risk identification and risk analysis chapters, where the focus will be on construction-related risks generally. The purpose of risk evaluation is to estimate if the risks are acceptable and decide whether further measures are needed. (ISO, 2018b)

Mainly used for managers in defining the most influential risks and hazards on a workplace, the FMECA (Failure mode, effects, and criticality analysis) gives an overview on hazards inherent in the workplace as well as which risk someone needs to be most aware of. The Risk Priority Number (RPN) indicates which risks can be most harmful. The FMECA is defined through various steps:

- Process step,
- Requirement,
- Potential failure mode,
- Potential failure effects,
- Severity grade from 1-10,
- Potential causes
- Occurrence grade of 1-10,
- Current controls,
- Detection grade from 1-10,
- Risk priority number,
- Actions recommended (weibull, 2020).

The process step is a description of what step the failure occurs on. A headline for the topic.

Requirement describes what is required to make the failure happen.

Potential failure modes are large factors in the FMECA which describe the initial problem and what step it could go wrong. The different potential failure modes used were found in table 3 with distribution and their occurrence rate in the construction sector. According to table 8, these failure modes are what define the injuries happening in the construction sector. The category of "**Others*" in table 3 is left out because there is no meaningful definition to it.

Potential failure effects are the injuries that the failure modes can bring with them. As an employee gets struck by "a moving object", the failure effect is the potential injury to the worker. The potential failure effect asks: *"What injuries happened to the person?"* (weibull, 2020)

The first rating of the FMECA comes from severity grade. It is graded on a scale from 1-10, the higher the grade, the severe an injury from the potential failure effects, with 10 being fatality and 1 being e.g. minor injuries to the skin. The severity rating is defined through statistics found in figure 19, showing the fatality rate of the different failure modes. By analyzing the distribution of how severe the failure modes are, a rating from 1-10 is given.

The potential failure modes can describe how the workers could be affected by the different failure modes. The potential cause asks: *"How could the injury occur?"*, mainly defining what went wrong so that the failure mode occurred. (weibull, 2020)

Occurrence is the second grading of the FMECA. Here, the statistics found in figure 18 were used. The statistics show the distribution of the different failure modes and how many worker accidents are due to the failure mode in percentage, defining a grade of 1-10. With 10 being the highest rating, meaning the failure mode occurs the most frequently, and a grade of 1 being of low occurrence.

Current controls refer to what is being done already to prevent failure modes from happening. (weibull, 2020)

The third and last grading in the FMECA is the detection of the failure mode, whether someone can predict something with a high probability prematurely. For example, shutting off an area because a crane is moving is a proactive choice because it is easy to predict that there is a potential risk of falling objects. Other hazards and risks, such as toxic gas, are harder to detect both because of its invisibility and low rate of leakage. The detection of the failure mode is also graded from 1-10. 10 is the highest rate, making it the hardest potential failure mode to detect before it happens. Detection is the only grading that is not based on statistics but rather on assumption.

The Risk Priority Number (RPN) has the three gradings of severity (S), occurrence (O), and detection (D) and are multiplied together as:

$$RPN = S \times O \times D$$

The RPN is about how influential a potential failure mode is for workers' occupational health and safety. The higher the RPN the more influential and dangerous for workers, ranging from 1 to a maximum of 1000.

The last part of the FMECA is the actions recommended, describing future improvements towards better safety. Used as a reference towards current controls, the recommended actions are made to improve what is already being done at a construction site. It will give the best answer progressing towards the desired level. (weibull, 2020)

Figure 26 shows the FMECA.

Process step	Requirement	Potential Failure Mode	Potential Failure Effects	Severity (1-10)	Potential Causes	Occurence (1-10)	Current Controls	Detection (1-10)	Risk priority number	Actions recommended
Foreign interference	Material movement	Striking against fixed or struck by moving object	Injury to bodyparts	5	Not noticed object	6	Safety equipment, mutual Awareness, observant when controlling cranes	5	150	Define hazardous areas and manage the safety
					Movement in hazardous areas		Safety equipment, mutual Awareness, observant when controlling cranes			Define hazardous areas and manage the safety e.g. through teaching and monitoring.
		Striking against fixed or stationary object	Injury to bodyparts	4	Not noticed object	4	Safety equipment, mutual awareness	1	16	Change of safety culture (Confidence, shutting doors etc.)
					Movement in hazardous areas		Safety equipment, mutual awareness			Define hazardous areas and manage the safety e.g. through teaching and monitoring.
		Trapped in or between objects	Squeezed and damage to organs	3	Movement in hazardous areas	2	Safety equipment, observant when	5	30	
		Struck by falling object	Material dropped on workers head	8	Movement in hazardous areas	1	Safety equipment, avoid movement when material is moved	5	40	
Movement		Slip, trip or fall on same level	Injuries to bodyparts and potential head injury	3	Improper equipment	10	Safety equipment, safety installations (Rails etc.)	7	210	Check of proper equipment and testing. Further installations of antislip
					Hazardous environment (Weather, gravel on ground)		Common sense			Regulations to prevent work in bad conditions and clean hazards such as gravel
		Injured while lifting or carrying	Injuries to bodyparts	3	Lifting too much / too big	7	Regulations and laws	7	147	Management control and obervation on lifting
					Hazardous environment (Weather, gravel on ground, slim ladder)		Common sense			Regulations to prevent work in bad conditions, clean hazards such as gravel and alternative routes
		Fall of person from height	Injury to bodyparts, and potential head injury	10	Not aware	4	Mutual Awareness, safety installations (Rails etc.)	5	200	Define hazardous areas and manage the safety e.g. through teaching and
					Lifting too much / too big		Regulations and laws			Management control and obervation on lifting
					Hazardous environment (Weather, gravel on ground)		Common sense			Regulations to prevent work in bad conditions and clean hazards such as gravel
Maintenance	Maximum efficiency	Contact with electricity	Electrocution of worker	5	Improper electrical installation	1	Certified installer	2	10	3rd party check-up
					Damage to installation		Randomly discovered			Regular check-ups

Figure 26 - FMECA of construction Hong Kong
Source: Authors

Given the RPNs through the grading system, there are many potential failure modes with a low RPN. S*truck by falling object* has the highest RPN (40) of those below 100. Even though both severity and detection are both graded high, the occurrence of the *Struck by falling object* drags the total RPN down to an acceptable level. Based on the statistical analysis, both severity and occurrence are hard to argue against, but detection is based solely on assumptions on a construction site.

The severity rating of 8 for *Slip, trip or falls on the same level* is determined by the authors. The severity rating of 8 is high and can be discussed to be lower. The detection of "rough" weather can be easily foreseen, but a gust of wind, gravel on the floor, or slippery surfaces, in general, can be hard to detect.

Four potential failure modes, *Striking against fixed or struck by moving object, Slip, trip or falls on the same level, Injured while lifting or carrying, and Fall of a person from height*, have a higher RPN than the rest. The RPN of *slip, trip or falls on the same level* equals 210. This potential failure mode should be a focal point as both occurrence and detection are rated high but severity low. The authors assessed the potential severity according to the statistics for fatal injuries (figure 19). According to statistics, very few die from slip, trip, or falls (>0,1 %).

The severity and occurrence rating are based on statistics from figure 18 and 19 respectively, they were graded by taking the highest severity rate, based on fatality, grading it a 10, and then comparing the rest of the injuries to that.

Slip, trip, or falls from the same level was rated as occurrence grade 10 and has the highest probability according to figure 18 (24,61%). Following, the most likely type of accident was used to calculate the occurrence grade of the others. For example, *striking against fixed or struck by moving object* (15,8%), was rated as 6, because of the probability of occurrence:

$$\frac{15{,}8\ \%}{24{,}61\%} = 64\ \% \approx 6/10\ grading$$

The severity rating was not calculated the same way, because within fatal injuries a fall of a person from a height is dominating the statistics with more than 50% according to figure 19. Instead, the rest of the potential failure modes were assessed according to their potential damage to the workers.

Using the FMECA and RPN, we see an indication of what potential failure modes are the worst at a construction site. *Slip, trip, or falls on the same level* have the highest RPN of 210, also because the highest graded detection grade in the FMECA so this type of accident requires prioritization.

Fall of a person from height has the second-highest RPN of 200. For *slip, trip or falls on the same level,* the main contributor is the occurrence grade, as it was the most frequent occupational injury to construction workers according to figure 18. This type of accident has a high severity grade because injuries will most likely lead to death.

4.10 Risk assessment summary

The HAZID showed there are several types of hazards naturally in construction work which pose mainly harm to construction workers. Construction sites are at times very crowded places with different types of workers (e.g. supervisors, foremen, steelworkers, scaffolders, bricklayers, electricians, carpenters, plumbers, and machine operators) who carry out construction activities closely and within only limited space. Other hazards are caused by running machinery, working at heights, hot work, working with electricity, vertical transportation, heavy lifting and heavy machinery equipment, a high degree of manual handling, awkward postures, and other ergonomically hazardous or forceful exertions while being exposed to abnormal weather conditions when working outdoors. (Jeong, 1998) Moreover, the short-lived and transitory nature of construction tasks generally leads to a dynamic workforce, so that construction companies must hire new workers regularly who may lack experience, skills, and training, making them susceptible to accidents. (Shao, Hu, Chen, Liu, & He, 2019)

Construction workers in Hong Kong have a high likelihood (4,105%) of suffering from any kind of injury. The risk analysis and evaluation showed that the highest risks are falling from heights (over 50,96% within fatal injuries) and slip, trip, or falls on the same level (24,61% within all injuries). As for fatal injuries, struck or being struck by falling objects, such as striking against fixed or struck by moving objects represent other high risks. (Shao, Hu, Chen, Liu, & He, 2019) According to previous studies, the most common type of non-fatal injuries, defined as those which result in at least 4 days of absence from work, are fractures, followed by contusions or bruises, and abrasions. (Jeong, 1998) (OSHA, 2020b) Moreover, the research indicated that accidents often occur around lunchtime, again in the afternoon, and mostly at the beginning of the week. This information can be useful for those who are responsible for managing or overseeing occupational health and safety in construction.

For analyzing the root causes of accidents, it must be remembered that occupational accidents (including injuries) happen due to unsafe conditions in the environment and mainly due to unsafe human behavior. Here, the research and data analysis of Hong Kong did not lead to sufficient results. The factors influencing unsafe behavior have been explained.

5. Risk management

After the risks have been assessed, adequate and effective controls can be introduced. The purpose of this chapter is to enhance knowledge about how risks in the construction industry can be prevented, managed, and most importantly, lives saved.

According to the International Standard Organization, ISO, risk management refers to "*coordinated activities to direct and control an organization with regard to risk*". Risk management is used to identify potential sources of harm or loss for people, assets, and the environment before they occur, or, in the case of opportunities, to try to leverage them to cause them to occur. (ISO, 2009) Risk management's main objective is to support the decision-maker in how risks can be eliminated or reduced risks to acceptable levels and to recommend suitable control measures against hazards and risks to provide a safer workplace without harm or injury for everyone. It shall also increase the probability of success, decrease the uncertainty of achieving objectives, and should be an evolving process. (Stroie, 2011)

5.1 Reactions to risk

After identifying, assessing, and evaluating all the risks that occur or may occur in construction, decisions, and risk control actions need to be undertaken to propose specific countermeasures of each of the identified risks. These actions may aim to complete neutralization of negative impacts on the project, process, or task or focus on reducing the pejorative influence. (Szymański, 2017) These reactions can be divided into four main alternatives, as illustrated in figure 27.

Figure 27 - Risk control alternatives
Source: (Szymański, 2017), graph made by authors

Risk acceptance (active or passive) involves the acceptance of risk at a specific level. When risks are accepted, the existing control measures are adequate, and no other action is needed to reduce the level of risk because we can accept its impact and the possible consequences. (RRC International, 2019)

Transfer of risk is associated with the transfer of hazard to another entity demonstrating the ability to neutralize risk. For example, a contractor could transfer the risk of falling from heights for a relatively inexperienced worker to another contractor whose workers are specialized in tasks involving working at heights and have a sufficient level of skills and experience. (Szymański, 2017)

Risk reduction or risk mitigation are actions that reduce the severity, the frequency, or the likelihood to occur overall. When the risk assessment has confirmed that the risks are too high, resources must be allocated to either reduce the risk to a level that is reasonably practicable, or at least tolerable. Tolerable implies that is not acceptable but it can be tolerated for a short time while interim controls are implemented. (RRC International, 2019) Often, the extent of risk reduction is described "as low as reasonably practicable" (ALARP). ALRAP involves assessing risk and comparing it with the required sacrifice of time, monetary resources, etc. against the benefit of reducing risk. It must be possible to validate that the cost involved in reducing risk is not disproportionate to the benefit gained. (WorkSafe Australia, 2013) (Worksafe New Zealand, 2016)

Risk avoidance involves either preventing the occurrence of risk or the elimination of risk. It is usually the most preferable option because a risk that does not exceed the acceptable level does not pose any loss, harm, or other negative consequences. (RRC International, 2019)

After decisions and actions in terms of choosing tools, setting priorities, and using optimal combinations in risk control were made, it is also important to further control, monitor, and evaluate undertaken activities. This involves checking and ex-post evaluation of the impact of undertaken actions, update and adjustment of the risk management process in the case of a wrong decision, such as further use of tools which will ensure success in risk management. (Szymański, 2017)

5.1.1 Control of risks through the hierarchy of controls

As shown in the previous risk assessment, some risks associated with construction activities must be accepted because there are certain hazards naturally in construction. For example, the hazard of working at heights cannot be eliminated as long as humans still perform tasks like scaffolding, roofing, etc. many meters above ground level. Therefore, the risk of falling from heights must be accepted to some extent. However, the risk of accidents and injuries due to unsafe behaviors (e.g. through not wearing a safety harness) should not simply be accepted because there is scientific evidence that they can be reduced.

For deciding on which strategies are most effective and suitable, the internationally recognized safety management standards ISO:45001 and ILO OSH 2001 recommend using the hierarchy of controls. (RRC

International, 2019) The hierarchy of controls is a logical method on how to decide which strategy for hazard control is best. (isoupdate, 2018) As indicated in figure 28, methods at the top of the graphic indicate potentially more effectiveness of protection than those at the bottom. "*Following this hierarchy normally leads to the implementation of inherently safer systems, where the risk of illness or injury has been substantially reduced*." (NISOH, 2015) One of the main reasons why elimination, substitution, and engineering controls are preferable for hazard control is because they are based on a technical solution approach rather than relying on human behavior. Humans will always be prone to make mistakes and human error has been cited by many researchers as a primary cause for occupational accidents, not only in the construction industry. In return, the prevention of human error is generally seen as one of the main contributors to better and more reliable safety systems. (Abdelhamid & Everett, 2000) (Choudry & Fang, 2008) (Fang, Xie, Huang, & Li, 2004)

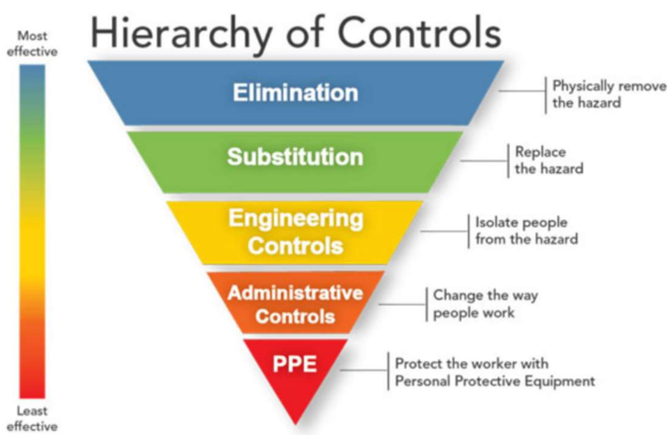


Figure 28 - Hierarchy of controls
Source: (NISOH, 2015)

The reader can obtain more information about each control in *Appendix 5 – Defining prevention and mitigation strategies for hazard control*.

5.2 Behavior Based Safety

Within the field of construction, many studies have been conducted to reduce accidents including legislation, engineering failures, safety awareness campaigns, safety training, and unsafe acts. Safety training has also been one of the essential methods for reducing incidents, because those who are trained, know what to do, and will conduct themselves in a good and reasonable way. (Choudhry R. M., 2014) However, evidence exists that safety training is not always effective. (Hale, 1984)

One successful and one of the most powerful approaches available for improving safety is Behavior Based Safety (BBS). In its essence, BBS is about engaging the front-line workforce to improve all aspects of safety, getting all employees involved in doing frequent, thorough hazard analyzes, fixing unsafe conditions, identifying and sharing best practices, and, most importantly, helping each other to develop safe habits. (Lingard & Rowlinson, 1997) (Skowron & Sobocinski, 2018) (Choudhry R. M., 2014) BBS is an operational learning theory on how to change attitudes about safety. BBS has been widely used in several industries of petroleum, manufacturing, nuclear power, transport, and occasionally, the construction industry in Europe and North America since the 1980s. BBS is the systematic application of psychological research on human behavior and aims to reduce occupational injuries and accidents. (Choudhry R. M., 2014) (Chen & Tian, 2012)

The idea behind BBS is behavior modification and based upon the principle that behavior is a function of its consequences and the frequency of desirable behaviors. The principles behind the theory assume that human safety consciousness and safety habits are not distinctive and can be improved by positively reinforcing safe behaviors and training, thereby eliminating the need for unsafe behavior. (Choudhry R. M., 2014) (Li, Lu, Shu-Chien, Gray, & Huang, 2015) The BBS approach is strongly influenced by behavioral science as conceptualized by Burrhus Frederic Skinner (1094-1990). His ideas and work on applied behavior assume an antecedent-behavior-consequence model. Antecedents are “triggers” of behavior, whereas the consequences (positive or negative) highly influence the probability of repeating the behavior in the future. (Skowron & Sobocinski, 2018) Skinners studies were developed in close contact with laboratory experiments and many studies were based on animal behavior particularly of pigeons and rats. (paedagogen.dk, 2020)

BBS strive for improving safety differs from traditional approaches in two ways. The first is its attention to observable safety behavior, instead of unobservable attitudes about health and safety. The second is its weight and emphasis on the encouragement of safe behaviors, rather than the penalty for unsafe behaviors. Studies revealed that punishment must take place whenever unsafe behavior occurred and as soon as possible. (Choudhry R. M., 2014) Although a construction company could improve its efforts into CCTV and cameras to monitor the workers, the company would probably still not succeed to punish every worker whenever unsafe behavior has been observed.

5.2.1 BBS implementation process

From the site implementation process, the BBS method appears primarily as bottom-up in the organization. It focuses on front-line workers but involves all other levels of supervisors, middle and senior managers, wherein critical behaviors are identified and targeted for modification. The process of BBS is illustrated in figure 29 and can be summarized as “DO IT” (D=Define target behaviors, O=Observe target behaviors, I=Intervene to improve behaviors, T=Test impact of intervention). (Chen & Tian, 2012)

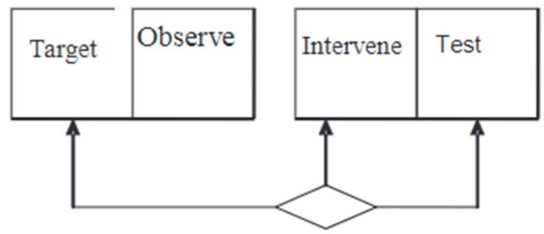


Figure 29 - BBS process of "DO IT"
Source: (Chen & Tian, 2012)

The implementation of BBS should begin with a target or goal-setting meeting of managers, subcontractors, stakeholders, foremen, and workers in which realistic and achievable goals for safety improvement are agreed upon. (Choudhry R. M., 2014)

As interviews revealed, construction workers claim that communication toward management is often lacking, therefore, it is emphasized that the implementation of a safety management system or safety initiative should be carried out in consultation and cooperation with frontline staff. Safety management begins at the top of the organization. The senior management must provide the leadership necessary to inspire and motivate managers at all levels to follow with priorities and objectives that they set their staff. It is recommended to let workers, foremen, supervisors, and construction site managers participate in goal-meetings, so those at the bottom of the organization can communicate present hazards and risks inherent in their work and get the opportunity to discuss with supervisors and management about possible improvement solutions. (RRC International, 2019) Goal-meetings also show that real efforts are taken to prevent accidents which can contribute to a better health and safety culture with fewer incidents. Workers will also feel more ownership of the improvement process, are more motivated to induce commitment, and happy to enforce safety standards because, after all, nobody wants to experience harm at work. (Choudhry R. M., 2014) (Chen & Tian, 2012) "*Having manageable goals with a clear plan of action will make a BBS approach more likely to be successful*". For example, a construction company could decide to reduce the number of accidents and near misses by increasing attention to housekeeping. Housekeeping on construction sites, generally, includes collecting spare nails in the work area, proper waste management, ensuring that floor openings are covered and guarded, not throwing objects from heights, and providing safety barriers around open excavations. (Choudhry R. M., 2014)

After the goal-setting meeting, feedback on safety performance should be provided regularly. Feedback charts can enhance performance, but the information must be easy to understand for workers, and charts are placed at appropriate places where operatives can see them. (Choudhry R. M., 2014) Graphic communication (e.g. pictures, symbols, or pictograms) and broadcasting methods (e.g. noticeboards, posters, films or videos, toolbox talks, and digital media and intranet systems) are suggested because they can reinforce key messages, avoid language barriers and pose low costs. Graphics can also generate interest among workers. However, safety information can become quickly part of the surroundings, trivialize important issues, and rely on the recipient to interpret the correct message from the image. (RRC International, 2019) The frequency or record of unsafe behavior can also be translated into a Safety Index (SI) measuring worker safety performance of workgroups and sites. (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

The process of observation is an essential part of BBS programs and should be done on a frequent or even daily basis. Prior, some people must be selected and trained to act as observers and anyone can be observed. It is also recommended that the observer inform the worker that they are being watched. The people selected for the observations should be competent, have experience with the task, enjoy a good reputation and respect among their colleagues, believe in the effectiveness of the BBS program, and be able to provide positive feedback for safe behaviors. They can be qualified supervisors with sufficient site experience or external experts. BBS intends to determine if workers perform tasks safely and identify any hazards that could potentially cause harm. Observation should be conducted with checklists or forms that break the task down into smaller components (task analysis). Thus, it creates also opportunities to look for issues within the task itself. With time, checklists can be modified by replacing more stable behaviors with risky ones. Measurement can be made by trade, crew, or group-wise. Written and simple observation notes enable to review and monitor the entire BBS life cycle and create more chances for its future effectiveness. (Zummack, 2018) (Choudhry R. M., 2014)

During the intervention, the observers should acknowledge unsafe behaviors and acts through coaching, discussion, and guidance, but they should not punish. However, behaviors that present an immediate threat to the life or the environment must be stopped immediately and a discussion between the observer and the worker should take place. (Zummack, 2018) One of the most powerful ways to promote and increase the probability of safe behavior is by providing social rewards in the form of recognition or praise. When safe behavior becomes an established part of the individual's response, rewards can be made on a less frequent basis. Notably, material rewards occasionally tend to discourage reporting accidents and near misses and are therefore less effective. Acknowledging safe work behavior positively will encourage workers to repeat the same behavior again and again, and co-workers are more likely to informally copy them. Moreover, encouraging desirable behavior is more likely to lead to success because, compared to punishment, it has not to be given immediately and every time. (Choudhry R. M., 2014) (RRC International, 2019)

BBS has already been discussed in many papers, but also tested and practically implemented in studies of construction sites in countries all over the world. (Winn & McAfee, 1989) (Sulzer-Azaroff & Austin, 2000) (Chen & Tian, 2012) (Choudhry R. M., 2014)

(Choudhry R. M., 2014) conducted a case study on a leading construction company in Hong Kong. The case study identified and measured the safety behavior of PPE, housekeeping, access to heights, plant, and equipment, such as scaffolding. At the end of the 9th week, a clear increase in safety performance was achieved across all five categories. For example, one project improved housekeeping from 86% at the end of week 3 to 92.9% in week 9. The results show BBS can lead to improvement of safety even in construction site environments. (Choudhry R. M., 2014)

5.2.2 Advantages of implementing BBS into the construction industry

BBS can improve conditions that contain risks and the achievements of implementing BBS can be defined in many ways. Although there are different measures and rates used by researchers and safety professionals, some of the common positive effects include:

- *"decrease in the number of unsafe behavior,*
- *decrease the number of injuries/injury rates and illnesses,*
- *decrease of absence from work caused by injuries and illnesses,*
- *lower costs of treatment*
- *lower insurance rates*
- *increase in the number of safety behavior*
- *more worker involvement in contribution to organizational safety*
- *overall improvement of the organizations' safety climate and/or safety culture"* (Skowron & Sobocinski, 2018)

For example, reducing the probability of unsafe behaviors reduces the risk of slip, trip, or falls because workers might remember to grab the handrail when using stairs and scaffolds. Thus, even external contractors gain from employees who have settled a better understanding of the value of safe work practices and a sense of self-determination and personal responsibility. Reduced claims, as well as other benefits that are more difficult to quantify, such as greater job satisfaction and an enhanced appreciation for quality, can be long-term effects. (safetymanagementgroup, 2020)

5.2.3 Disadvantages of BBS of implementing BBS into the construction industry

Despite BBS's great advantages and likely chances to improve behaviors on construction sites, one must be aware of the possible disadvantages.

The first big issue and characteristic of construction sites are they have usually a high-turnover of workers. Depending on the scope of the construction project, there can be several subcontractors who work perhaps only for a couple of days or weeks on site. This challenges the continuity and robustness of a safety behavior program because safe behaviors need sometimes to be learned and through practice remembered. (Chen & Tian, 2012)

(Choudhry R. M., 2014) reported that many operatives did not understand safety charts properly because they were lacking knowledge of how to read and interpret mathematical and percentage scores for safety performance used as a form of feedback. Other experiments also showed that behavior based applications can even deteriorate conditions on-site. The incentives may not always work as desired or even result in adverse effects. Workers prefer to work without supervision. Being constantly observed might cause additional stress than working in normal conditions. As already explained, stress has a great influence on the likelihood of unsafe behaviors. (Smith, 1999) claims that BBS programs tend to bring only short-term effects, as they focus mostly on the results, giving the false assumption that the root causes of problems were solved. (Skowron & Sobocinski, 2018)

BBS programs can lead to a climate of fear, instead of contributing to the safety climate or safety culture. This is mainly because BBS focuses on immediate causes and minimizes the importance of the environment. Workers do not want to be considered as “unsafe” and become reported in a file. This does not always have to be true for the entire organization, but fear and “victim-blaming” can spread to co-workers, work crews, or groups causing great reluctance to report injuries and especially near misses and undesired circumstances. A situation like this does neither improve accident prevention nor the way of thinking about safety, overall. Instead, the contradiction of the desired effects appears. (Skowron & Sobocinski, 2018)

The results of a case study of the San Francisco Bay Bridge rebuild project demonstrated that BBS programs can result in injury and illness rate manipulation. The project management provided all working crews with substantial monetary incentives, while foremen, supervisors, and managers of diverse levels were rewarded with "merit cards” which were compulsory for career improvement. The requirement for gaining rewards was that no injuries were reported within a certain period. Finally, the BBS program created an atmosphere of fear, as any injury report of an individual worker would result not only in losing his or her reward but might also put the rewards of other team members and the superiors at risk. (Brown & Barab, 2008) (Skowron & Sobocinski, 2018)

Observers must be always at the right place and the right time for the relevant and typical manifestation of safe behavior. Especially in construction, it is hard to monitor workers, as traditional construction sites are large-scale, making employees freer to roam around the site and monitoring may consume several hours for safety managers. (Li, Lu, Shu-Chien, Gray, & Huang, 2015) Moreover, many unsafe behaviors might not be detected by the observer, so they still result in accidents and injuries. (Oswal, Sherratt, Smith, & Hallowell, 2018)

(Lingard & Rowlinson, 1997) implemented and analyzed BBS on seven public housing construction sites in Hong Kong and included the effect of intervention withdrawal into their measurements. Their findings indicated that on four of the seven sites housekeeping performance even deteriorated significantly when the intervention was removed. Achieving persistent and sustainable success can be challenging for BBS in the construction industry.

BBS has the potential to increase safety performance, but attention must be paid to its focus and sensitive dependence on external antecedents and consequences. (Zhang & Fang, 2012) The concept is less suitable for changing internal factors such as attitudes, awareness, values, and personal characteristics. Targeting internal awareness or attitudes to make people think and act differently can perhaps only be achieved by extensive one-on-one interactions between a client and a specially trained intervention specialist or clinical psychologists in professional therapy sessions. Very few safety professionals or consultants hold the education, training, skills, and experience necessary to implement such an approach, thus, it is not cost-effective in construction. (Geller, 2001)

5.3 Proactive Behavior Based Safety

A more recent concept of behavior modification is Proactive Behavior Based Safety (PBBS). PBBS combines the traditional, qualitative principles of the BBS management (observation, training, and feedback) with a software called the Proactive Construction Management System (PCMS). The PCMS is used to provide virtual real-time-tracking of workers and allows immediate feedback of unsafe acts to workers and back to the system if a functional device is installed on workers' safety helmets. (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

PBBS was developed in the construction virtual prototyping laboratory (CVPL) of the Hong Kong Polytechnic University and one study shows its chances to be effective for reducing unsafe behaviors in construction. The two main improvements of PBBS are:

1) *"Enhancing the capacity of on-site workers in detecting sources of key location-related dangers and providing early warnings;*
2) *Recording the behavior of site workers when they are given warning signals by implementing the automatic observation of unsafe behaviors."* (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

5.3.1 PCMS system architecture

The PCMS is a location-based behavior observation software that integrates multiple information technologies. The system consists of two major parts, the real-time location system (RTLS) and the Virtual Construction Simulation System (VCS) as illustrated in figure 30.

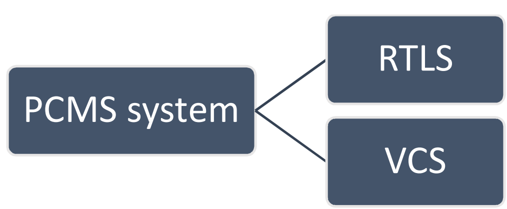


Figure 30 - PCMS system
Source: Authors

The RTLS consists of a real-time location network and a real-time location engine. It is a wireless network technology and operates in a wireless personal area network (WPAN) with a time of arrival (TOA) technique as a location method. It can track with an average error of one meter which allows more preciseness than current system alternatives of e.g. GPS, ultra-sonic, infra-red, ultra-wideband, or chirp-spectrum. (Karapistoli, Pavlidou, Gragopoulos, & Tsetsinas, 2010) (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

The location engine finds the coordinates of the tags using trilateration based on the three distance values while data are sent to the application server through the location network. The functions of the RTLS are "*to manage the location network, calculate the tag locations and relay danger alarm signals to specific tags through the location network*". (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

The VCS contains an application server, a user client, an end-user, a web server, and a database server. Through the user client, safety supervisors or managers can visualize construction processes, track people and equipment, and replay construction processes. The user client is a web-based application. The application server, web server, and database server form together with a connection that links the user client to the location engine. A 3D model of the site, nearby environments and the position of pre-defined hazardous areas are stored in the VCS, whereas the locations of the observed objects (workers, equipment, and vehicles) are visualized in real-time. (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

If the system detects distances between workers and their nearby pre-defined hazards that are fewer than an allowable safety value, the worker is considered to undertake an unsafe behavior. Warning signals are triggered and send to the real-time location engine, which then transmits the signal to activate the tag warning devices installed on the workers' helmets. "*Because continuous warnings of these unavoidable hazards are apt to attract excessive attention of the crew and interrupt normal construction tasks, consequently decreasing production performance, location tags fixed on helmets only sound three times when a worker is determined to be entering a danger zone. A limitation of the PCMS is the limited visibility of construction workers to their safety supervisors or safety officers, who can only detect location-based behaviors. However, compared to many manufacturing plants where workers are much more clearly visible to supervisors, the construction industry can achieve automatic relative visibility with the assistance of PCMS technology*". (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

The end-users, who include safety officers, safety supervisors, equipment operators, site workers, and system maintenance workers, are equipped with the e-tagging system (including data storage and retrieval) and can visualize all the unsafe location-based behaviors of the workers and conduct a safety report via an intuitive graphical user interface in a remote web center. The e-tagging system allows also many other benefits. For example, encoding worker e-tags with personal information (e.g., user profile, role, tasks, and existing project conditions) and obtaining safety performance (e.g., habitual unsafe behaviors, accident records, and past Safety Index scores). Finally, vehicle e-tags can be encoded with information on maintenance schedules and inspections, thus generating automatic updates to check the state of equipment. (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

5.3.2 PCMS function

PCMS has a lot of useful features but is recommended in construction project management that already relies on virtual construction software for building information modeling (BIM) to find and fix problems before the building process. Otherwise, it might consume a lot more time and work to create a virtual model of the construction site in which the observation and simulation can be modeled. (Li, Lu, Shu-Chien, Gray, & Huang, 2015) The PCMS allows the following functions.

Hazard detection: As elaborated in the risk assessment, the majority of Hong Kong's fatalities are due to falling from heights, contact with electricity, struck by falling objects, and striking or being struck by moving objects. Construction managers using a system like PCMS can assist on-site workers in detecting dangers and provide proactive warnings to them to reduce the risks and possibly prevent fatal consequences caused by falls from heights and moving objects. Another benefit of the system is that it is relatively easy to understand for workers and encourages workers to make safe behaviors habitual and to avoid unsafe behaviors. "*Workers who choose to ignore warning signals sent by the PCMS and head toward danger zones are regarded as exhibiting unsafe behaviors while those who take actions such as turning around or leaving the area quickly to avoid possible dangers are regarded as exhibiting safe behaviors*." (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

Safety data record: The PCMS can collect and record behavioral data (which the end-user considers as relevant) at any time in the database. Unsafe behaviors include, but are not limited to, ignoring warning signals, procedures, and moving toward dangerous or risky areas of an e.g., a moving tower crane's hook or the edge of a height, rather than circumventing them. "*With respect to safe behaviors, if a worker maintains a safe distance (- more than three meters) from the danger zone after three warnings, this is recorded as safe behavior. However, when a worker leaves and enters the same zone, the tag will sound again to warn him about the safety hazard, and the unsafe behavior is recorded."* (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

Thus, the combination of the real-time accident data, near-miss reporting, and equipment maintenance information allows managers and other potential stakeholders to study workers' performance, learn how to effectively allocate resources, establish or improve safety barriers, and enhance efficiency and safety on site. (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

Safety training: The record of workers behaving unsafely can be used for study and analysis conducted by competent managers. The visualization of behavior, as it is shown in figure 31, leads to more safety knowledge, fewer risks, better safety training, and education especially during a presentation in front of construction workers. (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

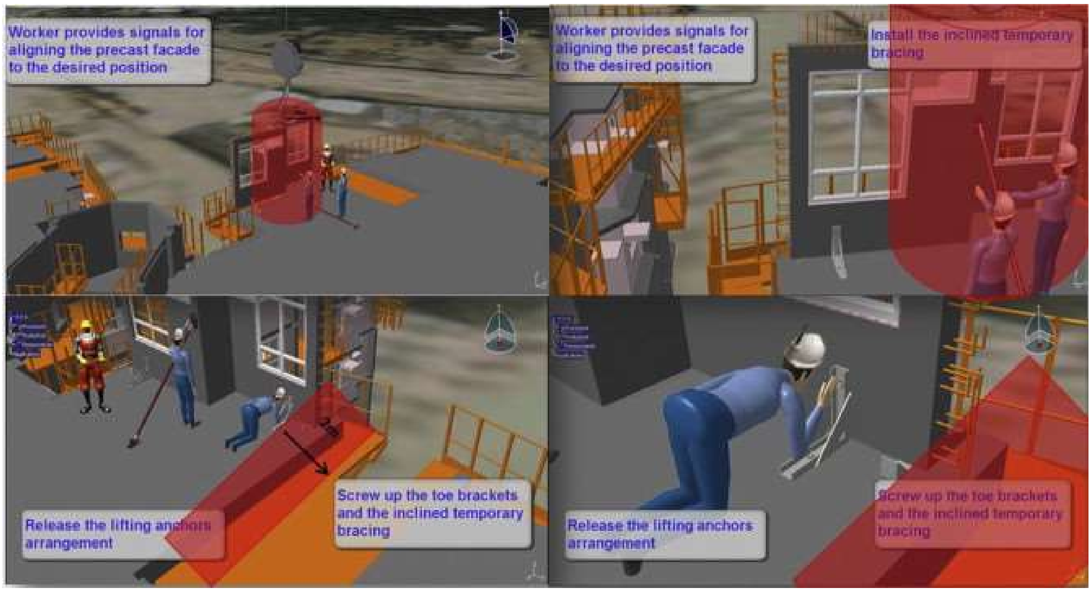


Figure 31 - Safety training in the PCMS
Source: (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

There are two key enhancements to safety training:

- **Real-time feedback**: During the job, the PCMS helps each worker to identify high-risk activities without thinking. "*Real-time proactive safety warnings increase the situational awareness of workers.*"
- **Post-real-time analysis**: During instructional sessions, the PCMS provides worker-centric feedback in the form of checklists of location-based behavior observations and can contribute to fewer barriers in the risk communication between supervisors and managers who are higher up in the hierarchy of the organization. (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

5.3.3 PBBS

The two concepts PPBS and BBS follow the same principle. Safety consciousness and safety habits are not inborn; thus, they can be improved with training. (Pearson, 1995) (Li, Lu, Shu-Chien, Gray, & Huang, 2015) As well as BBS, PBBS uses four basic steps. These are in their essence: (1) Baseline observation, (2) Safety training, (3) Follow-up observation, and (4) Feedback and reinforcement. Figure 32 presents this process graphically.

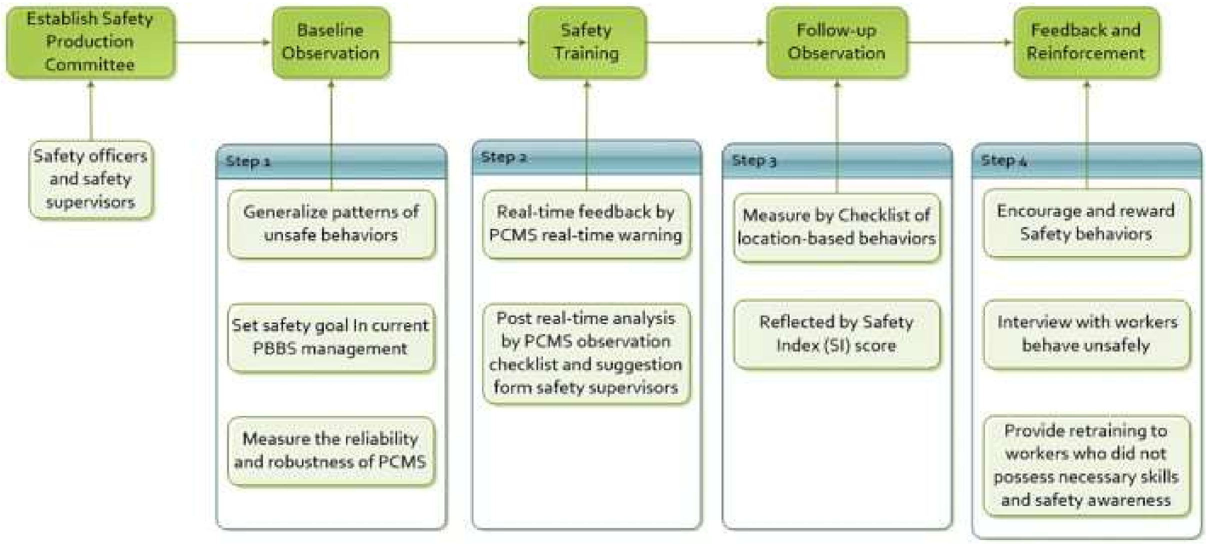


Figure 32 - Workflow of PBBS management
Source: (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

Establish a Safety Production Committee: Before conducting the PBBS observation, it is recommended to establish a "Safety Production Committee". Members should include safety managers, subcontractors, and foreman tasked with formulating policies to sustain the overall health and safety of workers and the workplace. All members of the committee must go through strict safety training until they are deemed to be well-trained safety representatives and ensuring high competence. The function of the committee can also be explained as the goal-setting meeting of the BBS concept in which achievable goals for safety improvement are agreed upon. Safety representatives are also streamlined through the PCMS. "*In general, one safety officer and two safety supervisors are needed per 100 workers, and the roles and responsibilities of safety officers and safety supervisors are clearly specified. The principle duty of the safety officer is to assist the client, that is, to advise the client of any necessary repairs or maintenance to the premises, plant, appliances, or equipment; to investigate and report to the client any accidents, dangerous occurrences, injuries or fatal accidents; to make recommendations to prevent the reoccurrence of similar events; and to prepare and submit a monthly safety report to the client. In turn, the duty of each safety supervisor is to assist the safety officer, that is, to conduct face-to-face interviews with workers with unsafe behaviors, and to prepare and submit weekly safety reports to the safety officers.*" (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

Baseline observation: To ensure effectiveness, worker's background information (including personal information, trade, and nature of their job, age, education, marital status, etc.) and attitude toward safety together with their accident/non-accident record must be collected and stored in the PCMS database. The baseline observation is then used to monitor all types of unsafe behaviors (including near-misses) by the PCMS which need to be previously defined in the PCMS checklist of location-based behaviors. (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

Safety training: Education about safety and training can, generally, improve the awareness and competence of employees and related parties to work safely. Training can cultivate and promote a positive safety culture in a group, the organization, or on the construction site. (Fang & Wu, 2013) In PBBS, verbal coaching by safety officers and supervisors in a formal (during a toolbox-meeting or in a safety training center) and in an informal setting (occasional dialogues) have a positive, meaningful, and longitudinal effect on safety training. On the other hand, those who are responsible for supervision must be trained too, so they can highlight what was done unsafely and improve one's professional skills in a specific trade. (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

Follow-up observation: The PCMS is effective, as long as dangerous zones are identified and associated unsafe behaviors (e.g. approaching the edge of a height) are defined in a location-based checklist. Moreover, the observed results and records should be converted into scores as percentages. For this matter, the Safety Index (SI) can provide meaningful insights. The formula is as follows:

$$\%SI = \frac{N_2}{N_1 + N_2} \times 100$$

of which N_2 is the number of instances of safe behavior, N_1equals the number of observed instances of unsafe behavior, and $N_1 + N_2$ is the sum of all instances of the previously defined safety-related behaviors. (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

As soon as the amount of unsafe behaviors rises, it necessitates taking actions to control accident occurrence. Hence, SI may be termed a proactive index. (Chen & Tian, 2012) Scores for different subcontractors can also be compared with each other. As same as for BBS, the results of workers' safety performance should be visibly posted. (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

Feedback and reinforcement: When a subcontractor team meets its periodic safety goal, a short meeting provides an opportunity to recognize the safety achievement. Workers in different trades who have the highest SI scores detail what they did to increase safe behaviors and reduce at-risk work practices by using PCMS devices and complying with BBS management. In return, safety supervisors and foremen should encourage and reward workers who behaved safely. They could interview workers and discuss their performances. Workers who did not satisfy the compulsory safety skills and awareness require training. (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

5.3.4 Field studies

PBBS was already tested on a large construction site in Hong Kong to validate effects. The experiment was conducted among two subcontractors, a sample size of 198 workers, and a total duration of nine weeks of which two weeks was baseline observation. The implementation process was conducted as required and some incentives, both financial and social, were awarded to construction workers who obtained SI scores over 80%. 33 workers had low SI scores (less than 60%) and were interviewed. Half of them indicated that they behaved unsafely because of productivity pressure. Overall, the SI scores of the two subcontractors increased from 64.12% and 63.96% during the baseline observation to 87.25% and 92.55%, which accounts for an improvement of 36.07% and 44.70%. According to these findings, PBBS has the potential to reduce occupational health and safety risks in construction as well as to improve the health and safety climate, however, it is uncertain if positive long-term effects can be expected. (Li, Lu, Shu-Chien, Gray, & Huang, 2015)

5.4 Analysis of the expected net benefit of implementing PBBS in the construction industry

The main research objective of this thesis was to analyze the expected net benefit of implementing PBBS in the construction industry.

The term expected net benefit can be defined in different ways. In this context, it shall mean an increase in the overall quality or quantity of safety that is likely to lead to a reduced number of injuries and accidents. (lawinsider, 2020b)

The implementation of PBBS composed of the traditional concept of BBS and the PCMS into a construction operation can have several positive outcomes. It can be useful due to three key reasons:

1. Almost 80% of construction accidents are caused by unsafe human behavior. (Hickman & Geller, 2003) PBBS is adaptable to tackle exactly such situations in the construction industry as long as those tasked to "correct" unsafe behaviors are competent enough to train workers, instead of punishing them. (Li, Lu, Shu-Chien, Gray, & Huang, 2015) It is of great use for construction sites with a high number of employees who have a lack of training and knowledge about safety, such as those who violate rules and procedures because of their bad attitude.

2. Several studies have demonstrated to improve safety performance through the application of BBS. One crucial disadvantage of BBS is, however, when intervention is withdrawn, conditions and safety performance are at risk to return to previous states or even deteriorate. PBBS can monitor workers all the time and fills this essential gap for a perhaps sustainable safe behavior culture. (Li, Lu, Shu-Chien, Gray, & Huang, 2015) PBBS

can also decrease the workload for single human observers (as in BBS) when the e-tagging system and PCMS software are working properly.

3. PBBS with its current proactive information technology, which includes real-time location monitoring and virtual construction simulation, can reduce some of Hong Kong’s major risks. These are falling from heights, struck or struck by moving objects, and struck by falling objects. Even slip, trip, or falls could be reduced when worker internalize the idea of behaving safe and adequate housekeeping practices. The PCMS is of high benefit, because it can send an alert automatically to the workers but also records safety data that highlights areas of risk. It creates many opportunities for safety training.

To be effective, construction employers must be aware of the requirements and limitations when using PBBS. They must give proper work instructions and assure that workers understand the reasoning behind the software. It is used as an addition to their PPE but does not eliminate or remove the need of thinking on how to do a job safely, identifying hazards, and taking actions when in doubt. Only when workers wear their safety helmet and the system is free of malfunctions, warning signals will occur and help to make the worker instantly alert of what he or she is doing. To ensure the effectiveness of the receiver (the PCMS system), it is crucial to install the e-tagging senders into every moving hazardous object and all dangerous zones must be identified. At the current stage, it is uncertain how reliable the software is overall, and especially when exposed to different kinds of heights, depths, materials, etc. There may be “grey” zones which could affect the accuracy of workers’ positions.

Although the existing field study provides evidence that safety-scores increase, the cost of such a system is probably high. It requires a lot of effort and perhaps many financial resources to establish the PCMS system and, most importantly, maintain it. First, the construction site itself should be already available in a virtual 3D model. Second, because of the dynamic, mobility, and changing nature of construction sites, the user of the software must update the system frequently on new hazards and changing construction site design. This requires a competent full-time safety manager with sufficient IT-skills and preferably experience with a system like PCMS. While the wage for such a manager can be predicted, no information has been available indicating the costs for implementation of the system. However, the cost of increased safety for employees will always have a positive economic influence on productivity, efficiency, and achieving business targets. The person responsible for the PCMS also needs to invest work into continuous improvements and relocation of equipment. For example, if an area was previously defined as hazardous but the task has been finished, the hazard may be eliminated. This needs to be updated in the software to avoid complications, confusion, and frustration because false warning signals may be triggered where they should not occur.

It seems that PBBS is recommended for larger construction companies only who want to invest in an auspicious safety system and can provide the necessary time, budget, and human resources to operate, update and maintain the PCMS. As of now the PBBS is a relatively new concept and there is a lack of field studies assessing all the advantages and disadvantages of the system. It is, therefore, uncertain if the PBBS leads to a better health and safety culture or if it creates a culture of fear due to the high degree of observation. Although workers are not punished directly, they might disagree that everything they do is recorded and used for “training purposes”. Some of the more skilled construction workers with more job opportunities might resign and leave where the management does surveillance 24/7, whereas “bad” workers with insufficient training and education about occupational health and safety will be left behind. Workers with a safety demoting attitude could also decide to simply work without safety helmets to avoid warning signals and carry on with unsafe behaviors. It would not improve conditions at all. Finally, PBBS only supports hazard identification. It does not remove the hazards as the source of risk directly. Some of the risks might be still overseen and remain.

5.4.1 Utility of using PBBS in construction Hong Kong

As stated in the chapter System Identification, there are several fundamental problems in the labor process of mainland China and Hong Kong. Multilayer subcontracting has been alleged to be one of the major causes of poor construction quality and is one of many root-causes for frequent occupational accidents, injuries, and fatalities in Hong Kong. (Yik & Lai, 2008) Although there is a lot of legislation regarding employer responsibilities, safety management systems, and training requirements for people working in construction, the whole construction industry in Hong Kong urges for improvement. It seems that those stakeholders with sufficient power to stipulate changes do too less for protecting occupational health and safety, and instead target other priorities like project success and profit. Where management fails to show clear direction and leadership, most workers will think and feel that health and safety are not important and behave unsafely as a result. (Teo & Feng, 2009)

The PBBS provides a good tool for the safety improvement of large construction companies in Hong Kong. Firstly, an organization that decides to implement PBBS, takes a step towards a more positive safety culture as they approach fewer hazards and risks at work. The organization has been found as one factor influencing behaviors. Establishing the Safety Production Committee and goal-setting will benefit education and training for everyone on the construction site. Fore-men and construction workers need to be consulted about the hazards and risks inherent in their work. Thus, workers will also feel more ownership of the process, leading to more positive safety culture and safety climate.

Second, in Hong Kong it is common practice to have many subcontractor teams and hundreds of workers on-site, so the PCMS can help to track people who perform unsafe behavior on regular basis but come around without an incident. However, the software can only be used by someone with sufficient time and monetary resources available. This will rather be true for the big main contractors than for small subcontracting teams who are desperate for any kind of project.

There is no doubt that hazard identification through proactive warning signals is a good thing to have in Hong Kong because many construction workers have too little education and knowledge in working safely. Overall, PCMS is a good supervision and analysis tool for management and can reduce risks caused by housekeeping, working at heights, and moving objects. On the other hand, it has the potential for leading to the opposite of desired consequences like BBS, namely through a culture of fear. Supervisors and employees responsible for the training of workers must be highly competent, so they do not blame or punish those who do mistakes. This might be an issue in Hong Kong because delays and additional costs can increase the pressure from construction management and other stakeholders to supervisors. (Zhang & Fang, 2013)

Since no contact to the inventors of PBBS could be made, implementation costs are uncertain. The maintenance and update of the program seem to be very time consuming but useful to save many lives in Hong Kong's dangerous construction industry. It is not the final solution to reduce hazards and risks in construction but a step towards a safer construction site.

5.4.2 Utility of using PBBS in construction Romania

For improving the Romanian construction industry through PBBS, it requires large amounts of investment from the construction company. The virtual model of the construction site should be already present, and managers are required to assess the results of the program. Utilities most Romanian smaller construction companies probably do not have. The PBBS is mainly aimed towards larger companies with the financial opportunity to invest in technology that increases safety. Although the Romanian construction sector consists of larger companies, mainly the smaller companies need the aid of PBBS. This is because they generally have lower safety education. Thus, PBBS would be a great supplement for major companies that aim to increase safety even more. (Thomas R. Cunningham, 2018)

5.4.3 Differences and similarities of construction in Hong Kong and Romania

It is very difficult to compare the construction industries of Hong Kong and Romania because they are on different continents, have different cultures and histories, legislation, safety management, and insurance systems, etc. However, one similarity for both economies is the employer is responsible for the health and safety of the employees. In addition to that, both countries require the employer to pay compensation when accidents occur. There is a trend for Hong Kong and Romania that occupational injuries are mostly due to construction workers' under-education in health and safety. In Hong Kong, the main requirement seems to be the "Green Card" which can be acquired through participating in a one-day safety course. (Chen, Cao, & Chow, 2012) It was found that a one-day safety course is also essential for people working in construction in Romania. (nationaltrainingsolutions.ie, 2020)

Hong Kong is strongly affected by the subcontracting system in which there is much financial risk shifted towards smaller trades at the lower end of the subcontracting chain. Subcontractors are often hired for very specific tasks and they carry the responsibility for their own work. (Yik & Lai, 2008) Thus, they are restricted in allocating sufficient resources for health and safety. In Europe and the EU, there is a tendency to hire fewer subcontractors and the main construction company that hired the subcontractors has the main responsibility for the quality of the project. Perhaps European countries are therefore less affected by the risk of bad quality, such as accidents, because they must ensure workers' competency to minimize losses. In Hong Kong, it seems that a cheap price and fast success is more important than the life of construction workers. (Ngai & Huilin, 2010)

Another difference in both economies is the payment method. Not every construction worker in Hong Kong is in possession of a labor contract and the risk of wage arrears is always present. If the main contractor is unsatisfied with the work, workers' chances of seeking help from the government are very limited. (Ngai & Huilin, 2010) Construction workers in the EU are better protected by the law, federations, and construction unions. The workers' health and safety are more in focus rather than the task that needed to be completed. (BWI, 2020) The Romanian standard consists of a 40-hour workweek with rules and regulations in overtime, rest times, holidays, etc. (constructionworkers.eu, 2020)

5.4.4 Risk communication and consultation when using PBBS in construction

According to ISO, risk communication refers to "*the purpose of communication and consultation is to assist relevant stakeholders in understanding risk, the basis on which decisions are made, and the reasons why particular actions are required. The communication seeks to promote awareness and understanding of risk, whereas consultation involves obtaining feedback and information to support decision-making. Close coordination between the two should facilitate the factual, timely, relevant, accurate, and understandable exchange of information, considering the confidentiality and integrity of information as well as the privacy rights of individuals.*" (ISO, 2018a) Adequate opportunities for communication and consultation with internal stakeholders (e.g. workers, supervisors, contractors, and management), and external stakeholders (financial insurance companies, local authorities, ministries, and the government) are essential within and throughout all steps of the risk management process to see effective results of hazard control and safety improvements. Different areas of expertise are needed for each step of the risk management process. (ISO, 2018a)

Risk communication needs to ensure that different perspectives are properly considered when using PCMS to define dangerous areas and risk criteria. Virtually analyzing the construction site may also provide more insights into risk evaluation and current safety barriers. For this matter, it is suggested to consult with people who have sufficient knowledge and experience about different hazards, engineering processes, and the construction site itself. For Hong Kong, it is suggested to seek help at least from the Labour Department, such as from design planners, and senior management of the main contractor.

As soon as there is oversight of the risks, they must be reviewed by the decision-makers of the construction site. It is important to build a sense of inclusiveness and ownership among those affected by risk. (ISO, 2018a) Construction workers must be informed why PBBS is used, namely to improve the safety awareness for everyone, not to observe anyone. A meeting with all workers may be a good opportunity to introduce the software, what it does, and where warning signals may not occur. It must also be easy to understand for workers that violations will not lead to punishment. It must be ensured that workers do not act against the system and attempt to destroy the tags, swap, or work without safety helmets.

6. Discussion

In recent years, new technology has become more widespread in every working sector around the world and the introduction of monitoring software has become more standard as well. This brings an ethical problem to the employer, as very few like the idea of being monitored at work. Only 10% of employees, in a US-based study, trust their employer with monitoring software, surveilling their workday. Employees stated: "*Big Brother' was watching over our work*". (Roddy, 2020) The same problem can arise, if a monitoring software, such as PBBS, is introduced to the construction sector, where workers' movement is traced on a computer all the time.

For construction employers, the best practice to reduce the risk of unsafe behaviors, such as loss, is through prioritizing safety over business targets. The employer has a moral, financial, and legal duty to ensure that everyone involved in the construction process is kept as safe as possible. Human error may lack rules, skill, or knowledge. To mitigate human errors and keep construction risks as low as reasonably possible, the employer must have a strong health and safety policy in place and provide rules and procedures, such as safe systems of work (e.g. permit-to-work, PPE free of charge, safe construction site, equipment, and processes). (ECITB, 2019) (RRC International, 2019)

Before the construction operation, employers should only hire and use competent persons and start with safety already at the design planning stage. During the operation, employers must conduct close supervision, collect all near-miss reports, perform proper accident investigation, ensure proper risk assessments and undertake safety inspections, sampling, and tours to monitor workers' safety performance and the control of the hazards and risks. (ECITB, 2019) (RRC International, 2019) Also, non-monetary incentives and strategies can help to remove the need and attractiveness of people performing unsafe acts or taking short-cuts. (RRC International, 2019) (greenwgroup, 2018b)

Workers should feel that their health and safety are always supported and understand that everyone's safety is something they can be achieved when they have the "safety first" attitude and their actions result in safe-promoting behaviors accordingly. This involves maintaining self-control, stay alert, always pay attention to the job and their surroundings, avoid distraction, have respect for rules and procedures, ensure good time management, be tidy and hygienic and have respect for others. Moreover, they must not come under the influence of alcohol and/or drugs. PPE must be worn, in a good shape, functioning, and any discomfort or arising problems from work must be reported as soon as possible to the employer. The use of PPE is the last line of defense to avoid hazards, accidents, and injuries. (ECITB, 2019) (RRC International, 2019)

To eliminate hazards and reduce the likelihood and/or severity of the risk, employer and employees must mutually take reasonable care of each other, consider the safety of other persons who may be affected by their acts or omissions, work in accordance with information, education, and training, carry-out checks that everything at the worksite is as it should prior the beginning of the shift, report any defects in plant and equipment or shortcomings in the existing safety arrangements to a responsible person without delays. They must not undertake any task for which authorization and/or training has been given. Stakeholders should provide reasonable worker contracts, consider workers' health and safety as a priority from top to bottom in the organization, prevent wage arrears, and establish proper accommodation for their construction employees. (ECITB, 2019) Especially the government in Hong Kong is considered as a stakeholder with a lot of power but in the perspective of the thesis authors too little is done to enforce compliance to legislation for construction employers and to solve fundamental issues in the subcontracting process.

To reduce the high fatal accident rate of Romania, legislations, and laws are required to lower the rates, both at the EU level and national level. Even though the Romanian parliament adopted a law in 2006 to improve occupational health and safety of workers (Law 319/2006 on occupational Safety and Health.), changes must be inspired by the rest of Europe on strategies and procedures, to improve those countries that have a high accident rate. The implementation of risk assessment programs, where databases and examples of good work safety are promoted and shared between EU members to also benefit other countries, where the impact might be even greater, such as Romania. (Vacaroiu, 2006)

7. Conclusion

The research interest of this thesis was to enhance the understanding of risk assessment and risk management for the sake of prevention of accidents in the construction industry. A lot of new knowledge was gained about managing risks that impose harm for construction workers, the causes of unsafe behaviors, and the human factors which should be addressed by risk management.

One of the main reasons for mainland China's and Hong Kong's rapid industrial development is the subcontracting system but it shifts most financial risk on low-level contractors. Construction workers are mostly undereducated, under-skilled, and untrained to work in a high-risk industry like construction. (Choudhry R. M., 2014) Without the help of effective site and safety management, rising technology, better equipment, and legislation, the number of injuries and fatalities of construction workers, especially in Hong Kong, would probably be much higher than they are today. For reducing the risks in construction, it is suggested to apply the correct hierarchy of controls. The optimal and most preferred choice is to eliminate the hazard at the source because the risk will disappear. (RRC International, 2019) This process might be easier for certain hazards but it very difficult in terms of human psychology. Nevertheless, it but can be done. The literature review and research indicated how unsafe acts can occur and factors shaping unsafe behaviors have been presented. Safety will never be perfect since acts can be done by mistake, unconsciously, and without knowing. However, negative attitudes towards health and safety should not be accepted on the job. (Khosravi, et al., 2015)

PPBS rather than BBS is suggested to internalize risk avoidance and control in Hong Kong. Existing studies reveal that BBS' intervention is probably too less effective in a relatively dynamic work setting like construction. (Cooper, 2003) (Choudhry R. M., 2014) The PBBS is a good approach and an additional line of defense against hazards and risks. When it is used, reasonable and efficient channels of risk communication must be established and maintained, so everyone involved and affected by changes understands what to do and who to consult with when in doubt. (RRC International, 2019) Nevertheless, the PBBS should not be used in preference to technical safety measures. For example, removing Hong Kong's practice of using bamboo for scaffolding would be a big step towards a safer construction industry with fewer falls from height. Unfortunately, the fundamental problems and challenges cannot be solved overnight.

In some instances, Hong Kong and Romania are similar in mainly construction workers' low education in occupational health and safety and the low safety culture within construction companies. The construction industry in Hong Kong can be considered worse for construction workers overall, as they are less protected against labor rights violations, wage arrears, working conditions, etc.

Final words

The thesis attempted to provide insights into each subject that is important to be mentioned. However, the authors would like to take a critical point of view for themselves and state there were several challenges.

First, the thesis authors could not gain access to the PBBS software program because their e-mails were not answered. Otherwise, it would have been of great benefit to interview the researchers behind PBBS in Hong Kong.

Secondly, the current pandemic did not allow to visit a construction site in Denmark or elsewhere. It could have improved the hazard identification (especially the HAZID) and the analysis of risks.

Thirdly, as mentioned in the research methodology, there is a lack of authentic field data when it comes to occupational health and safety in China, Hong Kong, and Romania. Several sources indicated that official data of China and Hong Kong is to some extent manipulated and the real picture of the construction industry is most likely much worse. (CLB, 2019) The same can be true for Romania.

Although human behavior has been the subject of different studies and articles for decades and many years, there are still uncertainties. Therefore, it is so challenging to implement an effective behavior based strategy that provides sufficient results and is sustainable at the same time.

Last but not least, the communication between both thesis authors was at times conflicting. This influenced the research direction and, thus, the quality of the content.

References

Lop, N., Mamter, S., Kamar, I., & Norazlin. (2014). Contractor's Awareness on Occupational Safety and Health (OSH) Management Systems in Construction Industry. *E3S Web of Conferences*, 5-6. doi:10.1051/e3sconf/20140301019

Abdelhamid, T. S., & Everett, J. G. (2000, February 01). Identifying Root Causes of Construction Accidents. *Journal of Construction Engineering and Management, 126*(1), 52-60. doi:https://doi.org/10.1061/(ASCE)0733-9364(2000)126:1(52)

Ahuja, H. (2017). *Managerial Economics (Analysis of Managerial Decision Making)* (9 ed.). New Delhi: S. Chand Publishing. doi:9352535189

Aires, D. M., Gámez, C. R., & Gibb, A. (2009, September). Prevention through design: The effect of European Directives on construction workplace accidents. *Safety Science, 48* , 1-2. Retrieved September 03, 2020, from https://www.researchgate.net/publication/222972655_Prevention_through_design_The_effect_of_European_Directives_on_construction_workplace_accidents

Alkaissy, M., Arashpour, M., Baabak, A., Hosseini, R., & Bai, Y. (2019). Safety management in construction: 20 years of risk modeling. *Safety Science, 129*, 1-11. Retrieved October 03, 2020, from https://www.sciencedirect.com/science/article/pii/S0925753520302022?via%3Dihub

Altenbach, T. J. (1995). A comparison of risk assessment techniques from qualitative to quantitative. *oint American Society of Mechanical Engineers (ASME)/Japan Society of Mechanical Engineers (JSME) pressure vessels and piping conference* (pp. 2-12). Honolulu: U.S. Department of Energy Office of Scientific and Technical Information. Retrieved October 28, 2020, from https://www.osti.gov/biblio/67753

Aneculaesei, C. (2020, July 13). Retrieved September 05, 2020, from https://medium.com: https://medium.com/history-of-yesterday/the-architect-of-modern-china-deng-xiaoping-e98f76ed804f

Avatara Software. (2020). *avatarasoftware.com*. Retrieved November 12, 2020, from https://actiontracking.avatarasoftware.com/learn/the_safety_triangle_why_you_should_track_near_misses_good_catches_observations_and_low_level_events

Aven, T. (2010, June). On how to define, understand and describe risk. *Reliability Engineering and System Safety , 95* (6), 623–631. Retrieved September 09, 2020, from https://www.sciencedirect.com/science/article/abs/pii/S095183201000027X

Aven, T. (2015). Risk assessment and risk management: Review of recent advances on their foundation. *European Journal of Operational Research, 253*, 4. doi:https://doi.org/10.1016/j.ejor.2015.12.023

Aven, T., & Renn, O. (2009, January 20). On risk defined as an event where the outcome is uncertain. *Journal of Risk Research, 12*(1), 1-11. doi: 10.1080/13669870802488883

Bertollini, V. (2019, May 14). *redshift.autodesk.com*. Retrieved December 06, 2020, from https://redshift.autodesk.com/global-infrastructure/

Beswick, J., Rogers, K., Corbett, E., Binch, S., & Jackson, K. (2007). *hse.gov.uk.* Retrieved October 15, 2020, from https://www.hse.gov.uk/research/rrpdf/rr518.pdf

Bianchini, A., Donini, F., Pellegrini, M., & Saccani, C. (2017, February). An innovative methodology for measuring the effective implementation of an Occupational Health and Safety Management in the European Union. *Safety Science, 92*, 26-33. Retrieved September 15, 2020, from https://www.sciencedirect.com/science/article/pii/S0925753516302375

BLS. (2019, December 17). *bls.gov*. Retrieved October 29, 2020, from https://www.bls.gov/news.release/pdf/cfoi.pdf

Britannica. (2016). *britannica.com*. Retrieved September 05, 2020, from Britannica: https://www.britannica.com/topic/Gang-of-Four

Britannica. (2019, Sep 24). *Britannica*. Retrieved from Britannica.com: https://www.britannica.com/topic/trade-union

Britannica. (2020). *britannica.com*. Retrieved December 23, 2020, from Britannica: https://www.britannica.com/place/Hong-Kong

Brown, G. D., & Barab, J. (2008, February). "Cooking the Books"—Behavior-Based Safety at the San Francisco Bay Bridge. *New solutions, 17*(4), 311-324. doi:10.2190/NS.17.4.g

BWI. (2020). *BWI*. Retrieved from BWI.org: https://www.bwint.org/cms/about-2

Canfora, C., & Ottmann, A. (2018, July). Retrieved December 20, 2020, from https://www.researchgate.net/: https://www.researchgate.net/publication/326317704_Of_Ostriches_Pyramids_and_Swiss_Cheese_-_Risks_in_Safety-Critical_Translations

censtatd.gov.hk. (2020, September 17). *censtatd.gov.hk*. Retrieved October 05, 2020, from https://www.censtatd.gov.hk/hkstat/sub/sp200.jsp?tableID=006&ID=0&productType=8

censtatd.gov.hk. (2020, September). *censtatd.gov.hk.* Retrieved October 24, 2020, from https://www.censtatd.gov.hk/hkstat/sub/sp452.jsp?productCode=B1050004

Census and Statistics Department. (2019). *Hong Kong Annual Digest of Statistics.* Hong Kong Special Administrative Region: Census and Statistics Department Hong Kong. Retrieved from https://www.statistics.gov.hk/pub/B10100032019AN19B0100.pdf

Chen, D., & Tian, H. (2012). Behavior Based Safety for Accidents Prevention and Positive Study in China Construction Project. *Procedia Engineering, 43*, 528-534. doi:https://doi.org/10.1016/j.proeng.2012.08.092

Chen, Q., Cao, Y.-G., & Chow, W.-K. (2012). Comparison of Legal System of Occupational Safety and Health between Hong Kong and Mainland China. *Open Journal of Safety, Science and Technology, 2*(3), 119-132. doi:10.4236/ojsst.2012.23016

Chiang, Y.-H., Wong, F. K.-W., & Liang, S. (2018, March 01). Fatal Construction Accidents in Hong Kong. *Journal of Construction Engineering and Management, 144* (3), 4017121. doi:10.1061/(ASCE)CO.1943-7862.0001433

cholarisk. (2020). *cholarisk.com*. (C. M. Limited, Producer) Retrieved November 11, 2020, from http://www.cholarisk.com/services/process-safety/qra-hazop/hazard-identification-studies-hazid/

Choudhry, R. M. (2014, March). Behavior-based safety on construction sites: A case study. *Accident Analysis and Prevention, 70*, 14-23. doi:https://doi.org/10.1016/j.aap.2014.03.007

Choudhry, R. M., Fang, D., & Ahmed, S. M. (2008, January). Safety Management in Construction: Best Practices in Hong Kong. *Journal of Professional Issues in Engineering Education and Practice, 134*(1), 20-29. doi:https://www.researchgate.net/deref/http%3A%2F%2Fdx.doi.org%2F10.1061%2F(ASCE)1052-3928(2008)134%3A1(20)

Choudry , R., & Fang, D. (2008). Why operatives engage in unsafe work behavior: Investigating factors on construction sites. *Safety Science, 46*(4), 566-584. Retrieved October 11, 2020, from https://www.sciencedirect.com/science/article/pii/S0925753507001087

CIA US. (2020). *cia.gov*. Retrieved December 23, 2020, from Central Intelligence Agency United States: https://www.cia.gov/library/publications/the-world-factbook/geos/hk.html

Cioca, L. I.-l. (2018). *Occupational accidents Assessment by Field of Activity and INvestigation Model for Prevention and Control.* Bucharest: Design and Development of Safety Production Management.

CLB. (2014, March 09). Retrieved September 07, 2020, from China Labour Bulletin: https://clb.org.hk/print/2624

CLB. (2018a, August 21). *https://clb.org.hk/*. Retrieved September 08, 2020, from https://clb.org.hk/content/china%E2%80%99s-most-dangerous-industry-getting-more-dangerous

CLB. (2018b, March 13). *https://clb.org.hk*. Retrieved September 30, 2020, from https://clb.org.hk/content/china-proposes-abolition-work-safety-body

CLB. (2019). *Understanding and resolving the fundamental problems in China's construction industry.* Hong Kong: China Labour Bulletin. Retrieved September 05, 2020, from https://clb.org.hk/content/understanding-and-resolving-fundamental-problems-china%E2%80%99s-construction-industry

CLB. (2020a, March 20). *https://clb.org.hk/*. Retrieved September 08, 2020, from https://clb.org.hk/content/work-safety

CLB. (2020b, August 13). *clb.org.hk*. Retrieved November 11, 2020, from https://clb.org.hk/content/workers%E2%80%99-rights-and-labour-relations-china

Conaty, A. (2017, May 31). *goodada.com/*. Retrieved October 06, 2020, from https://www.goodada.com/blog/foreign-enterprises-compensation-for-work-related-death-in-china/

constructionworkers.eu. (2020, 6 17). *Construction Workers*. Retrieved from www.constructionworkers.eu: https://www.constructionworkers.eu/en/ro/check-wages-and-working-conditions/romania

Cooper, M. (2003). Behavioral safety interventions a review of process design factors. *Prof. Saf., 54*(2), 36-45. Retrieved December 22, 2020, from https://www.onepetro.org/journal-paper/ASSE-09-02-36

Coppola, D. P. (2015). *Introduction to International Disaster Management* (3rd ed.). Butterworth-Heinemann. Retrieved December 12, 2020, from https://www.elsevier.com/books/introduction-to-international-disaster-management/coppola/978-0-12-801477-6

Croner-i Ltd. (2020, September 23). *croneri.co.uk*. Retrieved December 14, 2020, from https://app.croneri.co.uk/feature-articles/importance-supervision-construction-sites

CTBUH . (2020). *skyscrapercenter.com*. Retrieved December 23, 2020, from Council on Tall Buildings and Urban Habitat: https://www.skyscrapercenter.com/city/hong-kong

Curtis, P., & Carey, M. (2012, October). *deloitte.com.* Retrieved October 28, 2020, from https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Governance-Risk-Compliance/dttl-grc-riskassessmentinpractice.pdf

Cynthia, S. S. (2020). *dummies.com*. Retrieved November 22, 2020, from https://www.dummies.com/careers/project-management/pmp-certification/quantitative-risk-analysis-scenarios-modeling-and-simulations-for-the-pmp-certification-exam/

Dembe, A. E., Erickson, J. B., Delbos, R. G., & Banks, S. M. (2005, September). The impact of overtime and long work hours on occupational injuries and illnesses: new evidence from the United States. *Occupational and Environmental Medicine, 62*(9), 588–597. Retrieved November 24, 2020, from https://www.jstor.org/stable/27732586

Development Bureau. (1999, September). Retrieved January 01, 2021, from devb.gov.hk: https://www.devb.gov.hk/filemanager/en/content_191/chapter7.pdf

Dictionary Cambridge. (2020). Retrieved October 20, 2020, from dictionary.cambridge.org: https://dictionary.cambridge.org/dictionary/english/stakeholder

Dongping, F., Zhongming, J., Mingzong, Z., & Han, W. (2015, March). An experimental method to study the effect of fatigue on construction workers' safety performance. *Safety Science, 73*, 80-91. doi:https://doi.org/10.1016/j.ssci.2014.11.019

Dziadosz, A., & Rejment, M. (2015, December). Risk analysis in construction project - chosen methods. *Procedia Engineering, 122*, 258 – 265. doi:10.1016/j.proeng.2015.10.034

ECITB. (2019). *Work Safety Handbook.* Hertfordshire: Engineerung Construction Industry Training Board. Retrieved December 22, 2020

efbww. (2020a). *efbww.eu*. (E. F. Works, Producer) Retrieved October 13, 2020, from https://www.efbww.eu/activities/construction

efbww. (2020b). *efbww*. Retrieved from efbww.eu: https://www.efbww.eu/about-us

enablon. (2017, June 29). Retrieved January 03, 2021, from enablon.com: https://enablon.com/blog/safety-culture-safety-climate-knowing-the-difference/

EU. (2020, August 03). *europa.eu*. Retrieved from https://europa.eu/european-union/about-eu/countries/member-countries/romania_en

EUR-Lex. (2020, 12 1). *Eur-Lex*. Retrieved from eur-lex.europa.eu: https://eur-lex.europa.eu/homepage.html

European Commission. (2016, March 11). *ec.europa.eu.* Retrieved October 13, 2020, from https://ec.europa.eu/growth/sectors/construction/observatory_en

European Commission. (2018). *European Construction Sector Observatory.* June.

European Commission. (2020a). *https://ec.europa.eu/growth/sectors/construction_en*. Retrieved September 03, 2020, from https://ec.europa.eu/growth/sectors/construction_en

Eurostat. (2020, November). Retrieved December 29, 2020, from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Accidents_at_work_-_statistics_by_economic_activity

Eurostat. (2020d, January 24). *ec.europa.eu*. Retrieved October 29, 2020, from https://ec.europa.eu/eurostat/statistics-explained/index.php/Accidents_at_work_statistics#:~:text=In%202017%2C%20one%20fifth%20(20.6,NACE%20sections%20to%20record%20double%2D

Fang, D., & Wu, H. (2013, August). Development of a Safety Culture Interaction (SCI) model for construction projects. *Safety Science, 57*, 138-149. doi:https://doi-org.zorac.aub.aau.dk/10.1016/j.ssci.2013.02.003

Fang, D., Chen, Y., & Wong, L. (2006, June). Safety Climate in Construction Industry: A Case Study in Hong Kong. *Journal of Construction Engineering and Management, 132*(6), 573-581. doi:https://doi.org/10.1061/(ASCE)0733-9364(2006)132:6(573)

Fang, D., Xie, F., Huang, X., & Li, H. (2004, January). Factor analysis-based studies on construction workplace safety management in China. *International Journal of Project Management, 22*(1), 43-49. Retrieved September 08, 2020, from https://www.sciencedirect.com/science/article/pii/S0263786302001151

Fang, D., Zhao, C., & Zhang, M. (2016, September 01, Vol.). A Cognitive Model of Construction Workers' Unsafe Behaviors. *Journal of Construction Engineering and Management, , 142*(9), 04016039-1 - 10. doi:https://doi-org.zorac.aub.aau.dk/10.1061/(ASCE)CO.1943-7862.0001118

Fitzgerald, S., Chen, X., Qu, X., & Sheff, M. G. (2013, May 24). Occupational injury among migrant workers in China: a systematic review. *Injury prevention, 5*, 348-354. Retrieved September 29, 2020, from https://injuryprevention.bmj.com/content/injuryprev/19/5/348.full.pdf

Frunzaru, V. (2016). *Workplace health and safety committees in Romania. The gap between law and reality.* Retrieved from https://www.researchgate.net/publication/303376569_Workplace_health_and_safety_committees_in_Romania_The_gap_between_law_and_reality

Fung, I. W., Tam, C., Tung, C., & Man, A. S. (2005, October 07). Safety culture divergences among management, supervisory and worker groups in Hong Kong construction industry. *International Journal of Project Management, 23*, 504-512. doi:https://doi.org/10.1016/j.ijproman.2005.03.009

Geller, E. S. (2001). Behavior-based safety in industry: Realizing the large-scale potential of psychology to promote human welfare. *Applied & Preventive Psychology, 10*, 87-105. doi:10.1017.S0962184902010028

GitHub Inc. (2020). *github.com*. Retrieved from https://github.com/SilverDecisions/SilverDecisions.wiki.git

greenwgroup. (2018a, August 22). *greenwgroup.co.in*. (gwgindiaadmin, Editor) Retrieved October 15, 2020, from https://greenwgroup.co.in/unsafe-acts-conditions/

greenwgroup. (2018b, August 22). *greenwgroup.co.in*. Retrieved December 20, 2020, from https://greenwgroup.co.in/unsafe-acts-conditions/

Hale, A. (1984). Is safety training worthwhile? *Journal of Occupational Accidents, 6*(1-3), 17-33. doi:https://doi.org/10.1016/0376-6349(84)90026-9

Hickman, J. S., & Geller, E. S. (2003). A safety self-management intervention for mining operations. *Journal of Safety Research, 34*, 299 – 308. doi:10.1016/S0022-4375(03)00032-X

Hinze, J., Huang, X., & Terry, L. (2005, February). The Nature of Struck-by Accidents. *Journal of Construction Engineering and Management, 131*(2), 267. doi:https://doi.org/10.1061/(ASCE)0733-9364(2005)131:2(262)

Hoła, B., & Szóstak, M. (2015, June). Analysis of the State of the Accident Rate in the Construction Industry in European Union Countries. *Archives of Civil Engineering, 61*(4), 19-34. doi:10.1515/ace-2015-0033

Hossein, A., Motalebi, K. M., Zahra, A., Mahdieh, K., & Hamidreza, S. (2019, August). The relationship between job satisfaction and the incidence of unsafe acts in metal smelting industry workers in 2017. *Int Arch Health Sci, 6*(3), 127-131. doi:10.4103/iahs.iahs_40_19

HSE. (2020d). *Health and Safety Executive UK*. Retrieved November 18, 2020, from hse.gov.uk: https://www.hse.gov.uk/aboutus/occupational-disease/respiratory/construction-workers.htm

HSE UK. (2014a, January). *hse.gov.uk.* Retrieved October 10, 2020, from https://www.hse.gov.uk/pubns/indg401.pdf

HSE UK. (2014b, February). *hse.gov.uk.* Retrieved November 12, 2020, from https://www.hse.gov.uk/pubns/hsg245.pdf

HSE UK. (2020a). *hse.gov.uk*. Retrieved November 12, 2020, from https://www.hse.gov.uk/aboutus/index.htm

HSE UK. (2020b). *hse.gov.uk*. Retrieved October 05, 2020, from https://www.hse.gov.uk/toolbox/manual.htm

HSE UK. (2020c). *hse.gov.uk*. Retrieved October 05, 2020, from https://www.hse.gov.uk/construction/safetytopics/falls.htm

Huang, X., & Hinze, J. (2003, June). Analysis of Construction Worker Fall Accidents. *Journal of Construction Engineering and Management, 129*(3), 262-271. doi:https://doi.org/10.1061/(ASCE)0733-9364(2003)129:3(262)

iedunote.com. (2017). *iedunote.com*. Retrieved October 27, 2020, from https://www.iedunote.com/types-of-insurance

ILO. (2004, November 30). *ilo.org*. Retrieved December 03, 2020, from https://www.ilo.org/legacy/english/protection/safework/cis/products/safetytm/chemcode/02.htm

ILO. (2020a). *ilo.org*. Retrieved October 20, 2020, from https://www.ilo.org/global/topics/labour-administration-inspection/resources-library/publications/guide-for-labour-inspectors/how-can-osh-be-managed/lang--en/index.htm

ILO. (2020b). *ilo.org*. (I. L. Organization, Editor) Retrieved December 03, 2020, from https://www.ilo.org/global/about-the-ilo/lang--en/index.htm

ILO. (2020c, October 25). *ilostat.ilo.org*. Retrieved October 29, 2020, from https://ilostat.ilo.org/topics/safety-and-health-at-work/

Institutul National De Statistica. (2020). *Communicat De Presa.* Insse.

ISO. (2009). *iso.org*. Retrieved October 20, 2020, from https://www.iso.org/obp/ui/#iso:std:iso:31000:ed-1:v1:en

ISO. (2009). *www.iso.org/*. Retrieved October 01, 2020, from https://www.iso.org/obp/ui/#iso:std:iso:31000:ed-1:v1:en

ISO. (2018a, February). *ISO 31000:2018(en)*. (I. S. Organization, Producer) Retrieved October 10, 2020, from https://www.iso.org/obp/ui/#iso:std:iso:31000:ed-2:v1:en

ISO. (2018b, February). *ISO 31000:2018(en)*. (I. S. Organization, Producer) Retrieved October 10, 2020, from https://www.iso.org/obp/ui/#iso:std:iso:31000:ed-2:v1:en

isoupdate. (2018, April 03). *isoupdate.com*. Retrieved November 11, 2020, from https://isoupdate.com/resources/hierarchy-risk-controls-iso-45001/

Janicak, C. A. (2008). Occupational fatalities due to electrocutions in the construction industry. *Journal of Safety Research, 39*(6), 617. doi:https://doi.org/10.1016/j.jsr.2008.10.007

Jeong, B. Y. (1998, September 24). Occupational deaths and injuries in the construction industry. *Applied Ergonomics, 29*, 355-356. Retrieved September 04, 2020, from https://www.sciencedirect.com/science/article/pii/S000368709700077X

Jetten, J., & Hornsey, M. J. (2013, June). Deviance and Dissent in Groups. *Annual Review of Psychology, 65*(1), 462-465. doi:10.1146/annurev-psych-010213-115151

JISHA. (2019). *jisha.or.jp*. Retrieved October 29, 2020, from https://www.jisha.or.jp/english/statistics/index.html

Joanne Linnerooth-Bayer, K. W. (2009). *Insurance, Developing Countries and Climate Change.* 20: July.

Kamiński, B., Jakubczyk, M., & Szufel, P. (2018). A framework for sensitivity analysis of decision trees. *Cent Eur J Oper Res, 26*(1), 135–159. doi:10.1007/s10100-017-0479-6

Kaplan, S., & Garrick, B. J. (1981, March). On The Quantitative Definition of Risk. *Risk Analysis, 1*(1), 11-18. Retrieved December 31, 2020, from https://doi.org/10.1111/j.1539-6924.1981.tb01350.x

Karapistoli, E., Pavlidou, F.-N., Gragopoulos, I., & Tsetsinas, I. (2010). An overview of the IEEE 802.15. 4a standard. *IEEE Communications Magazine, 48*(1), 47–53. doi:https://doi.org/10.1109%2FMCOM.2010.5394030

Khosravi, Y., Asilian-Mahabadi, H., Hajizadeh, E., Hassanzadeh-Rangi, N., Bastani, H., & Behzadan, A. H. (2015, January 15). Factors Influencing Unsafe Behaviors and Accidents on Construction Sites: A Review. *International Journal of Occupational Safety and Ergonomics, 20*(1), 111-125. doi:10.1080/10803548.2014.11077023

Kim, K., Kang, H., & Kim, Y. (2015, April). Risk Assessment for Natural Gas Hydrate Carriers: A Hazard Identification (HAZID) Study. *Energies, 8*, 3151-3152. doi:10.3390/en8043142

Kowalik, T., Logon, D., Rybak, J., Ubsyz, A., & Wojtowicz, A. (2019, May). Chemical hazards in construction industry. *E3S Web of Conferences*, 1-5. doi:10.1051/e3sconf/20199703032

Kulkarni, G. K. (2007, January). Construction industry: More needs to be done. *Indian Journal of Occupational & Environmental Medicine, 11*(1), 1-2. doi:10.4103/0019-5278.32455

Labour Department. (2002, January). Retrieved December 27, 2020, from https://www.labour.gov.hk/eng/public/os/manage.pdf

Labour Department. (2012). *Occupational Safety and Health Statistics Bulletin.* Occupational Safety and Health Branch. Hong Kong: Labour Department. Retrieved November 18, 2020

Labour Department. (2013). *Occupational Safety and Health Statistics Bulletin.* Occupational Safety and Health Branch. Hong Kong: Labour Department. Retrieved November 18, 2020

Labour Department. (2014). *Occupational Safety and Health Statistics Bulletin.* Occupational Safety and Health Branch. Hong Kong: Labour Department. Retrieved November 18, 2020

Labour Department. (2015). *labour.gov.hk*. Retrieved December 31, 2020, from https://www.labour.gov.hk/eng/osh/content10.htm

Labour Department. (2015). *Occupational Health and Safety Statistics Bulletin.* Occupational Health and Safety Branch. Hong Kong: Labour Department. Retrieved November 18, 2020

Labour Department. (2016). *Occupational Health and Safety Statistics Bulletin.* Occupational Health and Safety Branch. Hong Kong: Labour Department. Retrieved November 18, 2020

Labour Department. (2017). *Occupational Safety and Health Statistics Bulletin.* Occupational Safety and Health. Hong Kong: Labour Department. Retrieved November 18, 2020

Labour Department. (2018, August). *labour.gov.hk*. Retrieved October 29, 2020, from https://www.labour.gov.hk/eng/osh/pdf/Bulletin2017_issue18_eng.pdf

Labour Department. (2018). *Occupational Safety and Health Statistics Bulletin.* Occupational Safety and Health Branch. Hong Kong: Labour Department. Retrieved November 18, 2020

Labour Department. (2019). *Occupational Safety and Health Statistics Bulletin.* Occupational Safety and Health Branch. Hong Kong: Labour Department. Retrieved November 18, 2020

Labour Department. (2019, March 27). *www.labour.gov.hk.* Retrieved October 1, 2020, from https://www.labour.gov.hk/eng/osh/pdf/archive/statistics/OSH_Statistics_2018_eng.pdf

Labour Department. (2020). *Occupational Safety and Health Statistics Bulletin.* Occupational Safety and Health Branch. Hong Kong: Labour Department. Retrieved November 18, 2020

Labour Department. (2020, August). *Occupational Safety and Health Statistics Bulletin.* Retrieved October 01, 2020, from www.labour.gov.hk/: https://www.labour.gov.hk/eng/osh/pdf/Bulletin2019_issue20_eng.pdf

lawinsider. (2020a). *lawinsider.com*. Retrieved October 20, 2020, from https://www.lawinsider.com/dictionary/governmental-authorities#:~:text=Governmental%20Authorities%20means%20any%20nation,commission%20or%20instrumentality%20of%20any

lawinsider. (2020b). *lawinsider.com*. Retrieved December 21, 2020, from https://www.lawinsider.com/dictionary/net-benefit

Lee, Y. S. (1993). Industrial subcontracting and labor movement: The Korean automotive industry. *Journal of Contemporary Asia, 23*, 24-40. doi:https://doi.org/10.1080/00472339380000031

Leung, M.-Y., Liang, Q., & Olomolaiye, P. (2016, January). Impact of Job Stressors and Stress on the Safety Behavior. *Journal of Management in Engineering, 32*(1), 130-141. doi:https://doi.org/10.1061/(ASCE)ME.1943-5479.0000373

Li, H., Lu, M. H., Shu-Chien, Gray, M., & Huang, T. (2015). Proactive behavior-based safety management for construction safety improvement. *Safety Science, 75*, 107-117. doi:https://doi.org/10.1016/j.ssci.2015.01.013

Li, J., Zuo, J., Cai, H., & Zillante, G. (2018, January 20). Construction waste reduction behavior of contractor employees: An extended theory of planned behavior model approach. *Journal of Cleaner Production, 172*, 1399-1408. doi:https://doi.org/10.1016/j.jclepro.2017.10.138

Li, R., & Poon, S. (2009, January). Workers' compensation for non-fatal accidents: review of Hong Kong court cases. *Asian Social Science, 5*(11), 15-24. Retrieved October 27, 2020, from https://www.researchgate.net/publication/304195662_Workers'_compensation_for_non-fatal_construction_accidents_Review_of_Hong_Kong_court_cases

Lingard, H., & Rowlinson, S. (1997). Behavior-Based Safety Management in Hong Kong's Construction Industry. *Journal of Safety Research, 28*(4), 243-256. Retrieved September 18, 2020, from https://www.sciencedirect.com/science/article/pii/S0022437597000108

Lipscomb, H., Dement, J., McDougall, V., & Kalat, J. (1999, October). Work-related eye injuries among union carpenters. *Appl Occup Environ Hyg., 14*(10), 665-676. doi:10.1080/104732299302288

Lombardi, D. A., Vermaab, S. K., Brennana, M. J., & Perry, M. J. (2009, July). Factors influencing worker use of personal protective eyewear. *Accident Analysis & Prevention, 41*(4), 755-762. doi:https://doi.org/10.1016/j.aap.2009.03.017

Marsden, E. (2017, July 01). *risk-engineering.org*. (E. Marsden, Editor) Retrieved October 19, 2020, from https://risk-engineering.org/concept/Heinrich-dominos

Marsden, E. (2020, October 08). *risk-engineering.org*. Retrieved December 11, 2020, from https://risk-engineering.org/concept/Heinrich-Bird-accident-pyramid

mayoclinic.org. (2019, July 11). *Mayo Foundation for Medical Education and Research (MFMER)*. Retrieved November 18, 2020, from https://www.mayoclinic.org/diseases-conditions/dermatitis-eczema/symptoms-causes/syc-20352380

Medical Dictionary. (2009). *medical-dictionary.thefreedictionary.com*. Retrieved October 28, 2020, from https://medical-dictionary.thefreedictionary.com/mechanism+of+injury

medlineplus.gov. (2020, July 30). *medlineplus.gov*. Retrieved October 23, 2020, from https://medlineplus.gov/lab-tests/chloride-blood-test/

Meliá, J. L., & Becerril, M. (2009, September). Health behaviour and safety in the construction sector. *Psicothema, 21*(3), 427-432. Retrieved October 15, 2020, from https://www.researchgate.net/publication/26685914_Health_behaviour_and_safety_in_the_construction_sector

mightyrecruiter.com. (2020). *mightyrecruiter.com*. Retrieved October 15, 2020, from https://www.mightyrecruiter.com/recruiter-guide/hiring-glossary-a-to-z/unsafe-conditions/#:~:text=Unsafe%20conditions%20are%20hazards%20that,such%20as%20goggles%20and%20masks.

Miguel A Camino Lopez, O. J. (2018). *The Risk Factor of Age in Construction Accidents: Important and Present and Fundamental in the Future.* Hindawi.

Nadhim, E. A., Hon, C., Xia, B., Stewart, I., & Fang, D. (2016, June 28). Falls from Height in the Construction Industry: A Critical Review of the Scientific Literature. *International Journal of Environmental Research and Public Health*, 1-18. Retrieved October 08, 2020, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4962179/

nationaltrainingsolutions.ie. (2020). *nationaltrainingsolutions.ie*. Retrieved January 06, 2021, from https://www.nationaltrainingsolutions.ie/safety-training/safety-in-construction/safe-pass-training

nebosh.org.uk. (2020). *nebosh.org.uk*. Retrieved November 05, 2020, from https://www.nebosh.org.uk/about-nebosh/our-recognition/

Ng, S. T., Chen, K. P., & Skitmore, R. M. (2005, October). A framework for evaluating the safety performance of construction contractors. *Building and Environment, 40*(10), 1347-1355. doi:https://doi.org/10.1016/j.buildenv.2004.11.025

Ngai, P., & Huilin, L. (2010, July). A culture of violence: the labor subcontracting system and collective action by construction worker in post-socialist China. *The China Journal, 64*, 143-158. Retrieved September 05, 2020, from https://www.researchgate.net/publication/259838961_A_culture_of_violence_The_labor_subcontracting_system_and_collective_action_by_construction_workers_in_post-socialist_China

nh.gov. (2020). *nh.gov*. Retrieved November 11, 2020, from https://www.nh.gov/safety/divisions/hsem/HazardMitigation/index.html

NISOH. (2015, 13 January). *cdc.gov*. Retrieved November 05, 2020, from https://www.cdc.gov/niosh/topics/hierarchy/default.html

Oetzel, J., & Miklian, J. (2017, December 11). Multinational enterprises, risk management, and the business and economics of peace. *Multinational Business Review, 25*(4). Retrieved December 10, 2020, from https://www.emerald.com/insight/content/doi/10.1108/MBR-09-2017-0064/full/html

OSHA. (2011, April). *osha.gov.* Retrieved December 31, 2020, from https://www.osha.gov/dte/outreach/construction/focus_four/struckby/struckby_ig.pdf

OSHA. (2020a). *osha.gov*. Retrieved November 05, 2020, from https://www.osha.gov/shpguidelines/hazard-prevention.html

OSHA. (2020b). (Occupational Safety and Health Administrative U.S. Department of Labor) Retrieved September 04, 2020, from https://www.osha.gov/Publications/OSHA3252/3252.html

OSHA Europe. (2007, January 23). *osha.europa.eu/.* Retrieved October 06, 2020, from http://www.osha.mddsz.gov.si/resources/files/pdf/E-fact_14_-_Hazards_and_risks_associated_with_manual_handling_in_the_workplace.pdf

OSHA U.S. (2016, October). Retrieved October 22, 2020, from www.osha.gov.

osha.europa.eu. (2001). *How to reduce workplace accidentds.* Luxembourg: European Agency for Safety and Health at Work. Retrieved October 22, 2020, from https://osha.europa.eu/en/publications/report-how-reduce-workplace-accidents

Ostrom, L., & Wilhelmsen, C. (2012). Event Tree and Decision Tree Analysis. In L. Ostrom, & C. Wilhelmsen, *Risk Assessment* (pp. 223-249). NJ, USA: Hoboken, John Wiley & Sons, Inc. doi:https://www.researchgate.net/deref/http%3A%2F%2Fdx.doi.org%2F10.1002%2F9781119483342.ch16

Oswal, D., Sherratt, F., Smith, S. D., & Hallowell, M. R. (2018). Exploring safety management challenges for multi-national construction workforces: a UK case study. *Construction Management and Economics, 36*(5), 291-301. doi:10.1080/01446193.2017.1390242

paedagogen.dk. (2020). *paedagogen.dk*. Retrieved November 28, 2020, from https://www.paedagogen.dk/artikler/burrhus-frederic-skinner-16660/

Park, I., Kim, J., Han, S., & Hyun, C. (2020, April). Analysis of Fatal Accidents and Their Causes in the Korean Construction Industry. *Sustainability, 12*(3120), 1-13. doi:https://www.researchgate.net/deref/http%3A%2F%2Fdx.doi.org%2F10.3390%2Fsu12083120

Pearson, J. (1995, May). Goal setting for safety. *Control and Instrumentation, 27*(5), 49-51. Retrieved December 12, 2020, from https://www.scopus.com/inward/record.uri?eid=2-s2.0-0029305465&partnerID=40&md5=2b4576da3b198d3ee0c98a381c763cfe

Pfortmueller, C. A. (2018, December). Serum chloride levels in critical illness-the hidden story. Intensive care medicine experimental. *Intensive Care Med Exp., 6*(1), 1-4. doi:https://doi.org/10.1186/s40635-018-0174-5

Roddy, S. (2020, August 6). Pros and Cons of EMployee Monitoring. *Clutch*.

RRC International. (2019). *RRC Study Text NEBOSH International General Certificate in Occupational Health and Safety Unit IG1: Management of Health and Safety* (1 ed.). London, UK: RRC International. Retrieved November 02, 2020

rrc.co.uk. (2020). *rrc.co.uk*. Retrieved November 05, 2020, from https://www.rrc.co.uk/about-us.aspx

Safe Work Australia. (2018). *safeworkaustralia.gov.au*. Retrieved October 29, 2020, from https://www.safeworkaustralia.gov.au/book/work-related-injury-fatalities-key-whs-statistics-australia-2018#work-related-injury-fatalities--8

safetymanagementgroup. (2020, February 20). Retrieved January 03, 2021, from safetymanagementgroup.com: https://safetymanagementgroup.com/using-behavior-based-approaches-to-enhance-construction-safety/

safetymanualosha.com. (2020, April 21). *safetymanualosha.com*. (eflanagan, Editor) Retrieved October 15, 2020, from https://www.safetymanualosha.com/unsafe-acts/

safetyskills.com. (2017, September 26). *safetyskills.com*. Retrieved October 05, 2020, from https://safetyskills.com/slips-trips-and-falls-in-the-construction-industry/

Salminen, S. (2004). Have young workers more injuries than older ones? *Journal of Safety Research, 35*, 513-521. doi:https://doi.org/10.1016/j.jsr.2004.08.005

Shafique, M., & Rafiq, M. (2019, May 20). An Overview of Construction Occupational Accidents in Hong Kong: A Recent Trend and Future Perspectives. *Applied Sciences, 9*, 1. Retrieved September 03, 2020, from https://www.researchgate.net/publication/333230539_An_Overview_of_Construction_Occupational_Accidents_in_Hong_Kong_A_Recent_Trend_and_Future_Perspectives

Shao, B., Hu, Z., Chen, S., Liu, Q., & He, W. (2019, January). Fatal accident patterns of building construction activities in China. *Safety Science, 111*, 253-263. Retrieved September 09, 2020, from https://www.sciencedirect.com/science/article/pii/S0925753517315394

silverdecisions.pl. (2020). *silverdecisions.pl*. Retrieved November 26, 2020, from http://silverdecisions.pl/

Skowron, B., & Sobocinski, M. D. (2018). Behaviour Based Safety (BBS) - Advantages and Criticism. *Production Engineering Archives, 20*, 12-15. doi:10.30657/pea.2018.20.03

Smith, T. A. (1999, September). What's wrong with behavior-based safety? *Professional Safetys, 44*(9), 37-40. Retrieved December 01, 2020, from https://search-proquest-com.zorac.aub.aau.dk/docview/200383656/fulltextPDF/6788038AD29E469DPQ/1?accountid=8144

Sonya Meekel, D. P. (2011). *Improving health and safety on construction in Romania. A comparison with Ireland; lessons to be learned.*

Statista. (2019, November 04). *statista.com*. (L. L. Thomala, Editor) Retrieved September 08, 2020, from https://www.statista.com/statistics/279243/number-of-construction-employees-in-china/

Statista. (2020, June). *statista.com*. Retrieved December 06, 2020, from https://www.statista.com/statistics/788128/construction-spending-worldwide/

Stoilkovska, B., Žileska, P. V., & Mijoski, G. (2015). Relationship of safety climate perceptions and job satisfaction among employees in the construction industry: the moderating role of age. *Int J Occup Saf Ergon, 21*(4), 440-447. doi:10.1080/10803548.2015.1096059

Stroie, E. R. (2011, December). Advantages and Disadvantages of Quantitative and Qualitative Information Risk Approaches. *Chinese Business Review, 10*(12), 1106-1110.

Sulzer-Azaroff, B., & Austin, J. (2000, January). Does BBS work? Behavior-based safety and injury reduction: A survey of the evidence. *Professional safety, 45*(7), 19-24. Retrieved November 11, 2020, from https://www.researchgate.net/publication/284306561_Does_BBS_work_Behavior-based_safety_and_injury_reduction_A_survey_of_the_evidence

Suraji, A., Duff, A., & Peckitt, S. (2001). Development of causal model of construction. *Journal of Construction Engineering and Management, 127*(4), 337–344. doi:https://www.researchgate.net/deref/http%3A%2F%2Fdx.doi.org%2F10.1061%2F(ASCE)0733-9364(2001)127%3A4(337)

Szymański, P. (2017). Risk management in construction projects. *Procedia Engineering, 208*, 174-182. doi:https://doi.org/10.1016/j.proeng.2017.11.036

Tam, C., Zeng, S., & Deng, Z. (2004). Identifying elements of poor construction safety management in China. *Safety Science, 42*(7), 569-586. Retrieved September 08, 2020, from https://www.sciencedirect.com/science/article/pii/S0925753503000602

Tang, X.-f., & Tao, J. (2017). Risk Identification and Prevention of International Construction Project. *International Conference on Information, Computer and Education Engineering (ICICEE 2017)* (pp. 560-566). Hong Kong: DEStech Transactions on Computer Science and Engineering. doi:10.12783/dtcse/icicee2017/17211

Taylor, B., & Li, Q. (2007, November 01). Is the ACFTU a Union and Does it Matter? *Journal of Industrial Relations, 49*(5), 701-715. doi:https://doi.org/10.1177/0022185607082217

Teo, E. A.-L., & Feng, Y. (2009, February). The Role of Safety Climate in Predicting Safety Culture on Construction Sites. *Architectural Science Review*, 6. doi:10.3763/asre.2008.0037

Thomas R. Cunningham, R. J. (2018). *Differences in safety training among smaller and larger construction firms with non-native workers: Evidence of overlapping vulnerabilities.* HHS Public Access.

Toole, T. (2002, June). Construction Site Safety Roles. *Journal of Construction Engineering and Management, 128*(3), 203-210. doi:10.1061/(ASCE)0733-9364(2002)128:3(203)

uk.nearmiss.dk. (2020). *uk.nearmiss.dk*. Retrieved October 15, 2020, from http://uk.nearmiss.dk/knowledge/what-is-what/

UN HDRO. (2019). *hdr.undp.org*. Retrieved December 23, 2020, from United Nations Human Development Report Office: http://hdr.undp.org/en/content/2019-human-development-index-ranking

urban-hub.com. (2019, March 19). Retrieved October 05, 2020, from https://www.urban-hub.com/cities/hong-kong-city-of-change-moving-mega-projects/

Vacaroiu, B. O. (2006, July 26). *Imspectia Muncii.* Retrieved from imspectiamuncii.ro: https://www.inspectiamuncii.ro/documents/66402/267275/Law+319+on+2006.pdf/43ef9465-6bf5-44c4-b912-3f7fa74eece8

Valente, F. (2019, December 09). *ww2.frost.com*. Retrieved December 06, 2019, from https://ww2.frost.com/news/press-releases/global-spending-in-construction-to-reach-17-5-trillion-by-2030-finds-frost-sullivan/

van der Molen, H. F., de Vries, S. C., Stocks, S. J., Warning, J., & Frings-Dresen, M. H. (2016, March). Incidence rates of occupational diseases in the Dutch construction sector, 2010-2014. *Occupational and environmental medicine*, 350-352. doi:10.1136/oemed-2015-103429

Wei, C. (2020, April 16). Retrieved January 05, 2021, from goldthread2.com: https://www.goldthread2.com/culture/bamboo-scaffolding-why-does-hong-kong-still-use-it-construction/article/3080274

weibull. (2020). *weibull*. Retrieved January 07, 2021, from https://www.weibull.com/hotwire/issue46/relbasics46.htm

WHO. (2020). *who.int/*. Retrieved December 10, 2020, from World Health Organization: https://www.who.int/occupational_health/activities/occupational_work_diseases/en/

Winge, S., Albrechtsen, E., & Mostue, B. A. (2019, February). Casual factors and connections in construction accidents. *Safety Science, 112*, 130-141. doi:https://doi.org/10.1016/j.ssci.2018.10.015

Winn, A. R., & McAfee, R. B. (1989). The use of incentives/feedback to enhance work place safety: A critique of the literature. *Journal of Safety Research, 20*(1), 7-19. doi:https://doi.org/10.1016/0022-4375(89)90003-0

Wood, R. (2019, December 19). Retrieved November 22, 2020, from safran.com: https://www.safran.com/blog/whats-the-difference-between-qualitative-and-quantitative-risk-analysis

worker-participation. (2016). *worker-participation.eu*. Retrieved January 06, 2021, from worker-participation.eu: https://www.worker-participation.eu/National-Industrial-Relations/Countries/Romania/Trade-Unions

WorkSafe Australia. (2013, May). *WorkSafe Australia.* Retrieved December 13, 2020, from safeworkaustralia.gov.au: https://www.safeworkaustralia.gov.au/node/1079

Worksafe New Zealand. (2016, October 09). *worksafe.govt.nz.* Retrieved from https://web.archive.org/web/20161009154527/http://www.worksafe.govt.nz/worksafe/information-guidance/all-guidance-items/hswa-fact-sheets/reasonably-practicable/reasonably-practicable.pdf

worldometers. (2021). *worldometers.info*. Retrieved January 05, 2021, from https://www.worldometers.info/world-population/malta-population/

Yan, E. J., & Liu, B. (2020, May). Retrieved December 09, 2020, from uk.practicallaw.thomsonreuters.com: https://uk.practicallaw.thomsonreuters.com/2-521-5363?__lrTS=20180603072119986&transitionType=Default&contextData=(sc.Default)&firstPage=true

Yik, F., & Lai, J. H. (2008, May). Multilayer subcontracting of specialist works in buildings in Hong Kong. *International Journal of Project Management, 26*(4), 399-407. doi:10.1016/j.ijproman.2007.05.009

Youjie, L., & Fox, P. W. (2001). *The construction industry in China: it's image, employment prospects and skill requirements.* Geneva: International Labour Office. Retrieved September 22, 2020, from https://www.researchgate.net/publication/242494768_THE_CONSTRUCTION_INDUSTRY_IN_CHINA_ITS_IMAGE_EMPLOYMENT_PROSPECTS_AND_SKILL_REQUIREMENTS

Zhang, M., & Fang, D. (2012, November 13). A continuous Behavior-Based Safety strategy for persistent safety improvement in construction industry. *Automation in Construction, 34*, 1. Retrieved September 03, 2020, from https://www.sciencedirect.com/science/article/abs/pii/S0926580512001860

Zhang, M., & Fang, D. (2013, January 2). A cognitive analysis of why Chinese scaffolders do not use safety harness in construction. *Construction Management & Economics, 31*, 207-222. doi:10.1080/01446193.2013.764000

Zhang, Murphy, Fang, & Caban-Martinez. (2015, April). Influence of fatigue on construction workers' physical and cognitive function. *Occupational medicine , 65*(3), 245–250. doi:https://doi-org.zorac.aub.aau.dk/10.1093/occmed/kqu215

Zhao, D., Thabet, W., McCoy, A., & Kleiner, B. (2014, September). Electrical deaths in the US construction: an analysis of fatality investigations. *International Journal of Injury Control & Safety Promotion, 21*(3), 282. doi:https://doi.org/10.1080/17457300.2013.824002

Zhao, W. (2018, November). Market control: understanding the China's construction industry. *Asian Journal of German and European Studies, 3:15*, 1-11. Retrieved September 05, 2020, from https://www.researchgate.net/publication/328897576_Market_control_understanding_the_China's_construction_industry

Zheng, L., Xiang, H., Song, X., & Wang, Z. (2010). Nonfatal unintentional injuries and related factors among male construction workers in central China. *American Journal of Industrial Medicine*, 588-595. Retrieved September 30, 2020, from https://pubmed.ncbi.nlm.nih.gov/20340101/

Zhoue, X.-H., Shen, S.-L., Xu, Y.-S., & Zhou, A.-N. (2019, August 18). Analysis of Production Safety in the Construction Industry of China in 2018. *Sustainability , 11*(17), 1-14. Retrieved September 08, 2020, from https://www.researchgate.net/publication/335316005_Analysis_of_Production_Safety_in_the_Construction_Industry_of_China_in_2018

Zou, P. X., Zhang, G., & Wang, J. (2007). Understanding the key risks in construction projects in China. *International Journal of Project Management, 25*(6), 601-6014. Retrieved September 07, 2020, from https://www.sciencedirect.com/science/article/pii/S0263786307000488

Zummack, D. (2018, August 9). Retrieved November 28, 2020, from blog.workhub.com: https://blog.workhub.com/what-is-behaviour-based-safety-observations

Aapaoja, A., & Haapasalo, H. (2014, January). A Framework for Stakeholder Identification and Classification in Construction Projects. *Open Journal of Business and Management, 2*(1), 43-55. doi:10.4236/ojbm.2014.21007

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Appendix 1 - Glossary

Construction

Construction is defined as general construction work (including new work, additions and alterations, repair and maintenance), installation work, and specialized services (e.g. painting, plumbing, and demolition) that generally last for less than one year at sites, buildings, and structures (e.g. bridges). A construction site is defined as a fixed area where one or more stages of construction work are being carried out. (Census and Statistics Department, 2019)

Hazard

A hazard is defined as a source or situation of the real or potential danger that may cause unintentional injuries or deaths to people or damage to, or loss of, an item, belongings, or material property. It can also be considered as the counterpart of safety; therefore, the assessment of workplace safety can be done by assessing all on-site hazard elements. (Fang, Xie, Huang, & Li, 2004) Hazards at construction sites can vary widely depending on the size and type of work being carried.

Risk

A risk is defined as a measure, or outcome, of the probability and severity of negative consequences. The probability is a statistical measure of uncertainty about future events and consequences, seen through the eyes of an assessor and based on some background information and knowledge and can be quite subjective. "*Severity refers to intensity, size, extension, scope and other potential measures of magnitude, and affects something that humans value (lives, the environment, money, etc.)"*. In construction, for example, it can be expressed in monetary values or the number of fatalities, in case that a scaffold barrier fails and leads to collapse. It is vital to note that the uncertainties refer to the events and consequences, whereas the severity is just a way of describing the consequences. (Aven, On how to define, understand and describe risk, 2010)

Vulnerability

According to the book *Introduction to International Disaster Management*, vulnerability is related to the terms hazard, consequence, and risk: "*Vulnerability is the measure of the propensity of an object, area, individual, group… or other entity to incur the consequences of a hazard."* The vulnerability can be decreased through actions that lower the tendency of the object/individual/group to behave in a certain way and thereby avoid harm. By lowering the vulnerability of an object, one can lower the risk too. This can be explained by the classical definition of risk: Risk = Probability * Consequence, where the probability includes the likelihood and frequency of an event, and consequences being the effect of the hazard on the asset. Hereby, the vulnerability of the asset will play a remarkable part in the consequences of the hazard. (Coppola, 2015)

Consequences

Consequences are described as following: "*Consequences are often seen in relation to some reference values (planned values, objectives, etc.), and the focus is normally on negative, undesirable consequences. There is always at least one outcome that is considered as negative or undesirable*". (Aven, 2015)

Accident

An accident is defined according to the definition of OSHA: *"An accident is unplanned, unwanted event that results in personal injury or property damage."* (OSHA, 2020b)

Incident

An incident is defined according to the definition of OSHA: *"An incident is an unplanned event that does not result in personal injury but may result in property damage or is worthy of recording."* (OSHA, 2020b)

Fatality

A fatality is defined according to the definition of OSHA*: "An employee death caused by a work-related incident or exposure; in general, from an accident or an illness caused by or related to a workplace hazard."* (OSHA, 2020b)

Unsafe act

An unsafe act is caused by errors in human behavior. Unsafe acts can be created by the environment or acquired through inheritance. An act can be understood as the performance of a task or activity that is conducted in a manner that may expose the health and/or safety of the individual itself, such as of other workers, to risk. Examples are lack of or improper use of PPE, operating equipment at an unsafe speed, failure to warn people in situations of danger, or use of tools or work equipment for other than their intended purpose. (uk.nearmiss.dk, 2020) (safetymanualosha.com, 2020)

Unsafe condition

An unsafe condition is a condition or situation in which the physical design of the workplace or work location, the status of tools, work equipment, and/or material are in contravention with existing safety standards. An unsafe condition may already be present before an activity has started and/or may develop after an activity has started. (Abdelhamid & Everett, 2000) Unsafe conditions increase the likelihood of risks occurring and have the potential to cause injuries and accidents and are majorly attributed to the individuals who work in the workplace. Examples are lacking safety procedures, malfunction or damage of work equipment or tools, and failure to utilize necessary safety equipment. (greenwgroup, 2018a) (mightyrecruiter.com, 2020)

Appendix 2 - Chinas transformation of the construction industry

The pre-industrial state

Following the Opium War (1839-1842) between the Qing dynasty and Western countries, China was forced to open up. Western construction companies arrived in China throughout the mid of 19th century starting to recruit employees through a labor subcontracting system to be wage laborers. (Youjie & Fox, 2001) After 1880, Chinese companies also introduced such a system which undermined the so-called guild system in the building industry. (Ngai & Huilin, 2010) “Master workers” controlled and monopolized construction techniques, and thus they were able to be in control of the recruitment, wages, and working hours of construction workers at the pre-industrial stage. Except for certain large-scale government or church projects, architectural design and production were not separated and building guilds were in control of the entire process. (Zhao W. , 2018) Some masters established their own companies, stopped working as carpenters or masons, and only the journeymen, their employees, still performed the manual labor. However, the journeymen soon experienced that they were lacking the support of their guild and found to be proletarians. (Ngai & Huilin, 2010) Following the foreign contractor’s scheme, more contractors were established in Chinese major cities. They similarly tendered for construction contracts as in Western countries. This system was still practiced when the People’s Republic of China was established in Beijing on 1 October 1949. From 1949 to 1957, construction projects became more state-organized and a smaller portion of the construction projects was carried out under the previous contracting system. (Youjie & Fox, 2001) In 1958, the labor subcontracting system was ended, and construction work was mostly organized under state-owned or collective enterprises. People working in rural or urban cooperatives usually received less protection and benefits than workers in state-owned enterprises, but they were provided with food, worked reasonable hours, and got paid regularly. Back then, working in construction was acknowledged as skilled work, enjoyed a good reputation, and people employed in construction companies were propagandized as “model workers” contributing to the rebuilding socialist country after the Second World War. (Ngai & Huilin, 2010)

The post-Mao era

After Mao Zedong died in 1976, the *Gang of Four*, composed of four Chinese Communist Party officials and Chinas leading political faction at that time, was disassembled. Hua Guofeng sustained on Mao-era policies as the new served Chairman of the Communist Party of China and the Premier of the People's Republic of China. In December 1978, Deng Xiaoping became the *de facto* leader of China as he outmaneuvered Hua Guofeng. China was about to launch a new area. (Britannica, 2016)

Xiaoping proposed many ideas and implemented far-reaching economic reforms and opening-up policies that transformed China in terms of structure and operating model. In terms of ownership, the change has been made from state-owned companies with a monopolistic appeal toward a combination of public and private enterprises. In regard to the operating model, the change has been made from a planned to a market economy. Through Deng Xiaoping's leadership, economic liberalization was established that allowed continual growth for the Chinese economy, making it globally more attractive, competitive, and earning Xiaoping the reputation as the "Architect of Modern China". (Aneculaesei, 2020)

However, the probably most dramatic change of all has been in the construction sector. (CLB, 2019) Until 1983, the construction industry was not even recognized as a separate economic sector contributing to the GPD. Instead, the industry was simply a subordinate workforce giving effect to the state´s fixed capital investment program. A vast number of people, including certain top government officials, supposed that construction activities would just include assembling building materials, plants, and other equipment by the other economic sectors to form buildings and civil engineering works but enhance no worth to the total social product. As part of the central planning process of China before the area of Xiaoping, construction work was organized and supervised by central government ministries or local governments which meant also that construction enterprises had to wait until the government assigned construction work for them. Inputs including building materials, equipment, technical and managerial personal, skilled workers and laborer's, working capital, and other contributions were all allocated by the supervisory government agencies. Hence, most of the enterprises lacked not only autonomy regarding workload but also insufficient horizontal mobility and experience in other sectors. (Youjie & Fox, 2001)

However, Xiaoping noticed that construction could be a profit-making industry, and through restructuring the industry's administrative system, opening construction markets, and allowing autonomy in state-owned enterprises, a competitive bidding system established and enhanced project managerial skills. (Ngai & Huilin, 2010) The reform programs for the construction industry included:

- *"Introduce a market mechanism into the construction market;*
- *Diversify ownership of construction enterprises;*
- *Deregulate employment in the construction industry;*
- *Deregulate building material supply;*
- *Diversify the business scope of construction enterprises;*
- *Use bidding procedures to allocate construction works;*
- *Bring the construction industry under a unified administration of the Ministry of Construction and its local agencies;*
- *Further, privatize the state-owned construction enterprises;*
- *Separate field operation from management"* (Youjie & Fox, 2001)

Before 1984, all workforce was employed through the Labour Bureau China, an agency of the local government. Once workers attained employment, they had an enduring status as "fixed workers". Unless they broke the law, nobody could dispose of them. However, in September 1984, the State Council (the central government of China) published a document stating: "*The state-owned construction and installation enterprises shall reduce the number of fixed workers gradually. In the future, they shall not, in principle, recruit any fixed workers except skilled operatives necessary to keep the enterprise technically operational. They shall enter into an employment contract with the recruits ('contract workers') for a limited number of years. The enterprises shall increase the proportion of the 'contract workers' in their workforce."* (Youjie & Fox, 2001) (Ngai & Huilin, 2010) This regulation enhanced change in the management and composition of the workforce with the purpose to increase the productivity and efficiency in construction projects. In addition to that, the "Separation of Management from Field Operations" stated in another regulation in 1984 that general contractors or contracting companies should not directly employ their blue-collar workforce. Instead, they should employ labor subcontractors for field operations who were to be responsible for recruiting the workforce. The system of subcontracting, driven by state initiatives, re-emerged in China. (Ngai & Huilin, 2010) As a result, construction enterprises were subsequently categorized into general contracting companies, specialist companies, and labor-only companies. While general contracting companies typically perform as the main or prime contractor, they also display most of the construction enterprises in China. Specialist companies are further sub-classified into numerous subgroups based upon their specialization, which can be excavation, piling, foundation, mechanized construction, equipment, and machinery installation, fitting out and finishing, urban utilities, or public works. (Youjie & Fox, 2001) Construction enterprises were increasingly marketized and field processes disconnected from direct management. (Ngai & Huilin, 2010)

Appendix 3 - Project risk identification in construction

The table illustrates five categories of *design risks*, *financial and economic risks*, *political risks, construction related risks,* and *environmental risks* with their associated (sub) risks. The list of risks was identified by research and through expert elicitation by the authors of this thesis supported. (Zou, Zhang, & Wang, 2007) (Tang & Tao, 2017)

Project risks in construction

Client and design risks	Financial and economic risks	Political risks	Construction-related risks	Environmental risks
Tight project schedule	Price inflation	Political safety	Site conditions	Weather
Project funding problems	Financial crisis	Political stability	Inadequate safety measures or unsafe operations	Natural disasters and other emergencies
Incomplete design scope	Exchange rate	Construction law, regulation changes	Poor competency of workers	Pollution of air, water, and soil
Variations by the client	Availability of funds and loans	Requirements for permits	Worker disputes	Diseases, ill-health
Defective design	Liquidity and cashflow		Unavailability of sufficient professionals and managers	
Errors & omissions	Change of investors		Poor management by contractors and subcontractors	
Incorrect cost estimate	Delays, budget overruns, or lacking quality		Unavailability of skilled workers	
Inadequate specifications	Supplier and logistics		Change of contractors	
Incomplete design scope	Quality and quantity of equipment and material		Lack of ready utilities on site	
Defective design	Not buying insurance for major equipment		Failure of machinery and equipment	
	Not buying safety insurance for employees			

Source: Authors

Appendix 4 - Calculations for the event tree

Year	Workers	Accidents	Fatalities	Non-Fatalities	% Accident	% Fatal	% Nonfatal
2011	62.635	3.241	23	3.218	0,0517	0,0071	0,9929
2012	71.295	3278	26	3.252	0,0460	0,0079	0,9921
2013	79.303	3354	22	3.332	0,0423	0,0066	0,9934
2014	82.795	3593	20	3.573	0,0434	0,0056	0,9944
2015	95.103	3882	19	3.863	0,0408	0,0049	0,9951
2016	107.799	3870	10	3.860	0,0359	0,0026	0,9974
2017	118.674	4136	22	4.114	0,0349	0,0053	0,9947
2018	111.849	3741	15	3.726	0,0334	0,0040	0,9960
Total	729.453	29095	157	28.938	4,105%	0,550%	99,450%

Source: Authors, made in Microsoft Excel 2016

Appendix 5 - Defining prevention and mitigation strategies for hazard control

The following will explain what is meant by the five elements of elimination, substitution, engineering controls, administrative controls, and PPE.

Elimination

If it is possible to eliminate a hazard, then the risk created by the hazard vanishes. This might be done by completely avoiding an activity that gives rise to risk. (RRC International, 2019) For example, we imagine a logistic company that has one big warehouse where logistic workers must pack, stack, and carry goods from one place to another. Because there are also people operating forklift trucks inside the same warehouse, a hazard is caused by the vehicles. Workers are exposed to the risk of being struck or hit by the forklift trucks and are likely to suffer from broken bones, internal bleeding, and could die. By prohibiting the activity of forklift trucks operating inside the warehouse when workers are present, the vehicles pose no hazard anymore and the risk of being struck by the forklift trucks is eliminated.

In construction, this can be more challenging because many hazards must be accepted. However, some hazardous substances can be replaced with materials that fulfill the same job requirement but present no risk to health. Lifting equipment such as hoists and lifts can be used to eliminate manual handling. Noisy machinery can be exchanged for such machinery that generates less noise so there is no risk of hearing damage. (RRC International, 2019)

Substitution

Decreasing risks by substituting hazards can also be achieved, whenever it is possible to substitute or replace one hazard with another that creates less risk. (RRC International, 2019) For our example, forklift trucks may be substituted by pallet trucks (wheeled trollies designed to lift and transport pallets). Such machines have a lower probability of hitting workers. Should a worker still be hit by a pallet truck, the severity can be estimated as lower because most foot, ankle, and leg injuries but probably no deaths could be the consequences.

On construction-sites, one hazardous substance classified as 'toxic' can be substituted with one that is 'irritant'. The substance remains still harmful, but far less. A handling aid such as a sack truck does not eliminate manual handling, but it does reduce the risk of injuries associated with moving goods. (RRC International, 2019)

Engineering controls

Engineering controls make use of an engineering solution to reduce the amount or degree of exposure to a hazard. It can be done by:

- Isolation or total enclosure of the hazard (e.g. acoustic enclosure of a machine which generates a lot of noise, safety guards around moving machinery to prevent contact, etc.)

- Separation or segregation by placing the hazard in an inaccessible location (e.g. placing trailing cables overhead where an electrical conductor is out of reach)
- Partial enclosure (e.g. partial enclosure of a hazardous substance through the means of a fume hood)
- Safety devices and features that ensure equipment or an item are used in the accurate way (e.g. interlock switches are fitted to movable guards on machinery) (RRC International, 2019)

For our example, one effective engineering control against the forklift trucks could be separating workers and forklift trucks by building robust barriers in which the workers are protected from the vehicles during their work.

Administrative controls

Administrative controls rely on procedures and human behavior. However, humans are likely to cause errors and workers could knowingly or unknowingly violate rules and procedures, therefore, administrative controls are usually considered as less effective than the hazard controls mentioned above. (RRC International, 2019) Administrative controls include:

- Safe system of work: this is a formal practice based on a systematic examination of work which defines a safe way of working that removes hazards, or minimizes the risks associated with them as best as possible. Safe systems of work (SSoW) are necessary whenever it is not possible to physically eliminate hazards, and some element of risk remains to prevent accidents or other incidents. Certain high-risk work activities (e.g. hot work, work on electrical systems, machinery maintenance, confined spaces, working at height) may be controlled by a permit-to-work system as a part of the safe system of work. A permit-to-work (PTW) system safeguards that all necessary actions are taken before, during and after tasks that are considered as high-risk work.
- Reduce degree of exposure: if the degree to which a worker is exposed to a hazard can be decreased, the worker will be less likely to suffer from that hazard. For example, a worker who needs to move between operating forklift trucks all day working is more likely to suffer from an accident than a worker who only spends one hour of their working day exposed to the same hazard.
- Reduce time of exposure: the dose of harm that a worker receives (e.g. caused by noise, vibration, radiation, etc.), determines the consequences. The dose is determined by the two principal factors of concentration/intensity and time of exposure.
- Information, instruction, safety training, and supervision: safety training is one fundamental method for enabling workers to become competent and act right especially during emergencies. A competent person is equipped with all the important information and fully aware of the hazards and the use of

suitable preventive measures. One simple way to provide basic health and safety information is through using clear and visible safety signs in the workplace.

- Supervision: by supervising, checking, and monitoring workers, management can ensure quality and exercise their authority to control behavior. However, the act of supervision does not necessarily mean persistent oversight of workers and the workplace because it would consume a tremendous amount of time, effort, and resources. To more effectively supervise workers, it is recommended to make occasional contact with them at suitable intervals throughout a working period or to supervise remotely (i.e. from a distance). (RRC International, 2019)

Personal Protective Equipment

Personal Protective Equipment (PPE) is worn or held by a worker to protect against one or more risks on their health or safety. There are various types of PPE available, such as

- eye protection against splashes of chemicals and molten metals, mists, sprays and dust, projectiles and radiation,
- ear defenders against noise,
- gloves to protect from sharp edges and hazardous substances for the skin,
- safety shoes with steel-caps against slip, trip and fall injuries,
- helmets to protect the head against falling objects,
- and respiratory protection against substances that can cause harm when inhaled. (RRC International, 2019)

In addition to that, PPE covers often the entire upper and lower body is brightly colored or has reflectors. Thus, workers can even be identified from others as such during day and night and from a distance. Compared to the other hazard control measures of the hierarchy, PPE is considered as least preferred because it usually protects only the individuum wearing it and not the collective. PPE could interfere with the wearer's ability to do the job because it might impair the senses (e.g. glasses that mist up), be uncomfortable to wear, or not fit correctly and fail to protect. However, in some situations, it might be interim control while more complex controls are put in place, or even the only hazard control option available. Using PPE is also crucial and needed as a back-up during emergencies when other controls may fail. (RRC International, 2019)