APPLICATION OF BUILDING INFORMATION MODELLING (BIM) FOR SAFETY MANAGEMENT (SM) DURING THE OPERATION AND MAINTENANCE (O&M) PHASE IN BUILDINGS IN KAZAKHSTAN

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DECLARATION

I hereby declare that this manuscript, entitled "Application of Building Information Modelling (BIM) for Safety Management during Operation and Maintenance (O&M) phase in buildings in Kazakhstan", is the result of my own work except for quotations and citations which have been duly acknowledged.
To the best of my knowledge and belief, I also declare that it has not been previously or concurrently submitted, in whole or in part, for any other degree or diploma at Nazarbayev University or any other national or international institution.

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Date: **08.04.2022**

Abstract

Safety management is one of the key concerns of the construction objects industry. Building information modeling enables the creation of a digital built environment of the building. It could also be applied for early safety issues identification and safety management throughout the construction project lifecycle. Currently, BIM usage for building O&M phase safety still has little attention. There are different studies evaluating its general efficiency in early safety risks identification and usage of the BIM model for safety management during building operation and maintenance. Kazakhstan is currently in the important stage of BIM adoption, but no studies observe BIM application for Kazakhstani building O&M safety.

The research encompasses a literature review of key topic-related concepts such as facility management, safety management, and BIM. The literature on various BIM application approaches was also reviewed for safety issues identified during the design phase related to the building O&M phase and their experimental testing in the BIM software. Then the Kazakhstani design procedure and the state of BIM adoption were reviewed. A questionnaire survey was conducted with Kazakhstani industry professionals on their perceptions about BIM for safety management during building O&M and their opinions about possible barriers and strategies during its implementation. This study aims to evaluate how BIM application would improve safety management during the O&M phase in Kazakhstan. It also recognizes the current state-of-the-art of the Kazakhstani industry in the context of the observing topic. It aims to provide possible recommendations on effective BIM applications for building O&M safety.

The online questionnaire survey to which 489 employees from 196 pre-design, design, construction, and facility management companies were invited revealed that there is a high degree of agreement among respondents that most of the safety issues related O&M phase could be prevented through design, that maintainability difficulties with building elements may cause safety issues. The involvement of such experts as safety engineers and facility managers in the design phase can substantially increase these issues' identification. Nevertheless, survey results also indicate that participants' companies majorly used BIM for modeling and visualization purposes and indicated quite a low degree of usage for identifying possible hazards related to the BOM.,

The results of the questionnaire survey also indicate that respondents perceive the key barriers to BIM application for BO&M safety in Kazakhstan as a lack of BIM qualified

specialists, difficulties associated with the cost of BIM implementation and frequent changes in the design during construction, and excessive work associated with the necessity of updating the model with as-built documentation. In contrast, as kye strategies for implementation, they propose preparation of BIM qualified specialists from high school organizations and providing training courses for industry professionals, preparation standard and regulative base for safety management during BO&M, increase awareness among clients about BIM benefits to motivate them to use BIM and introduce BIM application incentives by the government.

As the most efficient tools for early safety issues identification, the respondents mentioned the BIM model walkthrough in the BIM platform and the usage of automated safety checking systems. Respondents also identify the design stage as the most crucially affecting the further building operation and maintenance safety. At the same time, a literature review of the Kazakhstani design procedure indicates that the key process in the design affecting O&M safety is the usage of BIM by state non-departmental enterprises for design projects examination for model checking. An experimental study on BIM software indicates that a BIM model walk-through is less effective in identifying safety issues without a comprehensive checklist. At the same time, additional simulation of the maintenance activity increases the efficiency but is more time-consuming. The usage of automated safety checking systems showed high efficiency for repetitive issues identification but was found to be quite dependent on the knowledge library rules comprehensiveness and coding capabilities of the platform and checking plugin.

Under the analysis of study results, it is recommended the utilization of BIM model checking during the design phase by state nondepartmental enterprises for design projects examination by automated safety checking systems and BIM model walkthrough. The survey results also imply the involvement of facility managers and safety engineers in the model walkthrough procedure to increase the checking procedure efficiency and create a corresponding procedure checklist and rules and regulation database.

Acknowledgments

Firstly, I want to thank my lead supervisor, Dr. Abid Nadeem, for his patience and instructive guidance throughout my master thesis writing. His far-sighted vision of the subject and timely guidance kept me from getting lost while writing my dissertation. I would especially like to note his many hours of patient instruction on implementing a questionnaire survey, in which I felt my weaknesses in understanding the subject.

Secondly, I would like to thank the external supervisor, Professor MD Aslam Hossain, with whom I received the first understanding of the direction of BIM and its benefits in the construction and design industry. Even at the beginning of my master's study, Professor Aslam Hossain was able to inspire a true understanding of the importance of this direction in its application in the country.

Third, I would like to thank my groupmate Dinmukhamed Abaydilda, who has been a student of Nazarbayev University since the first years of his bachelor's degree and had a better understanding of the specifics of carrying out scientific activities. And within the policy of the integration of university students, did not spare his time to share his experience and knowledge in this direction.

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Table of Contents

List of Abbreviations & Symbols

AEC	Architecture Engineering and Construction
AECOM	Architecture Engineering Construction Operation and Maintenance
AR	Augmented Reality
ASCS	Automated safety checking system
BIM	Building information modeling
BO&M	Building Operation and Maintenance
CDE	Common Data Environment
DFS	Design for Safety
FAA	Federal Aviation Administration
GIS	Geographic Information System
IFC	International Foundational classes
JSC	Joint Stock COmpany
KazSRICA	Kazakh Scientific Research and Design Institute of Construction and Architecture
LLP	Liability limited Partnership
LOD	Level of Detail
O&M	Operation and maintenance
PMI	Project management Institute
RGE	Regional Governmental Enterprise
OSH	Occupational Safety and Health
SMS	Safety Management system
SR RK	Set of Rules of Republic of Kazakhstan
VR	Virtual Reality

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Chapter 1 – Introduction

1.1 Problem statement

Safety Management (SM) is one of the recent global topics, and various studies are observing the implementation of BIM in this context (Edirisinghe et al., 2017). But, at this stage, even BIM technology globally has a large scope of application in the safety management (SM) sphere and especially for construction safety (Edirisinghe et al., 2017), its application in the context of safety during Facility Management (FM) still has little attention. Recent studies revealed that maintenance personnel activities contribute to constant risk. There is a high rate of injuries and fatalities related to the FM (Wetzel and Thabet, 2015); it is important to provide safe working conditions for maintenance personnel. However, the real scope of potential for BIM usage in this context in the country was not identified. No studies evaluated the possibility of implementing BIM technologies for SM during the O&M phase in buildings in Kazakhstan. Currently, Kazakhstan is in the early stage of BIM adoption (Talapov V, 2018). There is clear importance of considering BIM application in this context. One of the possible ways of BIM tools implementation in the country is to study theoretically and practically global successful experience in the chosen direction and analyze its applicability in the country based on the study of Kazakhstani industry by providing a literature review and questionnaire survey evaluating its applicability in the country. The study evaluates the application of BIM for SM during building operation and maintenance in Kazakhstan. During the research, four staged studies that had separate objectives led to the achievement of the research aim.

1.2 Research Objectives and Objectives

Research Aims to identify how BIM applications can facilitate SM during building O&M in Kazakhstan and provide recommendations based on the survey results.

1. To study basic concepts of DFS, FM, SM, and BIM to understand the fundamental principles related to the topic.
2. To study current BIM application approaches for SM during Building O&M, classify them according to common execution patterns, and experimentally assess their general process execution in the BIM software.
3. Provide a literature review on Kazakhstani AEC/FM industry key components relating to the study.
4. Provide a questionnaire survey on the Kazakhstani industry professionals to acquire their perceptions on BIM application for SM during building O&M in the country.

1.3 Thesis structure

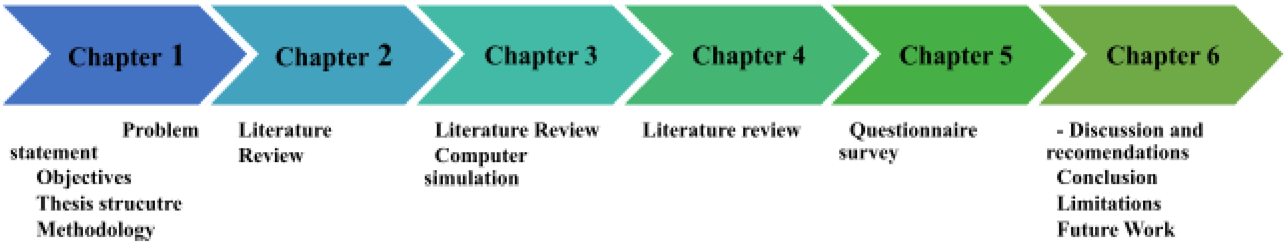


Figure 1.1 Thesis structure

As illustrated in Figure 1.1, the thesis consists of six chapters. The first chapter provides background information on the study as the problem statement, Research Objectives, thesis structure, and Research Methodology. Chapter 2 contains literature related to key concepts such as SM, FM, and BIM. Chapter 3 includes a Literature review on different BIM applications in the context of the study and their practical evaluation of the BIM software. Chapter 4 contains a literature review of key components of the Kazakhstani AEC/FM industry. Chapter 5 includes a Questionnaire survey conducted by Kazakhstani industry professionals on their perception of BIM application in Kazakhstan in the observing topic. In contrast, Chapter 6 discusses the research results, provides recommendations, and describes study limitations and proposals for future research.

1.4 Research Methodology

Figure 1.2 Research Methodology

The study consists of five stages (Figure 1.2) that cover separate objectives intended to lead to the achievement of the research objective.

Stage 1 – Literature review on SM, FM, and BIM.

The first stage was dedicated to achieving a fundamental understanding of the direction of the topic's key aspects, such as Facility Management (FM), Safety Management (SM), and BIM.

Stage 2 - Review of the literature and computer simulation

In this stage, the main objective was to acquire a theoretical and practical understanding of how BIM could be applied during the design phase to identify safety issues related to the building operation and maintenance (BO&M). At this stage, was performed a literature review was performed on the different BIM implementation approaches applied during the design phase in the context of BO&M safety. Then BIM these application approaches were classified and tested under computer simulation of the safety check process of 12 story dormitory building model in Revit and Sketch-up software.

Stage 3 - Review of the literature on key components of the Kazakhstani AEC / FM industry.

The third stage was a literature review to acquire knowledge of the Kazakhstani AEC/FM sector's key characteristics in the study context. In this stage, the Kazakhstani design procedure, BIM adoption state and key industry participants as facility managers, and the governmental enterprise of design projects stage.

Stage 4 Questionnaire survey and data analysis

In the fourth stage, a questionnaire survey was provided on Kazakhstani professionals such as engineers, architects, facility managers, BIM managers, and safety engineers/managers. The survey goal was to identify their perceptions of BIM application for SM during BO&M and study their opinions on possible barriers and strategies in BIM implementation in the context of the study in Kazakhstan. The survey was distributed to 489 respondents from 196 employees of pre-design, design, construction, and operating companies and received 103 answers comprising a response rate of 23%. The survey questions have consisted of four parts 1. Demographic questions, 2. Safety management during building operation and maintenance, 3. The BIM application for safety management during building operation and maintenance are provided in the Qualtrics platform (Appendix A). Then the survey results were generated on the platform.

Stage 5 Research report writing.

In this stage, recommendations for BIM application in the study context and writing a thesis content were generated.

Chapter 2 - Review of the literature on key DFS, FM, SM, and BIM principles

2.1 Introduction

The application of BIM technology for SM during building O&M is a multidisciplinary topic. The main disciplines related to the topic are 1. Safety management (SM), 2. Facility Management (FM) 3. BIM technology (Wetzel & Thabet, 2015). Listed disciplines have common directions among themselves. For example, the relation between BIM and FM disciplines comprises the direction of the BIM application for facility management. The relation between SM and BIM disciplines forms the topic of BIM application for SM. Thus interrelation between these three articles generates the topic of “BIM application for SM during O&M phase for buildings (see figure 2.1). Wetzel & Thabet (2015) noted this approach to literature review. In his work, the authors considered using a BIM-based framework to support secure asset management processes. This approach to the review of the literature has certain advantages since, at the moment, there are still a few studies on the topic as it is at its very beginning (Wetzel & Thabet, 2015). It is supposed that a review of the literature on separate disciplines and interdisciplinary topics will provide a broader understanding of the problem. However, considering this issue in the country's context also requires a filter of various types of BIM application methods for applicability for Kazakhstan. Therefore, in this work, a literature review is carried out by reviewing the listed three disciplines and their relationships and current disciplines' in the country context. In figure 2.1 is illustrated an adapted diagram from Wetzel & Thabet (2015), where a circle is added to the center, symbolizing the additional review of these disciplines in the context of Kazakhstan.

Figure 2.1 Literature review analysis: Application of BIM for safety management during operation and maintenance phase in building in Kazakhstan

Adapted from Wetzel, E. M., & Thabet, W. Y. (2015). The use of a BIM-based framework to support safe facility management processes. *Automation in Construction*, *60*, 12-24.. https://doi.org/10.1016/j.autcon.2015.09.004

2.2 Safety Management (SM)

Analysis of BIM application for the SM requires a clear understanding of the SM system's basic principles and key features. Also, since BIM tools application for the SM sphere of the country is quite a context-related issue, it is important to review the current SMS situation and its key characteristics. According to the Federal Aviation Administration (FAA), every safety management system (SMS) consists of four main components 1. Safety Policy – Defines commitment to senior management to constantly enhance safety. Establishes governing procedures, managerial structure, and activities to achieve safety purposes. 2. Safety Risk Management – Defines the conformity of existing or necessity in new risk control methods according to the evaluation of acceptable risk values. 3. Safety assurance – assessing existing risk control procedures and maintaining new hazards recognition. 4. Safety Promotion – works on the positive formation of a safety culture and contains communication, safety training, and various other processes. FAA also highlights that Safety Risk Management (SRM) and Safety Assurance (SA) are the crucial components of the SMS, and they are interconnected with each other. For example, the processes on safety risks such as risk identification and analysis, risk assessment, and control affect the performance of safety assurance systems as to how different organizations, products, or services meet standards on assuring safety requirements.

The safety assurance for Kazakhstani workers is mentioned in the Constitution of the Republic of Kazakhstan. According to the constitution, ‘Everyone has the right to work conditions that meet the requirements of safety and hygiene, to remuneration for work without discrimination, and social protection against unemployment. Even Kazakhstan shows a positive trend in reducing occupational accidents. The number of occupational fatalities within five years was reduced by up to 17% from 229 to 190, and occupational injuries by up to 8% from 2307 to 2111 cases between 2015 and 2019 (Bureau of National Statistics of Kazakhstan, 2019). However, these values are still higher compared to developed countries. The occupational injury and fatalities rate is calculated as the share of the number of registered occupational injuries for the 100 000 workers in the country. Figure 2.2 illustrates the comparison of the occupational accident rates of Kazakhstan with countries such as Malaysia, Japan, Singapore, and the United Kingdom. According to Figure 2.2, in 2019, the rate of fatal injuries in the country comprised 3.7, which is almost the same as Malaysia's 3.93 but approximately two times higher than in Japan, three times higher than in Singapore, and ten times higher than in the United Kingdom.

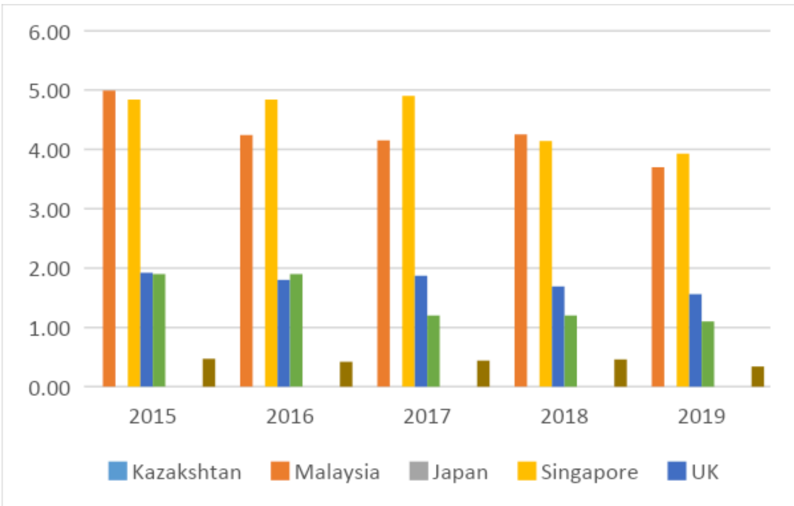


Figure 2.2 Fatal injury rate per 100 000 workers by countries between 2015 and 2019

Adapted from: Bureau of National statistics of Kazakhstan https://stat.gov.kz/official/industry/63/statistic/6, Malaysian Department of Occupational Safety and Health (DOSH) https://www.dosh.gov.my/index.php/statistic-v/national-occupational-accident-fatality-rate-v , Japan Industrial Safety and Health Association (JISHA) https://www.jisha.or.jp/english/statistics/index.html, Singapore Ministry of Manpower https://www.mom.gov.sg/-/media/mom/documents/press-releases/2021/0319-annex-a---workplace-safety-and-health-report-2020.pdf United Kingdom Health and Safety executive www.hse.gov.uk/statistics/tables/ridhist.xlsx

It could also be noted that these occupational accidents have different negative consequences. For example, according to the Bureau of National Statistics of Kazakhstan, five years between 2015 and 2019, the total number of lost working time due to work-related injuries was 724 849 days. The financial consequences of work-related injuries, fatalities, and illnesses equal 7.5 billion tenges. The indicator loss of working time equals the time missed by the worker due to an occupational accident or illness. In contrast, the financial consequences of work-related injuries, fatalities, and illnesses are the amount of money compensated to the employee based on his loss of ability to work and his monthly earnings. Also, in case of death is calculated based on the breadwinner's monthly earnings except the share related to the victim himself (Bureau of National statistics of Kazakhstan, 2019). Also, although a positive trend was noted in reducing the number of occupational accidents, the socio-economic costs of work-related injuries, fatalities, and illnesses are increased by the time between 2015-and 2019 (see Figure 2.3).

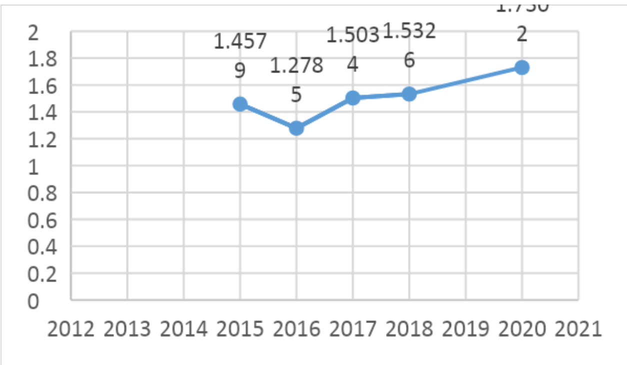


Figure 2.3 Economic costs of work-related injuries, fatalities, and illnesses, billion dollars

Note. Adapted from the Bureau of National Statistics of Kazakhstan
https://stat.gov.kz/official/industry/63/statistic/6

Considering BIM application in the safety management in the country, it should also be noted that the implementation of BIM technologies encompasses different sector activities of the implementing country (Azhar, 2011). According to the Safety policy, the laws and regulative base also play an important role in the correlation of different technologies in the sphere, according to the International Labor Organization (ILO n.d.). 'The Labour Code of 15 May 2007 is Kazakhstan's main occupational safety and health law. The aim of the Labour Code is the legal regulation of labor relations and other relations directly linked with labor and the establishment of minimum guarantees of rights and freedoms in labor. According to the Labour Code, one of the principles of the labor legislation of Kazakhstan is to ensure the right to working conditions that meet the requirements of safety and health" (ILO n.d.). Chapters 20 – 22 of the code provide information about the main policies in accident investigation and documentation, state and internal control policies to adhere to republic labor legislation (Labor Code of the Republic of Kazakhstan). According to the code, the employer is responsible for providing safe working conditions to the employee. Injury or death is accepted as work-related if injury or death to the employee’s health was caused during the performance of his work activities, except for cases where an accident occurred due to narcotic or alcohol intoxication when performing actions not related to the worker's functional responsibilities, intentional harm inflicted by a third person or when sudden issues caused the damage in the worker health not caused by production factors.

The review of the country’s safety accident recording policy also could give an understanding of their future applicability for BIM technologies' development in the context of safety. The deeper intersection of BIM application for safety accident recording and its relation to the current system recording will be specifically analyzed in the analysis section. However, the basic approach could be mentioned in the literature review section. According to the code, there are two approaches for investigating work-related accidents: first involves all the work-related cases not considered in a special case. The second approach involved a special case when the accident caused severe or fatal damage to the worker's health, a group accident involving simultaneously two or more workers, and cases of group people poisoning.

As the application of BIM technology in the country is quite a context-related discipline (Azhar, 2011), the literature review also included a review of the country’s SMS. ILO provided “Occupational safety and health in the Republic of Kazakhstan - national overview” (Later “National Overview”) study where the main structure of the OSH regulation system of the Republic of Kazakhstan was observed. The main structure of the National Review consists of 4 parts. 1. Overview of the legal regulation system - regulatory legal framework of labor protection. 2. Overview of the technical regulation system: technical, regulatory technical documentation: standards, rules, and rules. 3. Overview of the labor security system 4. OSH system overview The general framework of the Kazakhstani OSH system is illustrated in Figure 2.4 below. The specific parts of the OSH system and their characteristics will be mentioned in the discussion part when analyzing the application of various BIM application approaches in the Kazakhstani facilities' safety management context.

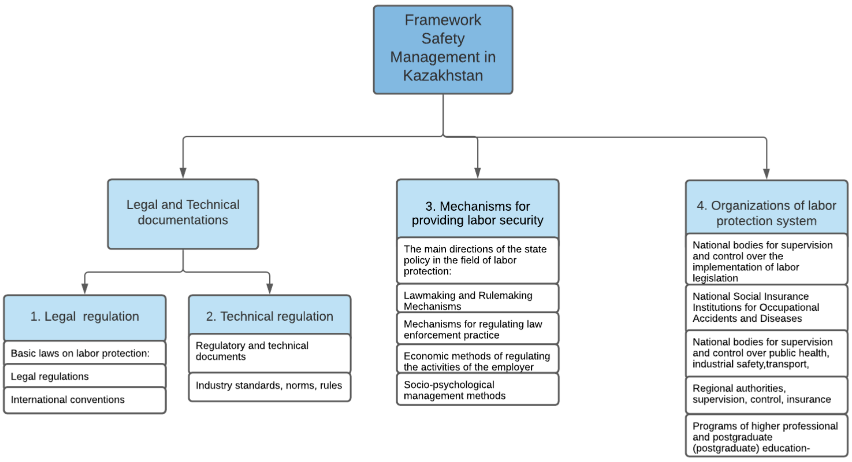


Figure 2.4 OSH system in Kazakhstan

Note. Adapted from the framework of main safety management mechanisms in Kazakhstan Adapted from the International Labor Organization, рана труда в Республике Казахстан: Национальный Обзор 2008 [Trans. Occupational safety and health in the Republic of Kazakhstan national overview 2008] https://www.ilo.org/wcmsp5/groups/public/---europe/---ro-geneva/---sro-moscow/documents/genericdocument/wcms_306180.pdf

2.3 Facility Management (FM)

In the context of the O&M phase, the literature review section will generally review basic facility management principles and facility management activities. In contrast, the Kazakhstani facility manager's activities and contribution to the BIM application for safer building O&M will be discussed constructively in the later Kazakhstani AEC/FM section. Facility management is a term that has different definitions. According to the International Facility Management Association (IFMA), "Facility management (FM) is a profession that encompasses multiple disciplines to ensure functionality, comfort, safety, and efficiency of the built environment by integrating people, place, process, and technology" (IFMA, n.d.). The IFMA also states that the facility managers are people from different professions responsible for ensuring the building spaces are comfortable, productive, safe, and sustainable for people's occupations (IFMA, n.d.). However, Enoma A. (2005) compares the FM to an umbrella that deals with various issues for the most effective and efficiently appropriate conjunction between cost, quality, and time. Also, Enoma A. (2005) differentiates the issues related to the FM into hard issues, which are building, installation and furniture, while soft issues are people, safety, environment, and activities. As it becomes clear that FM encompasses a wide range of activities performed by facility managers (FMs)

Facility managers are key contributors to the safety performance during the O&M, and various studies are reviewing their participation during the design phase. Bosch and Pearce

(2003) highlighted that the correct decisions during the design and construction stages might facilitate energy-efficient buildings and increase work productivity, which may lead to cheaper facility operation. Also, after reviewing the guideline documents for the facility managers and sustainable design, they informed that the active participation of the facility managers during the preoperative phase might ensure that operation strategies and policies planned during the design phase will be kept after the construction. On the other hand, Okoroh *et al*. (2003) emphasized the importance of the requirements correlation between the intentions of the facility use and its management, as there is a close link between facility operation planning, design, construction, and building maintenance. After studying the core activities planned in the hospitals and hotels, they concluded that it is important to plan facility operation and maintenance policies considering future possible demand changes in facility operation.

In another study, Enoma (2005) also investigated the role of the facility managers in the design process and its contribution to the overall design group's success. According to the author, the perception of the facility manager in the design team depends on his participation in project meetings and individual factors such as level of education, training experience, and discipline. The author also informs that according to Jaunzens et al. (2001) sturdy the FMr's role is to ask relevant questions, provide needed data, make a contribution in the context of policy, program, goals, and preferred strategies, identify fitting norms and KPIs, assign most appropriate documentation practice. The author also discussed the benefits and barriers to involving facility managers during the design phase. According to the author, the benefits of FM involvement can reduce procurement expenses in different ways, such as a decrease in alteration and rework activities and the creation of buildings that are easier to control, manage, and maintain. According to the author, the main barrier is the cost factor. First, to achieve cost-effective decisions, the major role is usually dedicated to reducing construction costs, missing its impact on future procurement expenses. Second, according to the author, there is usually a contradiction between the client's financial demands and future operational needs because it is generally believed that the client is not always a building occupier, thus reducing the importance of the participation of a facility manager in the early stages.

2.3 Maintenance

Building maintenance is one of the main activities during facility management that also should be reviewed while considering the safety during its execution. Currently, there are different explanations for the term facility maintenance. Puķīte & Geipele (2017) studied different meanings and explanations of the building management and maintenance concepts.

According to the authors, building maintenance can be interpreted as 'work' performed to maintain, repair, or improve building components to maintain the use of the building and its surroundings following the appropriate standards. They define building maintenance purpose to keep building condition and its provided services as follows firstly safe, secondly fit for usage, thirdly corresponding to statutory requirements and perform activities to maintain building physical assets values and quality. In terms of safety, according to the study management system of the building safety components are: "regulation for industry management, laws for building management, the function of property management departments, technical specifications for the general investigation of buildings, technical standards for design and construction as well as maintenance of buildings, building information system on the internet/intranet, emergency measures, popular education on building safety and expert decision-making system for building management". Some studies review the classification of maintenance activities. For example, Raposo, de Brito, & Fonseca (2013) divided maintenance and repair activities into three categories as:1. Preventive maintenance tasks (PM), Unscheduled maintenance tasks (UM), and Replacement work. (R). PM, including minor repair works, are planned tasks performed to keep the facility element in appropriate condition during its specified service time, while (UM) is not planned tasks consisting of crucial replacement or a major overhaul of the element performed as a response to emergency or service calls. In their study, Raposo, de Brito, & Fonseca (2013) reviewed four building maintenance guideline documents to prepare a list of planned preventive activities for facility managers with corresponding costs. The study author also provided maintenance expenses for one 3.7 m height and 4360 m^2 floor area American primary school (Abate *et al*. 2009) and provided its M&R cost distribution profile in figure 2.5 while in table 2.1 is provided its 50-year M&R cost summary.

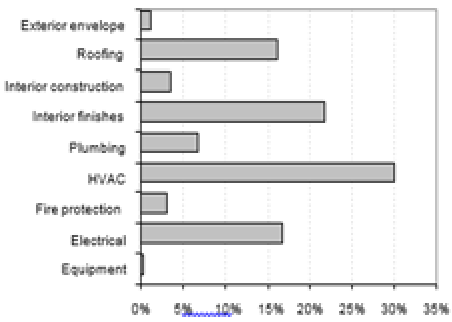


Figure 2.5 Distribution of M&R Costs

Task type	50 year total cost	Annual cost per gross internal floor area	Annual cost as % of replacement
PM & minor repair	1044770 €	0.44 €	0.29%
Unscheduled maintenance	805085 €	0.35 €	0.22%
Renewal & Replacement	4114134 €	1.75 €	1.13%
Total	**5963990 €**	**2.53 €**	**1.63%**

Table 2.1 50 year M&R Cost Summary

Note. Reprinted from 'Planned preventive maintenance activities: Analysis of guidance documents. by S. Raposo, J. de Brito, & M. Fonseca, 2013, *Durability of Building Materials and Components,* p.4.https://www.researchgate.net/publication/283326820_Planned_Preventive_Maintenance_Activities_Analysis_of_Guidance_Documents

In their study, the authors classified building components into four categories 1. Building envelope elements 2. Roofing 3, Interior elements, 4. Exterior and Interior Finish 5. Electrical 6. Fire protection and provided the corresponding frequency of preventive maintenance activities and their impact on intervention numbers (see Table 2.2). According to the authors, a list of data related to preventive maintenance activities is expected to be useful in planning these activities and during their practical execution.

Table 2.2 Summary of information on preventive maintenance

Element	*I*	*M*	*S (years)*	*Number of intervention (50 years)*
Exterior envelope				
Exterior walls	3 y	10 y (W)	NC	I=16; M=5; S=0
Windows	6 m	1 y	25; 35 (H); 75 (W)	I=100; M=50; S=2; 1(H); 0(W)
	1-4 y (I)	1 y (I)	50 (I)	I=50/12; M=50; S=1 (I)
Doors	6 m	1 y	25; 30 (H); 50 (W)	I=100; M=50; S=1(H); 1 (W)
	1-4 y (I)	1 y (I)	50 (I)	I=50/12; M=50; S=1 (I)
Mastic	-	-	10/15	S=5/3
s	-	-	15	S=3
Joinery	-	-	10	S=5
Joint				
Roofing				
Metal roofing	1 y	1 y (I;H)	25; 30 (I); 40 (W)	I=50; M=50; S=2; 1(I;W)
Flat roof	6 m	1 y (A;I)	20	I=100; M=50; S=2
	5 y (W)	1 y (W)	35 (W)	I=10; M=100; S=1 (W)
Skylights	1 y	6 m	20/30; 40(W)	I=100; M=100; S=2/1; 1 (W)
Rain water drainage	6 m	6 m	15; 40(W)	I=100; M=100; S=3; 1 (W)
Interior				
construction	3 y	10 y (W)	30	I=16; M=5; S=1
Walls	1 y	2 y	20	I=50; M=25; S=2
Gypsum board	1 y	2 y	20; 50 (I); 40 (W)	I=50; M=100; S=2; 1 (I;W)
Interior doors	-	5 y	10 (W)	M=10; S=10 (W)
Ironmongery	1 y	2 y	15; 40 (W)	I=50; M=25; S=3; 1 (W)
Sliding interior doors				
Finishes				
Painted wall render	3 y	3 y	15 (A,I); 10 (W)	I=16; M=16; S=3; 5 (W)
Ceramic wall cladding	1 y; 5 (I)	20 y (I)	NC	I=50; 10(I); M=2; S=0
Concrete	10 y (I)	20 y (I)	NC (I); 75 (W)	I=5; M=2; S=0 (I,W)
Wood panelling	1 y	-	30 (I)	I=16; M= -; S=1 (I)
Linoleum	1 y	-	10; 18 (w)	I=50; M= -; S=5; 2 (W)
flooring	3 y (I)	-	20 (I)	I=16; M= -; S=2
	1 y	2-5 y	40 (A; W)	I=50; M=25/10; S=1 (A;W)
Wood parquet flooring				
Electrical				
Fluorescent lighting fixture	1 y	1 y	8-10; 20 (W)	I=50; M=50; S=6/5; 2 (W)

Fire protection	1 y (A;I)	2 y; 6m	20	I=50; M=25/100 (I); S=1
Fire doors	-	1y (W)	40 (W)	I= -; M=50; S=1 (W)
	1 y (*)	1 y (*)	20/30 (*)	I=50; M=50; S=2/1
Fire extinguisher	-	5y (W)	12 (W)	I= -; M=10; S=4 (W)

Note. Reprinted from 'Planned preventive maintenance activities: Analysis of guidance documents. by S. Raposo, J. de Brito, & M. Fonseca, 2013, *Durability of Building Materials and Components,* p.7 https://www.researchgate.net/publication/283326820_Planned_Preventive_Maintenance_Activities_Analysis_of_Guidance_Documents

Finally, the authors concluded that main maintenance costs are related to the overhaul or replacement of facility components when their life cycle ends and especially occurs with buildings with a service life of more than 50 years. However, the maintenance costs calculation results may differ based on components' service life cost analysis. Using reference data organized in standard database form could help perform benchmark analyses.

The context of the study also assumes a clear understanding of the main building elements and their categorizations since safety assurance should encompass the fit condition of the building elements because certain failures of the building components also may cause additional harm to their occupants. In their study, Raposo, de Brito, & Fonseca (2013) classified building components into four categories: 1. Building envelope elements 2. Roofing 3, Interior elements, 4. Exterior and Interior Finish 5. Electrical 6. Fire protection provided the frequency of the corresponding preventive maintenance activities and their impact on intervention number NI. According to the authors, a list of data related to preventive maintenance activities is expected to be useful in planning these activities and during their practical execution.

Regarding the classification of building elements, Islam, Nazifa, & Mohamed (2019) classified 28 building components into three categories: 1. Architectural components (facade, painting, tiles, and ceilings, among others), 2. Structural components (beam, slab, and frames, among others), and3. MEP (plumbing, fire protection, HVAC, elevators, circuits, and cables, among others) systems. These components were classified in table 2.3 based on their difficulties in maintenance and, as a result, their influence on operation and maintenance costs.

The contribution of the FM phase in the project lifecycle is also quite substantial. Paralleling it to the project life cycle cost, it was identified that the building operation and maintenance costs also comprise a major part of the building life cycle cost. According to Akcamete, Akinci, & Garrett (2010), During the facility lifecycle, a major part of the expenses are related to the operation phase (Liu et al. 1994; Clayton 1999) because only 15% of the expenses contribute to the design and construction, while almost 60% (Teicholz, 2004) to the building operation maintenance. Also, according to the authors, exceeding costs are spent during reactive maintenance and replacement, especially in the facility maintenance and repair practice. It is also important to perform planned preventive activities instead of emergency responses to the reactive breakdown. Therefore, the authors advise identifying effective planning policies and assigning proactive maintenance tasks to reduce reactive maintenance activities. In one recent study, Islam, Nazifa, & Mohamed (2019) investigated factors affecting operation and maintenance cost increase and tried to classify building elements according to their operation and maintenance difficulty level. According to Islam, Nazifa, & Mohamed (2019), Goh and Sun (2015) stated that expenses for commercial buildings are higher than for residential, industrial, or institutional buildings. Although the commercial type of facilities is high-rise (height 22 m or more), commercial buildings' maintenance costs are higher. With height increase, facilities are installed with more complicated systems like HVAC, fire prevention systems, lifts, and others (Au-Yong et al. 2013). According to the authors, based on a literature review, they identified 16 crucial factors affecting facility maintenance costs and 28 building elements causing difficulties in operation and maintenance. It was revealed that the respondent perceived that Design errors, immaterial selection, lack of maintenance plan, poor construction quality, and lack of FM database and guidelines are the main contributors (see Table 2.4).

Table 2.3 Assessment of building components that affect the operating and maintenance cost

Serial	Building component	Mean	SD	RII	In group	Overal l
	Architectural components					
1	Façade	4.09	0.93	0.82	1	3
2	Partition wall	3.35	0.70	0.67	7	27
3	Doors and windows	3.30	0.75	0.66	8	28
4	Ceilings	3.74	1.11	0.75	4	15
5	Plaster works	3.61	0.92	0.72	5	16
6	Painting	3.83	0.64	0.77	2	10
7	Carpentry	3.61	0.82	0.72	5	16
8	Tiles	3.78	0.88	0.76	3	13
	Structural components					
9	Slabs	3.57	1.01	0.71	5	21
10	Beams	3.61	1.05	0.72	3	16
11	Columns	3.61	1.13	0.72	3	16
12	Stairs	3.57	0.65	0.71	5	21
13	Roofs	4.30	0.69	0.86	1	1
14	Construction joints	4.26	0.94	0.85	2	2
15	Masonry wall	3.48	1.02	0.70	7	24
	MEP Components					
16	HVAC	3.96	0.81	0.791	1	4
17	Lift	3.78	0.72	0.757	9	14
18	Pumps	3.86	1.08	0.771	6	9
19	Generators	3.86	0.90	0.772	5	8
20	Conduits and wires	3.87	0.99	0.773	4	7
21	Switch and socket	3.39	0.82	0.678	13	26
22	Switch board	3.52	1.02	0.704	11	23
23	Circuit breaker	3.57	0.88	0.713	10	20
24	Lights	3.48	0.97	0.696	12	25
25	Fittings and fixtures (e.g., floor trap and water closet)	3.83	1.05	0.765	7	11
26	Piping	3.83	0.96	0.765	7	11

27	Ducts	3.87	0.74	0.774	3	6
28	Sewer line	3.91	0.97	0.783	2	5

Note. Adapted from ‘Factors influencing facilities management cost performance in building projects’ by R. Islam, T. H. Nazifa & S. F. Mohamed, 2019, *Journal of Performance of Constructed Facilities*, 33(3), p, seven https://www.researchgate.net/publication/332251382_Factors_Influencing_Facilities_Management_Cost_Performance_in_Building_Projects

The statistical data from the Spearman correlation test provides the relation among ten crucial factors. Ten main building elements influencing FM cost were provided in the study illustrated in Table 2.4 below.

Table 2.4 Correlation between factors increasing FM costs and building components

Rank	Factors influencing FM cost	Roof	Construction joints	Façade	HVAC	Sewer line	Ducts	Conduits and wires	Generators	Pumps	Painting	Total number of significant correlations
1	Design errors		0.550^{a}				0.534^{a}					2
2	Lack of maintenance plan	0.642^{a}		0.646^{a}		0.603^{a}			0.426^{b}	0.624^{a}	0.473^{b}	6
3	Lack of understanding of FM with design and construction		0.519^{b}	0.575^{a}	0.532^{a}		0.458^{b}		0.515^{a}			5
4	Underestimating the impacts of FM	0.498^{b}		0.433^{b}			0.501^{b}				0.628^{a}	4
5	High maintenance cost due to lower maintenance quality	0.617^{a}	0.546^{a}	0.437^{b}	0.482^{a}	0.525^{b}			0.429^{b}			6
6	Absence of FM in design phase	0.638^{a}	0.542^{b}	0.419^{b}	0.440^{b}		0.660^{a}				0.465^{b}	6
7	Lack of trained employees		0.429^{b}					0.425^{b}			0.618^{a}	3
8	Work quality	0.422^{b}						0.680^{a}			0.609^{a}	3
9	Lack of FM database and guidelines			0.545^{a}								1
10	Initial and operational fund unavailability	0.547^{a}		0.535^{a}	0.465^{b}					0.413^{b}		4
	Total number of significant correlations	6	5	7	4	2	4	2	3	2	5	

Note/ Adapted from ‘Factors influencing facilities management cost performance in building projects’ by R. Islam, T. H. Nazifa & S. F. Mohamed, 2019, *Journal of Performance of Constructed Facilities*, 33(3), p, nine https://www.researchgate.net/publication/332251382_Factors_Influencing_Facilities_Management_Cost_Performance_in_Building_Projects

Finally, the authors concluded that their work is of practical importance for design and facility management professionals, as it may be helpful to the facility management of buildings to reduce FM costs, emphasizing crucial factors contributing to this FM cost increase.

There are also a lot of decaying buildings in the country, which condition also may affect their safety performance during operation. In one recent study, Chan (2019) investigated the strategy effectiveness of the mandatory building inspection scheme (MBIS) proposed for introduction in Hong Kong city for safer building maintenance. The strategy is a possible statutory measure for the problem of urban decay caused by impaired aged buildings in the city.

According to the strategy, buildings aged 30 years or more will be inspected by the registered inspector (RI), and under inspection, the Registered contractor (RC) will provide the rectification works. The inspection process consists of three stages: organizational, inspection/repair, and after repair stages and encompasses four categories of building elements as external components, structural, fire safety, and drainage system elements (see figure 2.6 below).

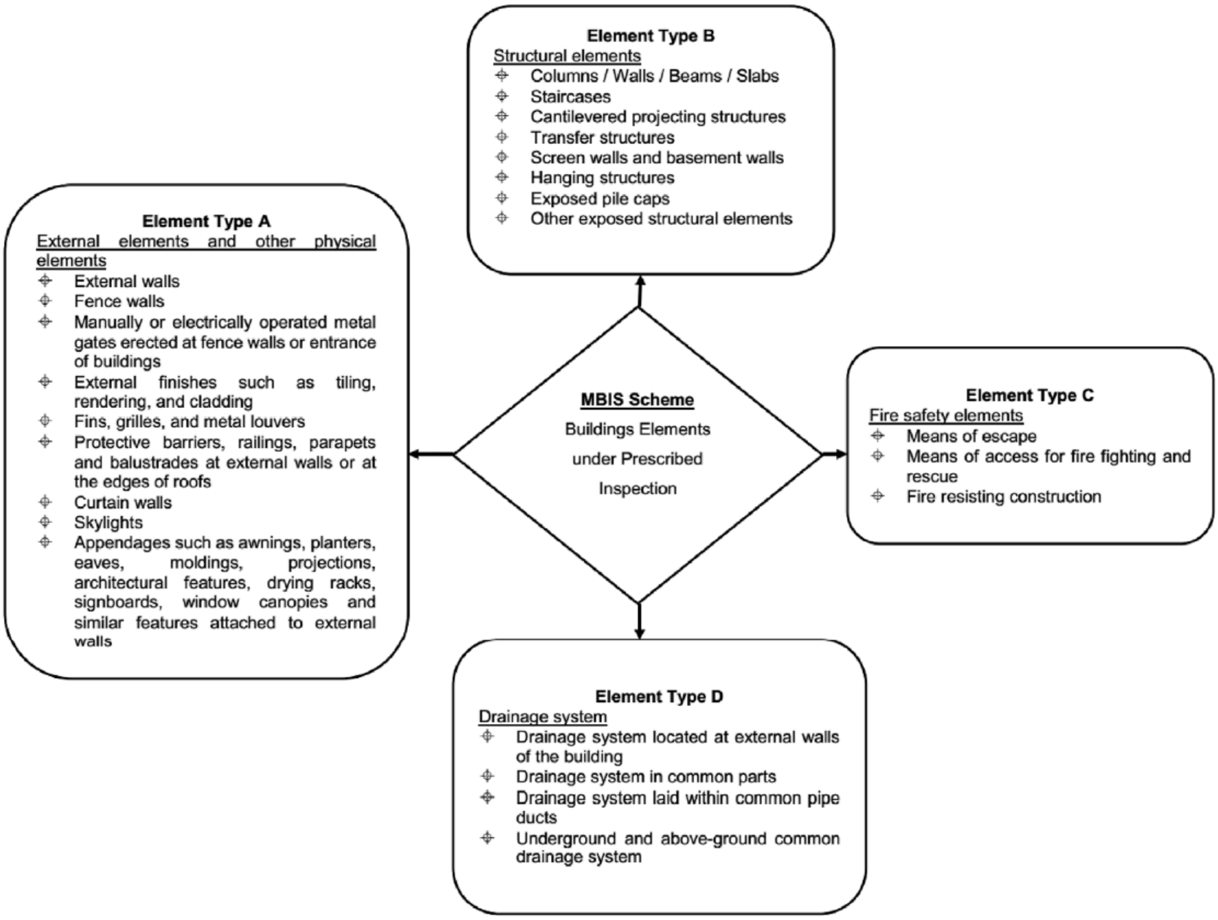


Figure 2.6 Examples of building elements under the prescribed inspection of MBIS

Note. Reprinted from Sustainable building maintenance for safer and healthier cities: Effective strategies for implementing the Mandatory Building Inspection Scheme (MBIS) in Hong Kong by D. W. Chan, 2019, Journal of Building Engineering, 24, 100737, p.4
https://doi.org/10.1016/j.jobe.2019.100737

In the study Chan (2019) also provided a self-administered survey questionnaire from civil engineers, facility surveyors, architects, and other disciplines. They investigated their perception of the 13 recommendations for MBIS execution. During the survey, 852 blank forms were sent, and 340 were received. Under the forms, analysis was identified that most of the respondents highlighted three main recommendations in inspection execution 1. Development of comprehensive guidelines and standard base for building inspection. 2. Government technical and financial for property owners in the execution of the MBIS. 3. Increase citizens' awareness of MBIS through media tools. The author concluded that the government possesses a crucial role in MBIS execution and highlighted that it is advised to adhere to survey recommendations for proper MBIS execution in Hong Kong. Also, similar inspection procedures could be implemented in other developed countries to mitigate the urban decay issue.

2.4 Building Information Modeling (BIM)

BIM is an informational model of facilities with both graphical and functional characteristics (Haron, Soh, Ana, & Harun, 2017). According to Doumbouya, Gao, and Guan (2016), the benefits of BIM encompass all the phases of the projects as tender, design, construction, and FM phases. BIM can be a platform for FM systems, and facility managers can use this data for their future analyses during building operation and maintenance practice (Akcamete, Akinci, & Garrett, 2010). The authors informed that BIM might help gather and transfer the facility data from the design and construction stages to the operation and maintenance stage. For example, Computerized Maintenance and Management Systems (CMMS) and/or Computer Aided Facility Management (CAFM) Systems are software that allows facility data transfer from the BIM model for future building operation purposes. Also, according to the authors Construction-Operations Building Information Exchange (COBIE) specification is a system that provides facility data capturing in early stages from different project participants for enabling later building users to use this information in later stages (East, 2007)—for example, transferring BIM facility data and importing it as maintenance and instruction spreadsheet format for facility managers to use in CMMS software (East et al., 2009). According to the authors, it is expected that to retrieve insight (main causes, impacts of the M&R issues), authors highlight the importance of timely storage of M&R data and its graphical illustration in the BIM model of the building so that it can later be analyzed or transferred to the CMMS systems. Creating such facility management activities history records could also help prioritize M&R works for more effective maintenance and future planning. The envisioned approach of capturing M&R data and visualizing it in a BIM model for future analysis is presented in Figure 2.7.

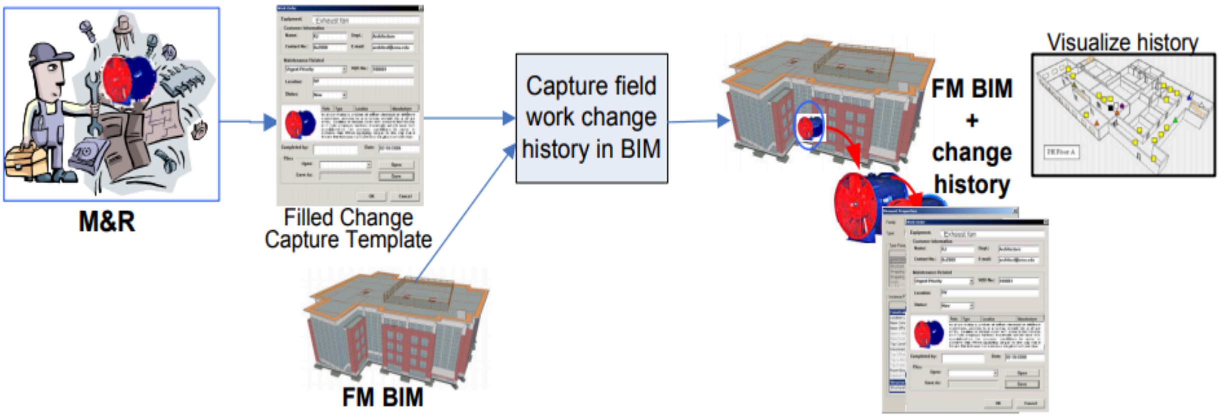


Figure 2.7 Envisioned approach of the BIM application for M&R works

Note. Reprinted from Potential Use of building information models for Planning Maintenance Activities by A. Akcamete, B.Akinci, & J. H. Garrett, 2010, *In Proceedings of the international conference on computing in civil and building engineering*, p 154. https://www.researchgate.net/publication/260056325_Potential_utilization_of_building_information_models_for_planning_maintenance_activities

Then authors illustrated these maintenance activities in the building BIM model assigning specific symbols and colors to the different categories of work (light replacement, ceiling replacement, and other works). Figure 2.8 shows the visualization performed on floors A, 1, and 2 of the building.

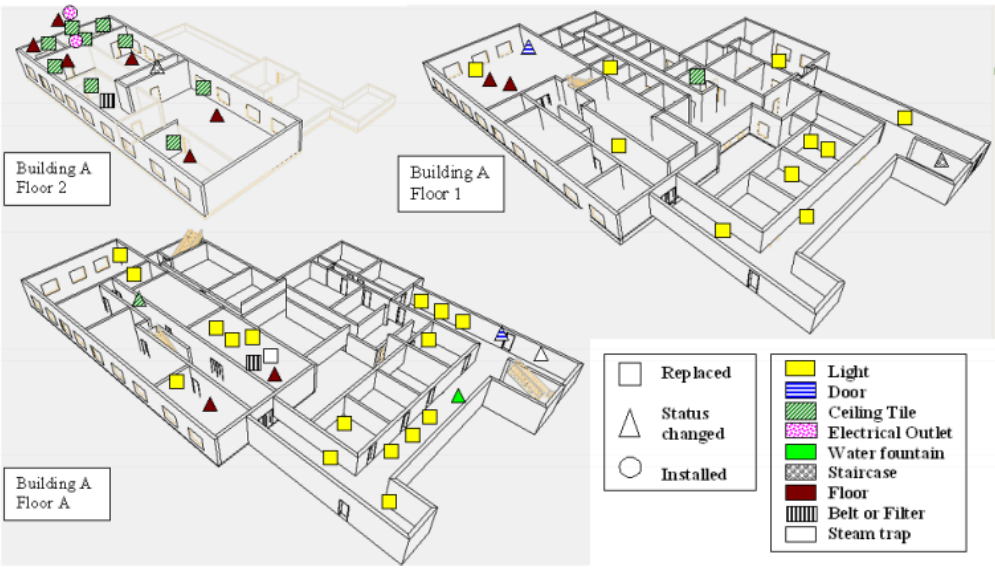


Figure 2.8 Maintenance and repairs from 01.01.2008 to 12.31.2008.

Note. Reprinted from Potential Use of building information models for Planning Maintenance Activities by A. Akcamete, B.Akinci, & J. H. Garrett, 2010, *In Proceedings of the international conference on computing in civil and building engineering*, p 154. https://www.researchgate.net/publication/260056325_Potential_utilization_of_building_information_models_for_planning_maintenance_activities

According to the authors, under the analysis of the illustrated maintenance works in the BIM model, the authors identified four key patterns in repair works, which are the following:

1. ‘85% of the light replacements have been performed in rooms without windows, in the building within which only 25% of all rooms do not have windows;

2. 90% of ceiling tile replacements have happened on floor 2, which is immediately below the roof;

3. 60% of floor cleaning/replacement needed to be done in rooms that have the ceiling tile replacements performed;

4. 80% of the floor cleaning/replacements have happened in labs.”

Based on these patterns, the authors discussed that the first pattern indicates that excessive light changes occurred in rooms with no windows. More replacements occurred as a result of the necessity of artificial lighting. The visual representation of this data may be helpful for designers to provide rooms with windows or design these rooms with energy-efficient types of lighting. The second pattern implies that most of the ceiling replacements occurred due to a roof leak, as 90% of the ceiling tile replacements were performed on the floor below the roof. The third pattern allows tracking of the relation between M&R works, as most of the floor cleaning/change activities were provided in the rooms where ceiling tile changes. It implies that floor cleaning/change activities may be reduced by mitigating ceiling tile/roof issues. It is also applicable for identifying lab usage characteristics and involves the necessity of certain M&R works. Under the study, the authors concluded that there are several barriers to applying this approach. Firstly, this approach requires timely capture of the maintenance data as it is complicated to restore it for the following analysis of these data that was not timely stored. Secondly, modeling any building elements is time-consuming. Of course, using different visualization approaches could be presented without modeling the element. However, in this case, less information will be available for future analysis as some element features and components will not be illustrated in the model. Thirdly, it is required to develop a comprehensive user interface dialog strategy with software because if all the information about M&R activities is presented on the model, it will cause visual overload. So most of the information will be provided by the special user orders.

Thus, as a result of the literature review on the topic forming key concepts could be assumed that safety management in the context of the study assigns the safety risk control through its early identification. Mitigation and control during the operating phase to avoid a possible hazard, including its source, causing mechanisms, severity, and outcome. All the listed measures are part of the safety management system, including safety culture promotion and safety assurance policies implementation. While facility management mainly focuses on the safe and effective management of building space, occupying residents, and occurring processes during the provision of building operation and maintenance activities where maintenance activities are activities performed to keep building elements in proper usable condition while the operation is all the activities occurring in the building except maintenance activities. Regarding BIM discipline, it became clear that key BIM characteristics of BIM in the context of the study are to properly visualize the characteristics of the building for early identification of safety risks and most comprehensively include the functional characteristics of the building to allow future safety manipulations with other plugins and different engines added engines to the platform. The key characteristics of the concepts reviewed are presented in the figure 2.9 below.

Figure 2.9 Characteristics of key SM, FM, BIM concepts related to the scope of the study

Chapter 3 –BIM application approaches to identify BO&M safety issues during the design phase (later BIM application approach).

3.1 BIM application approaches – Literature review

The use of BIM technologies for early identification of possible safety issues at an early stage of design increases its implementation. This approach has already proved its effectiveness and represents the main principle of the DFS concept. This chapter focuses on the Design for Operation and maintenance safety DFOMS. Therefore the reviewed sources focus on identifying safety problems associated with the O&M of the building at an early stage of design. The safety problems themselves are extremely different since the operation period is the longest in duration compared to other phases and, therefore, has a wide range of processes and factors that can lead to injuries to building occupants. Thus, the observed safety checking studies differ in their checking principles and algorithms.

For example, some studies propose the usage of BIM properties to create a space environment of the building to check and simulate possible people's most effective behaviors in cases of emergencies. Nica and Wodyński (2016) studied BIM from the design phase to optimize FM processes in different directions, such as space management, renovation planning, and safety/emergency management. Figure 3.1 illustrates the static simulation of the evacuation procedure from the public building. They highlighted that it is needed to have ready solution pathways established in the model in case of an emergency evacuation. That spatial understandable and available rescue units have a ready solution before arrival. While. Wang et al. (2014) provided a dynamic simulation of possible safety issues. They focused on this direction and proposed the usage of BIM with the integration of virtual reality and game engines to construct a real environment to solve key issues with emergency management. Figure 3.2 illustrates the simulation of the fire situation in the building where the authors used the Unity gaming engine to review possible pathways and use different fire against tools to provide a safe fire escape from the building. Finally, the authors concluded that the proposed method could be used as a real-time evacuation guideline generator in case of fire emergencies. These studies make it clear that possible O&M activities could be simulated both in static and dynamic modes.

Figure 3.1 Modeling the evacuation from the public building

Figure X Retrieved from Nica, A. K., & Wodyński, W. (2016). Enhancing facility management through BIM 6D. *Procedia Engineering*, *164*, 299-306

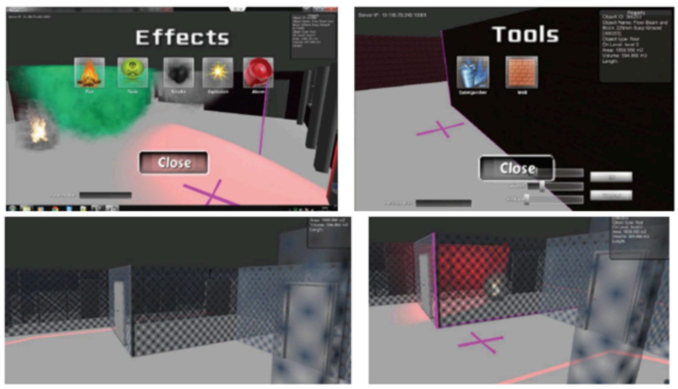


Figure 3.2 Dynamic fire emergency simulation by BIM and Unity server

Figure X retrieved from Wang, B., Li, H., Rezgui, Y., Bradley, A., & Ong, H. N. (2014). BIM-based virtual environment for fire emergency evacuation. The Scientific World Journal, 2014

In addition to these studies, the emphasis was put on identifying problems associated with temporary structures such as scaffolds, which also have a wide application at the stage of a complete overhaul of buildings, when the sequence of installation and finishing of building elements is completely disrupted compared to the construction process when it is possible to pre-assign installation sequence according to its suitability for efficiency and safety. Therefore, scaffoldings are widely used in the repair and reconstruction of a building, which in turn enable access to the necessary elements of the building and provide the necessary protection of workers from falls—the study of Kim, Cho& Zhang. (2016) revealed the importance of planning temporary structures used during construction works and focusing on the scaffolds; they provided a framework for checking the BIM model by ASCS for possible issues that may be involved with the temporary structures. They also highlighted the importance of considering the sequence of scaffolds as it also may cause possible safety risks. They concluded that using the ASCS inserted as a plugin to the BIM software might reveal various safety issues that the project managers may miss.

Hongling et al. (2016), in their study, confirmed that possible design shortcomings in the structural elements of the building could lead to possible safety problems. He mainly focused on the issues related to the construction phase. However, the findings of his study could be paralleled to the O&M phase as the building comprising elements also transfers to the operating phase, and not the identification of these issues could lead to the possible difficulties in the post-construction phase. He found that poor element design can lead to fall injuries and provided algorithms against which the BIM model can be checked. Having generated a list of safety rules associated with the building elements, he integrated it into the automatic-check system. Thus, a system database of rules and codes corresponding to the BIM model elements was formed. They provided an experimental study on four-story buildings, checking the Model in Autodesk Revit and Unity 3D software of possible safety risks related to the design deficiencies in building windows design. The figure 3.3 below illustrates unsafe design factors coming from building windows design and the process of safety checking when the dialog between the user and the checking system is performed by the guideline user interface (GUI) Finally, the authors concluded that the automated DFS approach reduces the time and effort spent on security hacking compared to traditional approaches

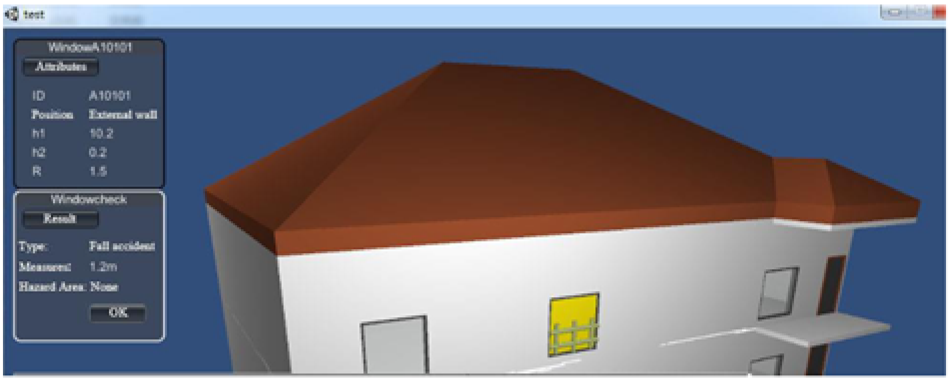


Figure 3.3 Automated Safety Checking of the building elements

Hongling, G., Yantao, Y., Weisheng, Z., & Yan, L. (2016). BIM and safety rules-based automated identification of unsafe design factors in construction. *Procedia Engineering*, *164*, 467-472

In another study, Sydora, C., & Stroulia, E. (2020). Rule-based compliance check and generative design for building interiors using BIM. Automation in Construction, 120, 103368. In his research, he found that some flaws in the interior of the building can also lead to possible problems during the operation of this building. Provided a study of simplified, progressive, and domain-specific language used for the generative design of BIM model interiors.

The proposed language integrates the model checking and generative design capabilities of the BIM platform. According to the authors, some of the deficiencies in the interior may cause difficulties during the operating period. Thus model checking and generative design capabilities of their language may facilitate the problem's solution and automate the process. The picture below presents the experiment results during the BIM model interior checking processes. Takim, Zulkifli & Nawawi (2016) studied the usage of automated safety checking systems for the construction industry in Malaysia. They provided a questionnaire survey among the industry specialists of Malaysia's public and private companies using BIM. They reported that the scope of BIM automated checking systems in the context of safety is much less than its application for automated clash detection and interoperability of BIM objects.

Furthermore, they highlighted that there is still work to be done to develop and integrate such ASCS in the country's construction industry. Liu, & Issa, (2013). BIM also provided a survey that investigated the possible implementation of BIM during the early design phase to decrease the possible issues related to the maintainability of the building elements. They provided a questionnaire survey from industry professionals to study the possible creation of a knowledge database to avoid maintenance issues, the frequency of occurrence of these issues, and the practitioners' perception of whether these risks could be considered in the different project lifecycle.

A study also reviews the solution to maintainability issues by applying BIM technologies during the design phase. Liu, R. & Issa, R. R. (2014) proposed the usage of the Solibri model checker and Revit software to check the BIM model for possible maintainability risks. For the experiment, they tested the maintenance of the exhaust fan. Below in Figure 3.4 is presented the possible maintenance issue for an electrical circuit found through the algorithm of free is in front of the element in the Solibri model checker. The authors concluded that most maintenance issues are neglected during the design phase, and clash detection in Navisworks does not completely cover the identification of these problems. They also mentioned that it was needed to convert the model from Revit into IFC format for checking the BIM model. Unfortunately, after conversion revealed some problems as some of the elements were not recovered after conversion into IFC format.

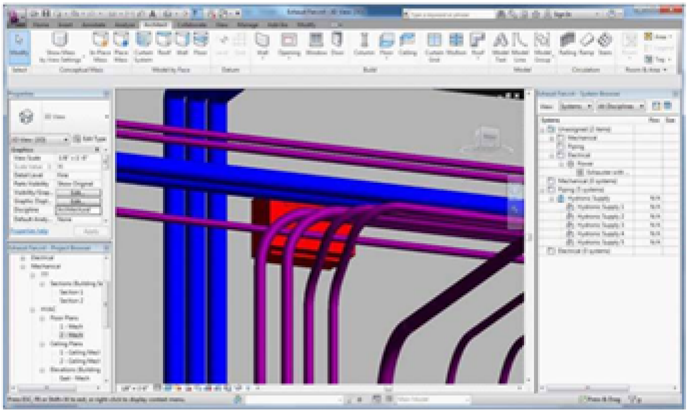


Figure 3.4 Building elements maintainability checking in the Solibri model checker

Liu, R., & Issa, R. R. A. (2013). BIM for facility management: Design for maintainability with BIM tools. In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction* (Vol. 30, p. 1). IAARC Publications

In the study of Akanmu, Olayiwola, & Olatunji (2020) authors reviewed the usage of BIM as a platform where the observer can review the building and check it for possible problems during design through virtual reality. They proposed using the BIM model to solve maintainability issues occurring during the building elements' maintenance. They mentioned that problems with access to them might cause inconvenience for the maintenance process and raise additional safety issues. The figures 3.5 and 3.6 below illustrate the process of the BIM model walkthrough with the involvement of facility managers when were identified issues with building elements' maintainability.

Figure 3.5 Inaccessible light fixture above the stairs

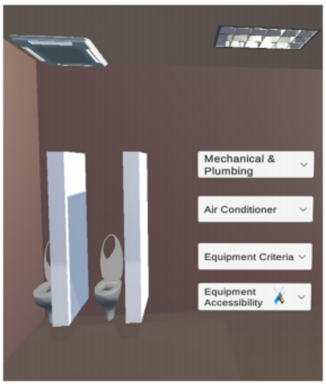


Figure 3.6 Inaccessible air-conditioning system

Note. Reprinted from Automated Checking of building component accessibility for Maintenance by A. A. Akanmu, J. Olayiwola, & O. A. Olatunji, 2020, *Automation in Construction*, *114*, 103196, p.3 https://doi.org/10.1016/j.autcon.2020.103196

In another study, Hu et al. (2018). highlighted the importance of using BIM technologies for the management of MEP elements during the operation and maintenance phase. According to the authors, BIM integrated digitized MEP-related information may increase the efficiency of routine MEP maintenance tasks and security response for MEP causing emergencies, thus facilitating safe MEP system management. They observed the MEP elements' relationship organized in the BIM-based O&M system. The authors also concluded that the system could also be open for integration and storage of maintenance-related data. At the same time, the study by Deng et al. (2019) and Wang et al. (2013) reviews the usage of BIM for spatial analysis of the occurring processes in the building. In their study, Deng et al. (2019) used animation of activity in a BIM platform to simulate emergency management situations for engineering projects. The figure 3.7 below provides the schematic diagram of the accident and emergency; the conclusion is that the animation module could also be used for safety training purposes. Wang et al. (2013) proposed the application of BIM for the simulation facility management activity through a gaming module. They concluded that it might solve the issues with difficulties with workspace allocation. In the figure 3.8 is illustrated the thid-person view of the BIM model walkthrough procedure simulation during maintenance path traveling.

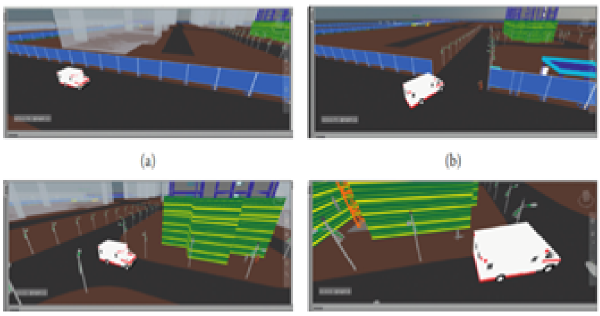


Figure 3.7 Schematic diagram of the accident scene of the ambulance arrival animation simulation.

Deng, L., Zhong, M., Liao, L., Peng, L., & Lai, S. (2019). Research on the application of dangerous sources of safety management in engineering construction based on BIM technology. Advances in Civil Engineering, 2019. https://doi.org/10.1155/2019/7450426

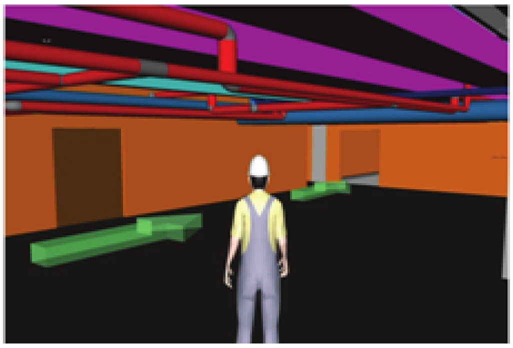


Figure 3.8 Third-person view of simulation maintenance traveling path

Wang, Y., Wang, X., Wang, J., Yung, P. & Jun, G. (2013). Engagement of facilities management in the design stage through BIM: framework and case study. https://doi.org/10.1155/2013/189105

3.2 BIM application approaches – classification.

The literature review identified that there are various approaches to the implementation of BIM-based tools for the SM of buildings during O&M. Before practical testing of these methods, they could be classified according to their common application principles and procedure characteristics. The categorization could be provided through the creation of a simplified logical framework for different BIM application approaches in the context of SM during FM, and it is expected that through analysis of each BIM application approach framework, they could be grouped through common characteristics and patterns involved in the method to certain categories. The general structure of the framework is illustrated in the figure 3.9 below.

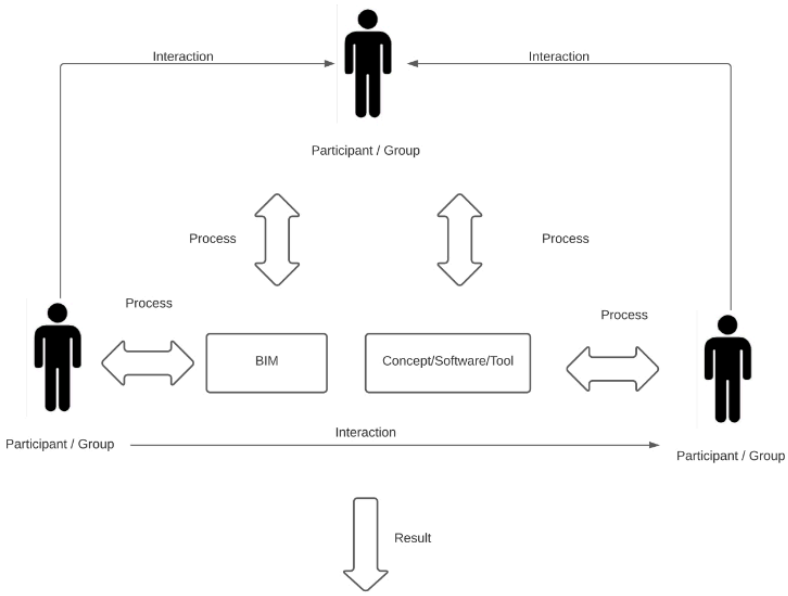


Figure 3.9 Logical simplified framework for checking the Method applicability for Kazakhstan

Where the key components of the framework is illustrated in table 3.1:

Table 3.1 Components of the BIM method diagram

#	Diagram elements	Key features
1	Participating groups	Facility Managers, Design team members, Building owners, Governmental agencies, Contractors, and others.
2	Relationship arrows	The relationship between the participating groups.
3	Concepts	BIM and other concepts, software, BIM plugins, and others (for example, VR, CMMS, CAFM, Visual studio, gaming module).
4	Activities	The processes occurring between the participating group and BIM and other items on an equal level with BIM.
5	Result	Output type

After the provided literature review and the analysis of the BIM application approach frameworks, all the BIM methods were classified into three main groups:

1. Experience-based methods
2. Semi-experience based
3. Rule-based methods

In the first experience-based approach, the BIM platform, in collaboration with different visual modules, for example, VR or AR, serves as a graphical and functional representation of the building to the viewer. A viewer is a person who possesses sufficient safety skills to observe the BIM model and identifies possible safety risks that may occur during building O&M. In this method, the result of safety checking mainly depends on the viewer's experience, which is a reason for calling Experience-based. In the second method, in an attempt to reduce the dependence of the procedure on the viewer experience and increase the quality of checking results, different visual simulators are used to simulate for the viewer possible FM activities. The activities simulation could be provided both in the animation or gaming modules. In this second method, the result of safety checking is divided between the viewer experience and simulation quality; this method is semi-experience-based. In the third final method, to maximize the dependence on the viewer safety experience, they developed a special plugin inserted into the BIM platform that performs automated BIM model safety checking. In this method, the result mainly depends on the rules library in the plugin under which are provided a checking; thus, this method is called rule-based. The simplified logical frameworks for these three BIM methods are illustrated below.

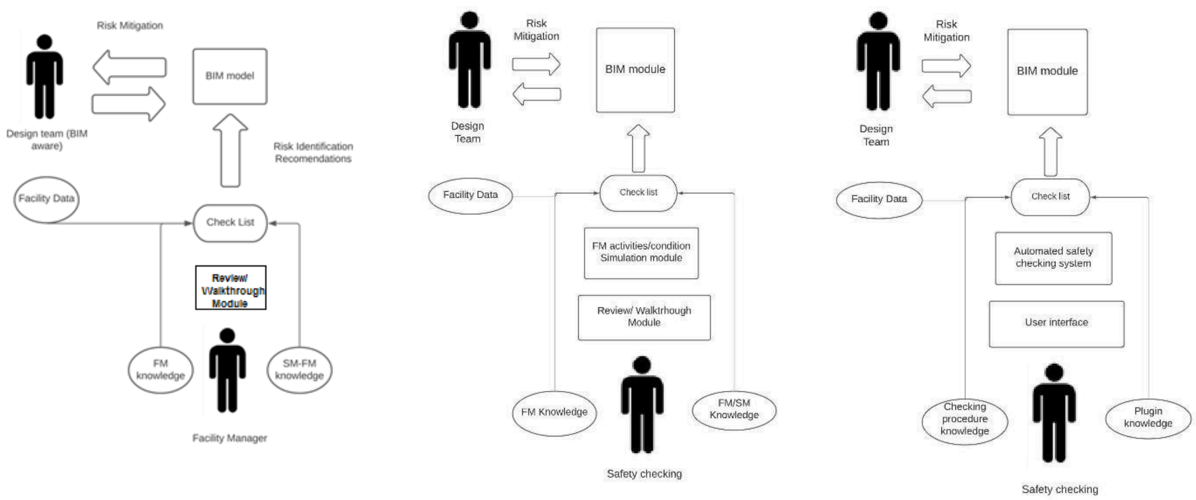


Figure 3.10 Framework of experience-based method b) Semi experience-based framework c) Rule-based framework

It should be highlighted that at this stage of the study, it could be concluded that the third method is the most time-effective and automated type of checking. Generally, the main components of these ASCS could be divided into three parts: 1. Knowledge library – database with safety data 2. The search engine is an engine that provides a checking process based on the knowledge library. 3) Guideline user interface (GUI) - dialogue window that receives the user commands, plots results and performs manipulations with results. The main advantage of ASCS implementation in the design phase is that one of the RM processes covers the early risk identification and mitigation/recommendation before building construction or O&M begins. However, it could be concluded that the knowledge library is the main part of the system and the efficiency of the method is mainly dependent on the comprehensiveness of the included rules library.

3.3 BIM application approaches, experimental testing.

3.3.1 Procedure description

Under the study, a BIM model of the 12 story building on the Revit software will be constructed. There are four elevators in the building by, 2 for each corner of the building. The building consists of the sailboat on the first floor, then 11 floors with dormitory rooms, the technical floor on the roof, and the roof. In the sailboat, the main mechanical room for the HVAC system and different rooms are located for educational and recreational purposes for the dormitory students. On the floors with dormitory rooms, there is a kitchen and electrical rooms. In the floor corridor, shafts are located the ventilation tubes of the HVAC systems. There is an atrium in the middle of a building with all 12 floors. The screenshot picture of the Revit model creation of the building is provided below.

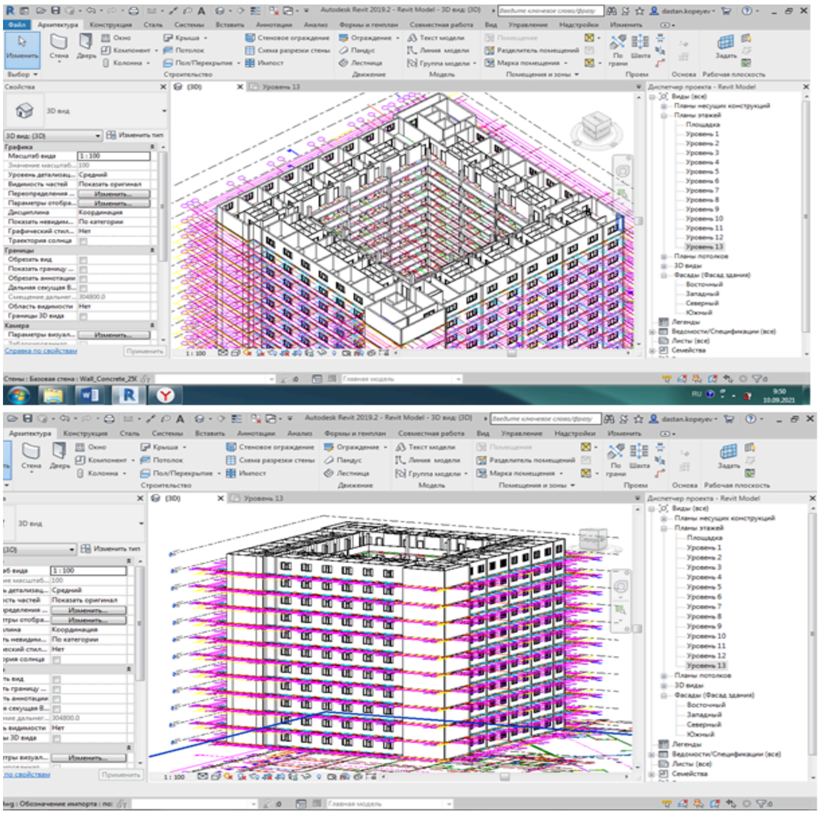


Figure 3.11 BIM modeling process in Revit

The study identified that Sketchup software has better representation characteristics and the model can be transferred to IFC format and opened in Sketch software. Screenshots of the building are provided in the figure 3.12 below.

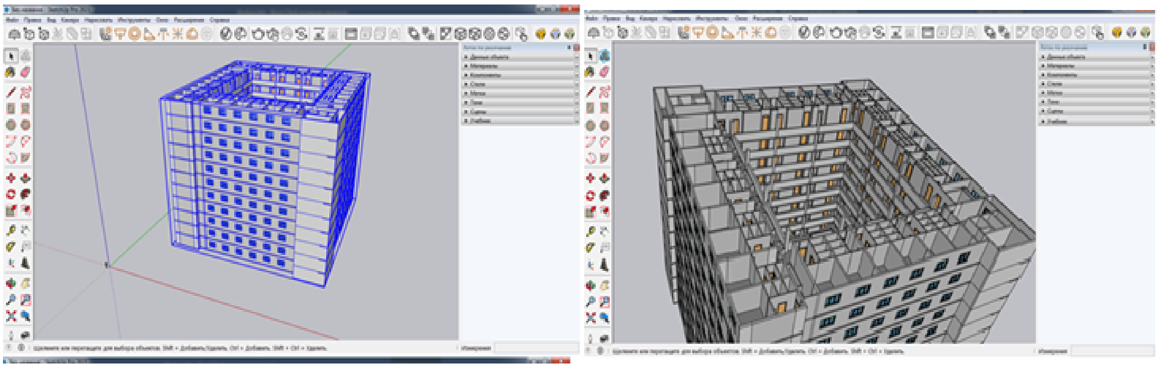


Figure 3.12 Model walk-through process in Sketchup

3.3.2 BIM model check using the experience-based method.

The process of checking by an experience-based method considers model walkthrough in BIM platform software or by using such tools as VR, and AR but without simulating the O&M activities in the model. In the study, the first method was tested by a model walkthrough in Sketch-up software of the converted IFC model of the building. The first method of testing began with the walkthrough of the model in the corridor. During the walk-through, it was identified that two possible issues related to maintenance activity should be taken into account. The first is the possible maintenance issues with decorative elements installed on every floor of the building that possibly will require a cleaning or additional fixing procedure that could cause difficulties due to the element's location right in the space of the atrium. The second issue in the corridor has mentioned the change of lamp in the ceiling that is located near the height difference between the open space of the atrium and corridor parapet. The Figure 3.13 below illustrates the screens of the walkthrough process in the Sketch up software.

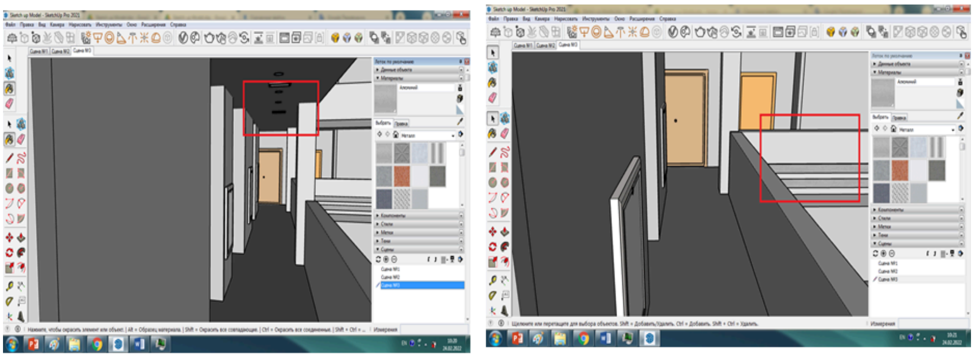


Figure 3.13 Walkthrough of the BIM model in the corridor

Then during the review of the models, the possible issues related to the HVAC element located right above the shower in the bathroom were identified, and the electrical circuit service located above the bed. Regarding the HVAC element, it is located above the shower may cause difficulties with its maintenance as low accessibility to the element may cause additional difficulties during the maintenance process leading to possible safety risks. Regarding the electrical circuit, it would be difficult to service it staying on the bed as it will be higher than the convenient location of hands during the service and thus it becomes necessary to remove the bed to make maintenance work with the circuit. Thus, when planning maintenance work of these circuits, it should be considered that two workers are needed for this process. It requires the removal of the bed to perform the circuit and put the bed in its previous place. The pictures of the location of the HVAC element and electrical circuit in the model are illustrated in figure 3.14 below. However, when observing the model for safety issues, it was identified that the exact likelihood and danger of the process were difficult to identify because of the lack of visual scenes of the dangerous process. And without knowing facility management activities and safety management background, it is difficult to develop a constructive model of safety checking through the walkthrough. Also could be concluded that for this method it is quite important to have a clear checklist as a guide for the walkthrough procedure. But the scope of the study does not include the objective to study the ways to increase the efficiency of the method but to achieve practical experience of the approach for later better quality analysis.

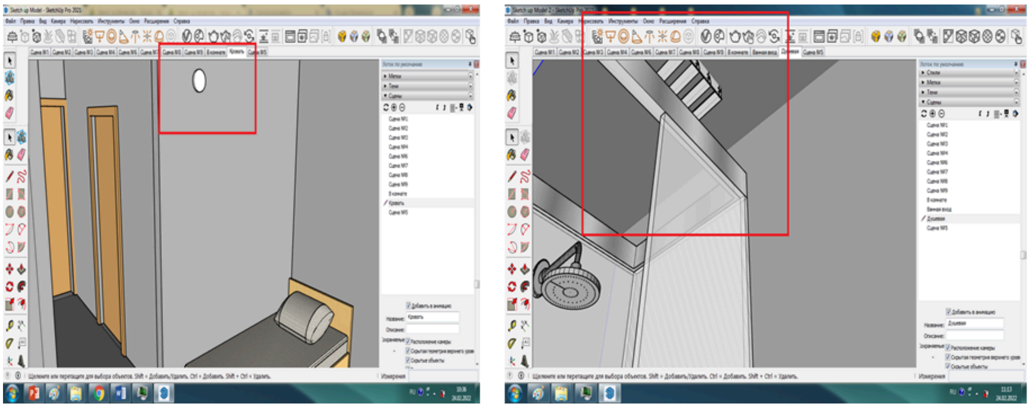


Figure 3.14 BIM model walkthrough in the rooms

3.3. BIM model checking by the Semi experience-based method.

The second semi-experience-based method considers the additional possible O&M activity simulation in the model to acquire a better picture of the possible safety issues identification. Thus the model was checked whether the simulation of the processes would give a clearer picture of the hazard probability and accosted risks with it. Under these considerations, the process of the light change in the corridor was statically simulated, and it became clear that simulation gave a clearer understanding of the safety risks associated with the light-lamp change in the corridor. It was concluded that there was a low likelihood of hazards associated with these maintenance activities. Under this method, it could be concluded that the second method possesses higher efficiency in identifying possible safety issues but requires more time and effort.

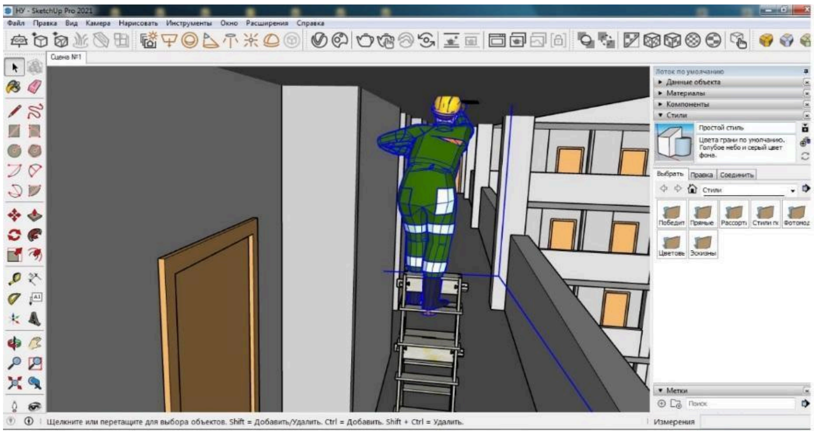


Figure 3.15 Maintenance activity simulation in the BIM model

3.3.2 BIM model check using the third Rule-based method.

The third rule considers model checking in automated safety checking systems such as Solibri or the introduction of special automated checking plugins into the BIM platform. Under the study were provided graphical illustrations of the observed method due to a lack of coding knowledge and access to such software as Solibri. In this method, the maintenance issues were tested because, according to the literature review, the possible element maintainability issues may cause additional safety difficulties. During the walkthrough, it was identified that there are a lot of HVAC elements located in the shafts and also electrical elements located in the ceiling area that needed access for their service and required installation of opening hatches before these elements. It was noted that a large number of these elements makes it difficult to check previous first and second methods one by one, thus it is recommended to check them by automated checking systems. Under the study, the process and algorithm of the checking were graphically illustrated. The algorithm consists of checking each element for the compliance needed free space before the object where when the condition is not satisfied the hindering element was shown by red color in the model. The process of checking could be performed both in the ready checking systems as the Solibri model checker or performing it in the special checking plugins in the BIM platforms. The same approach could be applied to checking the accessibility of the HVAC element located above the shower that was identified during the walk-through of the model's room. The graphical illustration of the automated approach is illustrated in figure 3.16 .

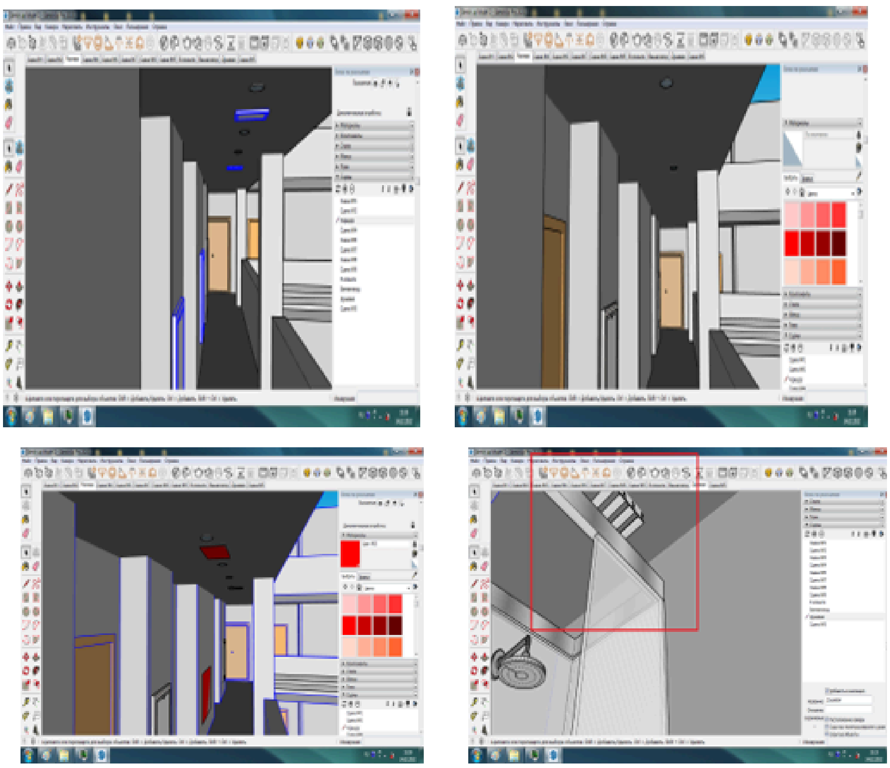


Figure 3.16 Graphical representation of the algorithm of ASCS working procedure

Even the automated checking method proved effective for these repetitive types of checking. However, it was difficult to illustrate how it could be applied for such checking cases as the change of lamp in the corridor process. For example, if the second method was effective for checking this activity, some comprehensive coding approach for checking this issue by the rule-based method would be needed. Thus, it could be concluded that the rule-based method proved its effectiveness in checking for some repetitive safety issues but the second simulative approach possesses higher efficiency as it gives a comprehensive picture of possible safety issues. However, a simulative approach requires more time than the walk-through or automated approaches.

Chapter 4 - Review of key components of Kazakhstani AEC/FM industry

4.1 BIM adoption state in Kazakhstan

According to Talapov (2018), the BiIM adoption in Kazakhstan began in 2017 when the Concept of BIM implementation was created that assigns main goals and objectives and determines key milestones of the BIM adoption process in the country. Concepts assign the BIM adoption process to a key phase between 2017-and 2022. From the concept, it becomes clear that Kazakhstan is currently in the BIM adoption process, and to identify the current scope of BIM usage in the country, the adoption phases can be reviewed more deeply. The main BIM adoption process could be divided into three main phases: 1. Preparation 2. Standard and regulative base formation and 3. Practical implementation. Analyzing the current state of BIM in the country, it may be mentioned that the first phase contributed to the BIM adoption concept creation and Kazakhstan in the second and third phases of the BIM adoption. In terms of the standard and regulative base, there are also clear achievements in this direction. KazRICA has already provided 12 regulatory documents dedicated to the management of information models creation and their usage throughout the construction object lifecycle. It means that BIM is going to be implemented not only in the design creation or construction phases but also in the building operating periods. For example, 2 of the 6 main implementation strategies assigned in the concept contributed to the facility management processes. The concept targets 6 main objectives and 5-6 of them mainly relate to the facility management discipline: 1. To generate main strategies of BIM adoption in the construction sector of the country 2. Generate a better environment for collaboration between the project stakeholders 3. To form transparent approaches for cost formation policies in the sphere. 4. Define the key stages of the implementation of information modeling in the country's construction sector. Generate the approaches for the formation of main key milestones of implementation of BIM in the sphere of building O&M. 6. Form favorable conditions for O&M experiences (in terms of data storage and analysis) to create better decisions during the creation of standard and regulative bases in the sphere of building O & M. It is assumed that the main standard base in the context of informational modeling sphere will play a crucial role on evaluation of the applicability of certain BIM-based approach for SM during building O&M, thus in the literature review section, some main principles of the approved standard in the usage of BIM in the facility management in the country. The Institute of Construction and Architecture of the Kazakh Scientific Research and Design has already posted approved standards for BIM implementation throughout the lifecycle of the project were assigned the main procedures of the design information transfer to the building operating side while the main features of the BIM during the O&M phase are assigned in the standard SP RK "Application of information modeling in the operating organization".According to the standard, the BIM model should be transferred to the operating companies and could be used for Service, Maintenance, Repair, Major overhaul, and renovation purposes and assigns four types of works with BIM information as

4.2 Building design procedure in Kazakhstan

In the beginning, to analyze the applicability of the method, it is needed to identify the scope of the study. The first step is to formalize the term of the building and its borders in the scope of the study. In this study, the focus is exclusively on civil buildings, namely public and residential buildings. According to SNiP 1.01-32-2005 "Construction Terminology" 1.01-32-2005 " Building – is an artificial facility which consists of load-bearing and building envelope structures that form a facility with ground adhered closed volume and which according to the functional purpose is used for people living staying or performing production processes, as well as the storage of material values". The regulative standard subdivides the main two types of buildings, Industrial and Civil. Industrial buildings accommodate industrial and agricultural production and provide the necessary conditions for people to work and operate technological equipment. At the same time, civil buildings are subdivided into public and residential. Residential buildings - apartment buildings for permanent residence of people and hostels for living during work or study. Public buildings are public buildings and structures intended for social services to the population and the placement of administrative institutions and public organizations.

After we have decided on the term of a building, it is necessary to designate the boundaries of the building since when designing buildings, the building project also includes a functional package that carries out its normal operation. For example, during the main building design, simultaneously building landscape design and building engineering communications. However, there may also be buildings or networks indirectly related to the building, such as additional buildings on-site, off-site networks, or off-site landscaping. Figure 4.1 illustrates the borders of building-related structures in terms of the scope of this study. However, this research only considers on-site networks and building on-site landscaping only in terms of their possible impact on the safe operation and maintenance of the building.

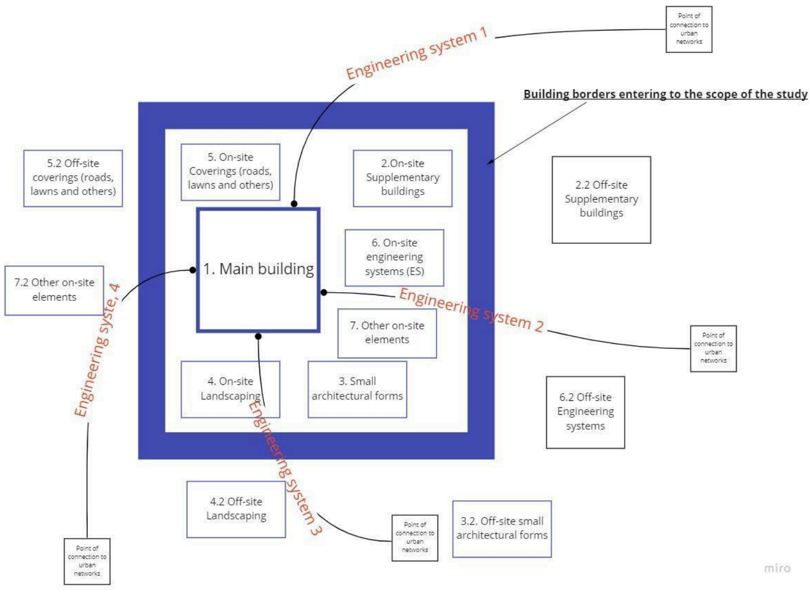


Figure 4.1 Building borders entering the scope of the study

Then secondly, it should also clarify the understanding of the operational period of the building in terms of the construction project lifecycle. According to SP RK 1.02-112-2018 Life Cycle of Construction Objects, which Kaz RICA developed, the life cycle of any construction object is divided into three stages: 1. Creation of a construction object which includes pre-design, design, and construction phases, 2. Operation of a construction object and 3. Completion of the existence of a construction object. As can be seen from figure 4.2, the design process consists of pre-project preparation. This study examines the impact of the entire design process, including pre-design preparation, on safety during operation, including all 4 subsections. Figure 4.2 illustrates the approximate relation between predesign and design and operation and maintenance stages.

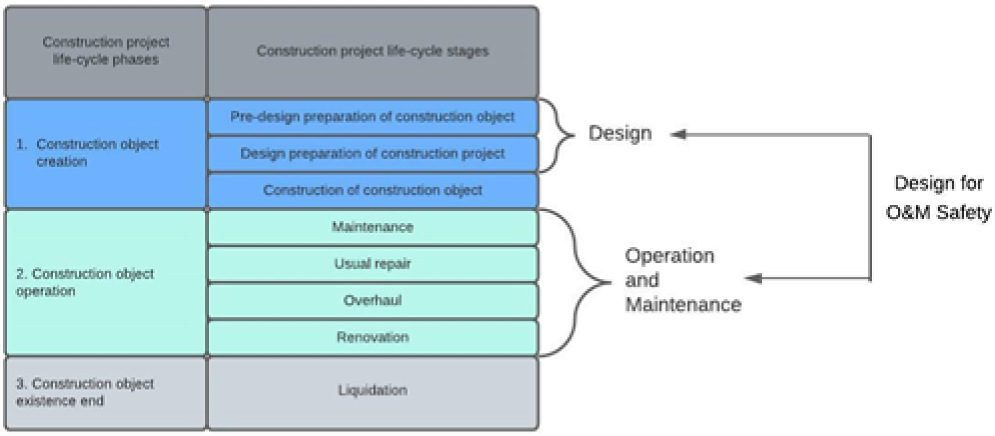


Figure 4.2 Design for operation and maintenance safety

SP RK 1.02-112-2018 LIFE CYCLE OF BUILDING OBJECTS
https://drive.google.com/file/d/1rfIYziRKWyy6ETYYduOZI7QexN_ydEWu/view

4.2.1 Obtaining land permits

To have a comprehensive picture in the context of this scientific work, the entire process up to the construction stage related to the building cycle was reviewed. According to the diagram about the concept of the terminal building, it can be understood that the building itself has an external common area, which will have to be maintained during the operation and the parameters of which may also affect the operation of the main building itself. Therefore, in this context, it is also necessary to consider the process of assigning the location of the building site, the property of which can affect maintenance processes during the operation and maintenance. The very first stage begins with the decision on the need to build a building. According to the law "Provision of a land plot for the construction of an object within the boundaries of a settlement (2015) obtaining land consists of two stages, the first is obtaining an act of choice land for the construction of a building where the customer fills out an application and uploads it to the E-Gov portal, that is, an information system that is a single-window for access to all consolidated government information, including the regulatory legal framework, and to public services, provided in electronic form. In the context of the permission for land disposal procedure, the government coordinates the process with the authority in the field of architecture and construction of the region that coordinates the location of the object. The customer sends an application through the e-government portal that attaches an application for the selection of a specific plot of land for construction, which attaches a situational diagram of the proposed construction site. After receiving an application from a customer through the E-Gov portal, the regional body in the field of architecture coordinates the possibility of locating this building by coordinating enterprises such as users of city networks of water, electricity, sewerage, and communication networks, an agency of ecology, power plants, etc. In the event of the approval of the customer application, the act of choosing a land plot is generated. The location of the site with its boundaries and situational land is indicated. Also, the act of choosing a land plot contains the address of the location of the site and the approval of communal city network supply organizations that permits connecting the building to the main city utilities such as water supply (sewerage) heat supply gas supply electricity supply and others. Figure 4.3 illustrates the fragment of the act of choosing and plot.

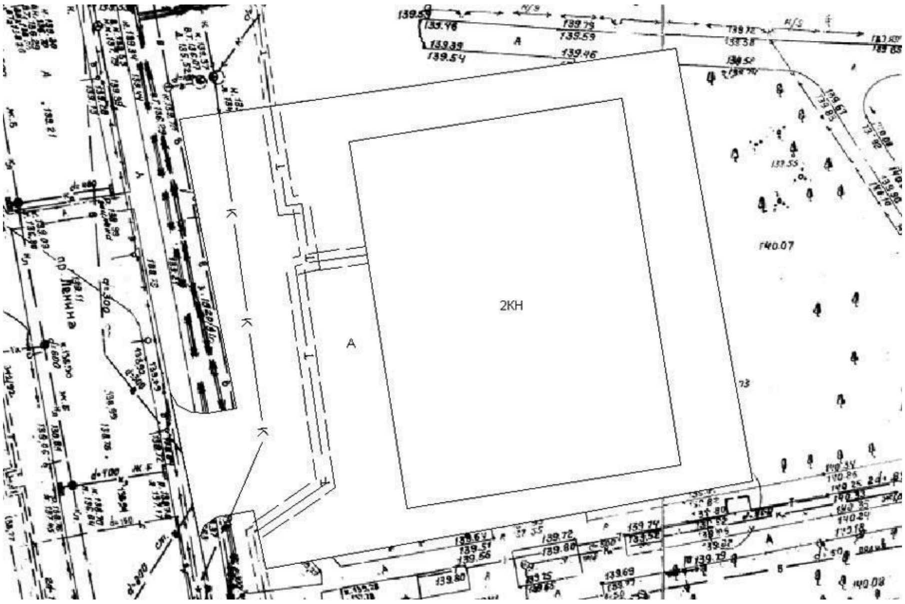


Figure 4.3 Fragment from the act of choosing a land plot
Appendix No. 3 of the law On approval of forms of documents when providing land plots for the construction of facilities within the boundaries of a settlement
https://adilet.zan.kz/rus/docs/V1400009952

In the second stage, as the building location has been established, the customer submits to the portal of the state corporation a request for obtaining a cadastral land plan and a land lease agreement. At this stage, the E-gov portal sends the request of the customer to the regional authority in the field of architecture and construction, which coordinates the location of the object with authority in the field of land relations, which prepares the cadastral land plan and the lease agreement after the completion of this procedure, the location of the building is considered fixed. The data on the cadastral plan of the customer's land is being introduced into a single automated system of the state land cadastre. Each plot has its boundaries and a unique identification code corresponding to the document issued by the land cadastral plan. Figure 4.4 illustrates the plan of the location of the land plot in the land cadastre survey.

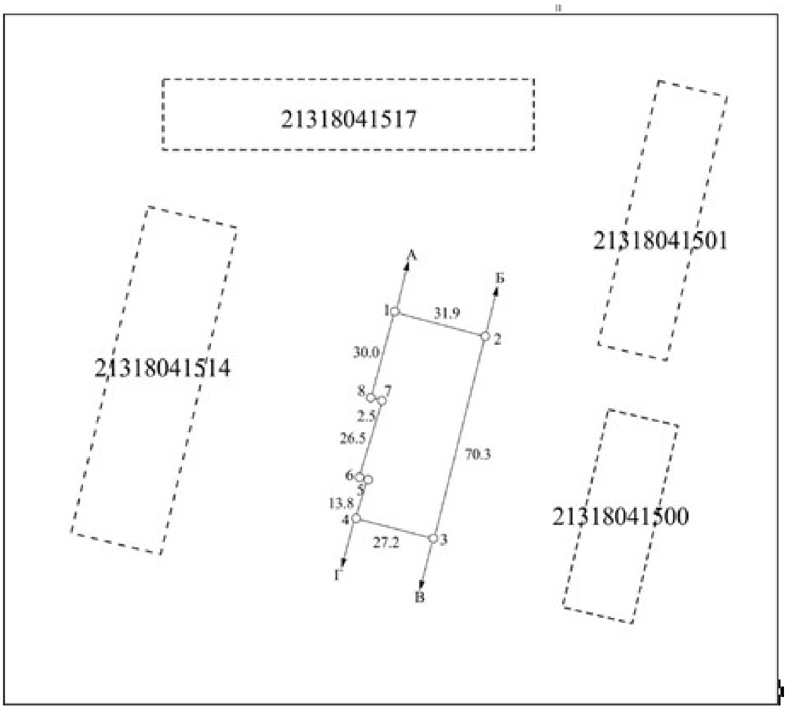


Figure 4.4 Plan of location of the land plot in the land cadastral survey

dated November 5, 2014, No. 67 (https://adilet.zan.kz/rus/docs/V1400009952)

The important aspect of this stage is when the future location of the building is assigned. As a result, it assigns how the building will be connected to the city networks and maintained. It should be noted that the nearby surroundings can affect the safe operation and maintenance. Also, like the location and network connection way is already assigned in this stage the design team in the initial stage of the design has to deal with limited decision scope. Thus it could be assumed that consideration of safe maintenance of the building at this stage also could affect to this stage future operation and maintenance of the building to some extent but the real scope of the influence is still not identified. From the drawing on the map of the land cadastre, we understand that the location of the plots is carried out exclusively in 2D format. However, considering if all the new buildings will be provided in BIM format including its exterior infrastructure it may lead to gradual BIM digitalization of each building in the city can lead to the creation of a BIM twin of the entire city. This situation can provide an opportunity to identify possible problematic issues related to further building maintenance coming from exterior parts of the adjacent building and connection to the city supply networks earlier in the pre-design phase.

For example, according to the Department of Digitalization of Public Services of the city of Nur-Sultan, “The creation of a geographic information center of the city of Nur-Sultan was completed using the digital twin of the capital. In total, 801 km2 of land plots of the capital were digitized with an accuracy of 3 cm per 1 pixel. Fully built digital terrain and relief models of the city are built 100% 2D and some of them are in 3D models of the built-up part. More than 16,000 km of engineering networks have been digitized. As a result of engineering and geodetic work, about 144,000 wells of main and intra-quarter networks were filmed. Also, internal processes in terms of land relations, architecture, and urban planning have been automated. However, the real applicability of the digital twin on an urban scale for the safety of the operation of buildings has not yet been determined. The land cadastre is used in Kazakhstan only in 2D format with a numerical indication of the terrain, as shown in Figure 4.5.

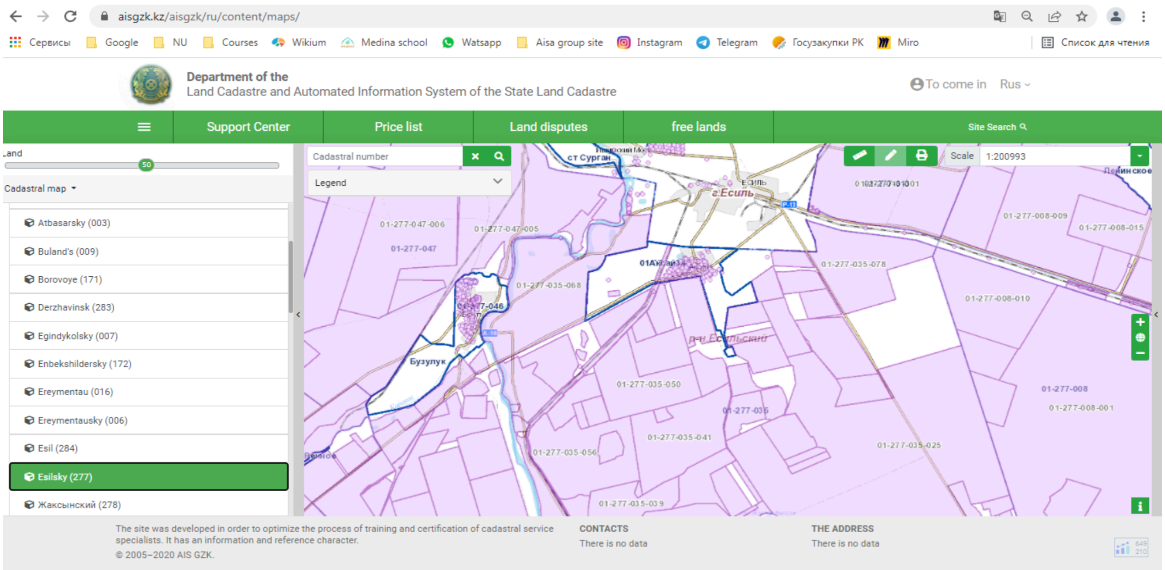


Figure 4.5 Online cadastral map of the city building (2D digital twin of the city buildings)

https://aisgzk.kz/aisgzk/ru/content/maps/

4.2.2 Obtaining initial data for the design and approval of the sketch design and coordinating the sketch design

According to the ‘Regulation on the approval of the rules to organize development and passing permitting procedures’, the next step is to obtain an architectural planning task and technical conditions to connect to city networks. Connection requirements are issued by local operating communications authorities for various networks such as water supply networks, heat supply, sewerage, communication networks, etc. These authorities, under the location of the building and the location of the near connection points to their communications, provide technical conditions for connecting to the city networks that the customer will have to adhere to during the design of the facility. According to these connection requirements, these services will accept the designed and built networks to add these networks for their responsibility for future operation and maintenance. At this stage the architectural planning is issued by the regional body in the field of architecture and urban planning assigns a task, which, under the detailed city planning plan and the functional features of the building, gives the task of the key architectural characteristics of the building that the customer will have to adhere during the design phase. Then, after construction ends, the authority will accept the building into the operation and maintenance phase. However, the main external characteristics of the building are approved at the next stage of approval of the sketch design. According to the law on approval of the rules for organizing development and passing permitting procedures,

Design sketch preparation and approval are also important in the pre-design phase 9see figure 4.6). According to the regulative base, "Sketch design is a simplified view of the design (planning, spatial, architectural, technological, constructive, engineering, decorative or other) solution, made in the form of a diagram, drawing, initial sketch (drawing) and explaining the intent of this solution". It outlines the key architecture and design solutions of the facility as key building material types for facades and finishes, location of the external infrastructural elements and building plans, sections, and façade views. Thus is clear that the building exterior elements later also will require their maintenance and thus possible inaccuracies in considering the types of the exterior elements, their locations and other characteristics may cause difficulties during their design, construction, and O&M in the context of the safety management. Thus, a possible BIM application in this pre-design phase should also facilitate further safety during the building operation and maintenance.

Figure 4.6 Fragment of the sketch project

Adapted from https://astana-pro.kz/eskizniyproekt/#image-2

4.2.4 Design stage and non-departmental enterprise of examination of design projects

According to the BIM adoption concept in Kazakhstan, it is expected that initially, the BIM implementation will begin in public buildings for a high and medium level of responsibility, which means that the design of these buildings could be performed only by medium and licensed first-degree design companies not allowing small design companies to participate in it. Also, concerning the BIM application, currently, the country has opened different private educational centers and provided training of government expertise of construction project department personnel. The Republican state enterprise "State non-departmental examination of projects" informed about the training of their personnel on informational modeling for different regions of the country as Mangistau, Aktobe Atyrau, WKO, SKO, Kyzylorda, Zhambyl, Almaty regions, and Almaty and mentioned that the educational service provider is "StroyDevelopment" LLP, which has the status of a partner in the sale of the licensed software and an authorized training center of Autodesk Corporation in Kazakhstan. (see Figure 4.7). The 'StroyDevelopment' LLP company began to train government professionals in Autodesk software products as Autodesk Navisworks Manage software complexes. The mentioned software also should be considered while observing the different BIM application approaches as it became clear that the main governmental departments of the design project inspection in the country's personnel begin their education mostly on this software. Also according to The Republican state enterprise "State non-departmental examination of projects" the implementation of automated design checking software as CoreNet company software could be applied in the design inspection procedures and may improve the efficiency of the department activities (Republican state enterprise "State non-departmental examination of projects").

Figure 4.7 BIM technology training for governmental expertise personnel in Almaty and Atyrau. Adapted from 'Republican state enterprise on the right of economic management', 'State non-departmental enterprise of examination design projects'.
http://www.госэкспертиза.kz/node/5439

On 2 February, RSE Go Expertiza started a program to train enterprise experts in modern software products Autodesk Revit and Autodesk Navisworks, which implement BIM (building information modeling) building information modeling technology. The goal of the program is the desire to study modern technologies, as well as opportunities to improve the quality of projects. The training was conducted by one of the leading teachers of Autodesk in Russia and the CIS - Alexander Vysotsky, General Director of Visotskiy Consulting LLC (St. Petersburg), together with StroyDevelopment LLP, an authorized partner of Autodesk. While working in a new environment for themselves, the experts of RSE "Gosexpertiza" noted a significant potential for increasing labor productivity through the usage of this technology. In addition, it was proposed to encourage domestic design companies to create projects using BIM technology. In the process of training, experts performed independent work of varying degrees of complexity, based on models of real construction projects. At the end of the course, students were issued internationally recognized Autodesk certificates in a solemn atmosphere.

4.2.5 Key processes in the building design phase

BPMN diagram creation illustrating key processes and stakeholders' interrelations during the design phase (including pre-design and design stages) was provided under the provided literature review (see figure 4.8) . As an important process where the possible BIM application in the context of the safety BO&M safety could be considered, two processes in the pre-design stage and one in the design stage. The processes in the pre-design stage are first is the creation of technical requirements by city engineering networks supply enterprises that assign the key routes, connection points, and characteristics of how city networks will supply the building. The second is creating and approving the building sketch design when all the exterior elements' location and exterior building materials are assigned. The third process contributes to the design phase. It is considered the most important because, in this stage, the complete design project of the building is emanated and approved by the state non-departmental enterprise of design projects examination.

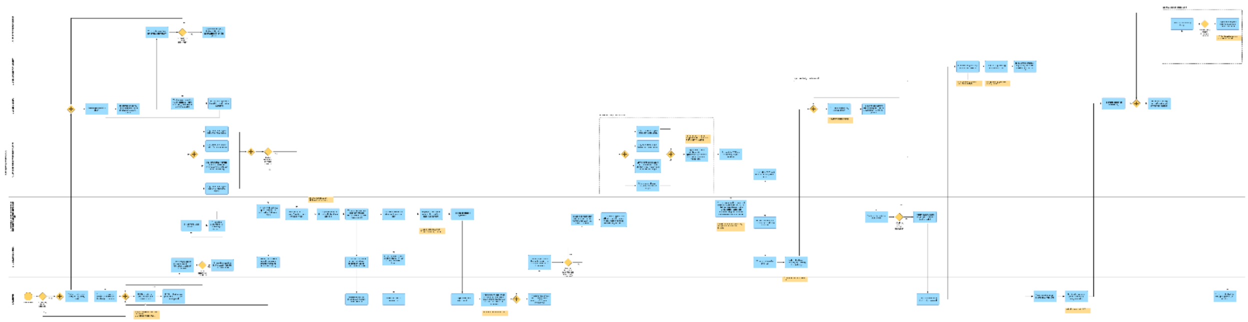


Figure 4.8 Key processes for SM during BOM considerations

4.4 Facility Managers in Kazakhstan

During the previously provided literature review, it was identified that facility managers could also could be involved in the process and can play a crucial role in facilitating early safety issues. Thus, there is an important review of the Kazakhstani facility managers' expertise to consider their ability to properly participate in the BIM processes. If considering building management specialists in the context of Kazakhstan, they are usually broad-based specialists with a wide range of responsibilities that includes not only the maintenance of the building in proper condition but for provision of safety requirements of these activities and possesses qualification requirements for safety knowledge. For example, consider the case of a public administration building. Depending on the type of building, the "typical staffing of employees of state organizations of the Republic of Kazakhstan" appoints a certain staff of employees who are aimed at maintaining the building in a suitable condition. For example, it assigns staff for the building of post-secondary special education (number of students over 1121 people) 33 types of specialties from different fields among them also the staff assigned for facility management: 1. Deputy Director for Facility Management (ZavHoz in Russian) Affairs - 1 person. 2. Head of Facility Management (including warehouse) -1 person 3. Workers for maintenance and current repair of buildings (for each building) - 2 people. Also, according to the Qualification Handbook of the positions of managers, specialists, and other employees, the two key facility management employees, the Deputy Director for FM Affairs and the Head of the FM, possess these types of duties. "They supervise the supply and maintenance of the organization or its divisions. Ensures the safety of household equipment, its restoration, and replenishment, as well as the observance of cleanliness in the premises and the adjacent territory. Monitors the condition of the premises and takes measures for their timely repair. Provides employees with office supplies and household items. Supervises the work of the service personnel. Ensures that employees comply with safety and labor protection rules, industrial sanitation, and fire safety requirements". As could be noticed the facility managers have a wider range of responsibilities assigned by the regulations. They should also have these experiences. “Legislative and other regulatory legal acts of the Republic of Kazakhstan concerning the economic services of the organization means of mechanization of labor of service personnel, rules for the operation of premises, the basics of labor organization, labor legislation, internal labor regulations, industrial sanitation, fire safety requirements. Qualification requirements. And work experience in household services for at least 1 year or general secondary education and work experience in household services ‘ In reviewing service workers, according to the ‘Unified Tariff and qualification reference book of Jobs and professions of workers of the Republic of Kazakhstan’, they have these kinds of qualification requirements: ‘the secondary education or technical and vocational education and work experience in the specialty of at least 2 (two) years. The duties of which entail carrying out work on the proper maintenance and operation of buildings, structures, structures, adjacent territories, and other real estate objects located on the territory of the employer and its structural divisions, including regularly scheduled inspection of the technical condition of real estate objects; performance of related works”. Reviewing Kazakhstani state enterprises building facility managers' responsibilities and qualification requirements implies that facility managers are specialists in a wide range of facility management skills and could have important knowledge applicable for the study or application during the design phase by the design team.

Chapter 5 – Questionnaire survey results

5.1 Questionnaire survey - description of the procedure.

To receive information on the current state of BIM implementation for SM during O&M in the country and the perceptions of industry professionals on possible barriers and effective strategies in BIM application in the observation direction, an online questionnaire survey. The survey was carried out in the Qualtrics platform, which has sufficient options to construct the types of questions and to retrieve the results in the required form. The scope of the survey encompasses all regions of Kazakhstan. After the preparation of the survey questions and generating anonymous links the survey companies' list was created on the data from the 2GIS platform and the survey was distributed to the companies and companies' employees through email, LinkedIn social platform, and WhatsApp. At the end of a survey, the results were retrieved from the Qualtrics report option. The figure 5.1 illustrates the key steps of the questionnaire survey procedure while figure 5.2 illlustrats the fragments of the consent form and questions of the survey.

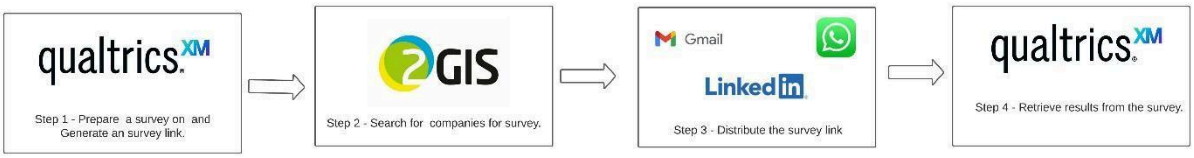


Figure 5.1 Key steps of the questionnaire survey

The survey link was distributed to 489 employees from 196 pre-design, design, construction, and operating companies. Survey participants are architects, BIM specialists, civil engineers, design engineers, facility managers, HSE specialists, etc. At the end of the survey, 157 responses were received, but only 118 of them answered until the 15th question and only 103 finished the survey. Thus the response rate of finished surveys comprised approximately 23%.

Figure 5.2 Conducted online survey: Consent form page (on the left) and question page (on the right).

https://nukz.qualtrics.com/jfe/form/SV_9vJTDu6jPmpsi2O

5.2 Participants in the questionnaire survey

The application of BIM for BOMS is related not only to the FM phase but also to some earlier phases such as pre-design, design, and construction because some solutions and actions performed during those phases may also influence the safety performance during the O&M phase. The majority of the respondents were almost equal, 36% and 30 indicated their organization type as construction and design, then 13% indicated facility management, and 8%, 7%, 6% were from the client, engineering survey, and other organization types respectively. The results also demonstrated that 46% of the respondents performed roles as industry engineers, 8% as BIM managers, and almost equally approximately 10% as architects, project managers, safety engineers, and others. The least share was contributed to the upper management and facility management and specialists comprising only 2% and 1%, respectively. Among the 13 respondents with other roles in the company was a product technician from Autodesk software selling company, an instructor from an educational center organization, a design drafter, two design engineers, a site engineer, a planning engineer, a block manager, a coordinator, and a construction supervision consultant. More than half of the respondents are from large companies (57%) while medium and small companies are 23% and 20% respectively. One of the possible reasons for the dominance of people from large companies could be that during the preparation of the list of companies, a preference was made for companies that had an official site registered on the 2GIS platform.

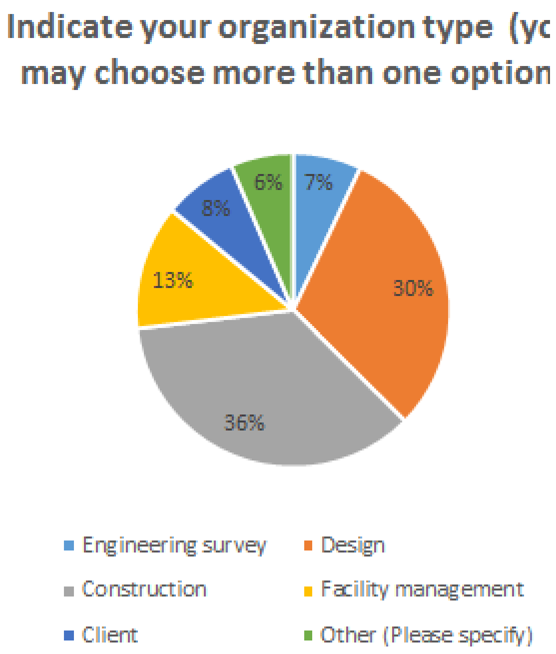


Figure 5.3 Organization types of respondents

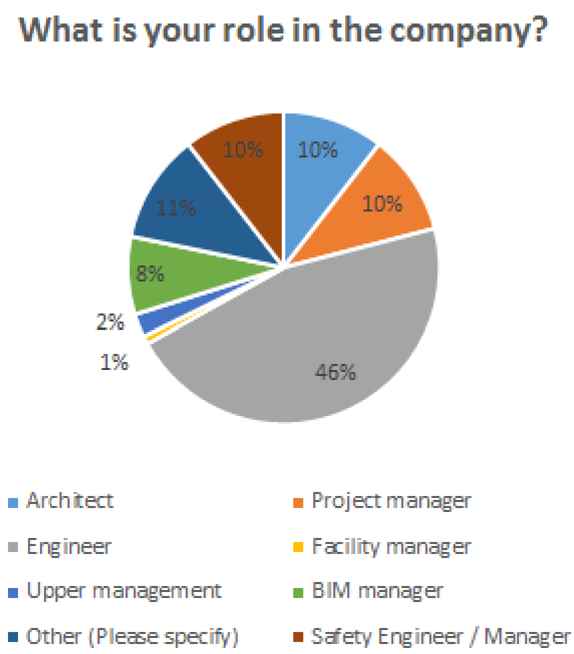


Figure 5.4 Respondents' roles in the company.

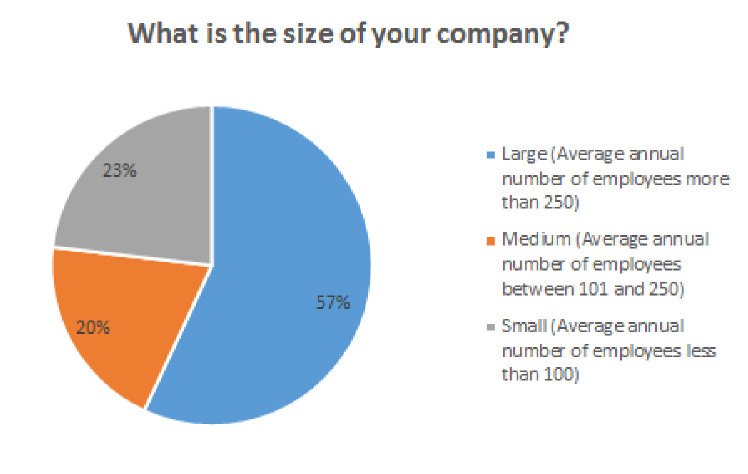


Figure 5.5 Respondents' company size

5.3 Work of the respondents and BIM experience

During the survey, participants were asked about their work and BIM experiences. Most of the respondents (47%) had 3-10 years of work experience, 29% between 10 and 25 years, and 21% with less than three years of experience. Also, there were 3% of respondents without industry experience and no respondents with experience of more than 25 years. Regarding the respondents' BIM experience, 43% of them had less than 5 years, 13% between 5 to 10 years, and 40% with no BIM experience while only 4% had BIM experience of more than 10 years.

Considering the integration of BIM technology into the country, the 2017 survey shows that 28% of the respondents began using BIM before 2017 and 72% after. The prevalence of BIM usage after 2017 among respondents also was noticed in the study of Akhmetzhanova et al. (2022) where the share of BIM implementation in recent three years and before 2017 were 59% and 41% respectively. Correlating the respondents' BIM experience according to their company size some points could be mentioned: dominates the share of respondents with BIM experience and no experience in the large and medium companies is almost equal while in the small companies the number of BIM experienced higher in large and medium enterprises, the share of respondents with BIM experience between 5 and 10 years higher in the small enterprises' respondents than in large and medium respondents. Regarding the correlation according to the respondent's roles in the company: the share of the BIM experienced respondents is slightly higher than with no experience respondents among industry engineers, among architects, project managers considerably dominate the share with BIM experience while among safety engineers dominate the share no experienced respondents, among other this share almost equal while all the BIM manager and upper management respondents had BIM experience.

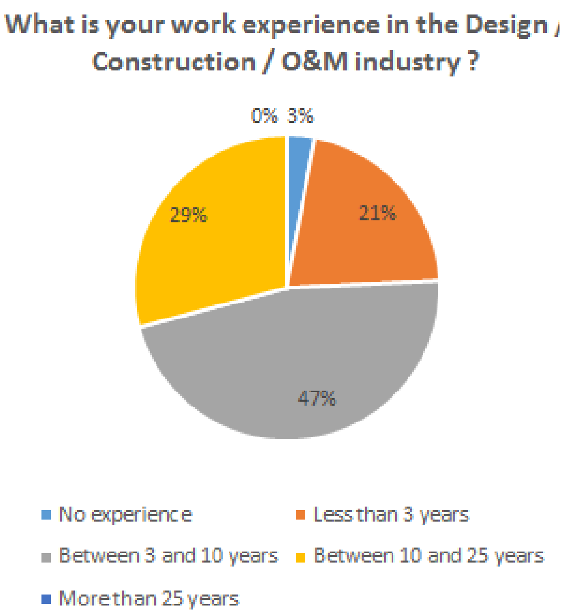


Figure 5.6 Respondents' work experience

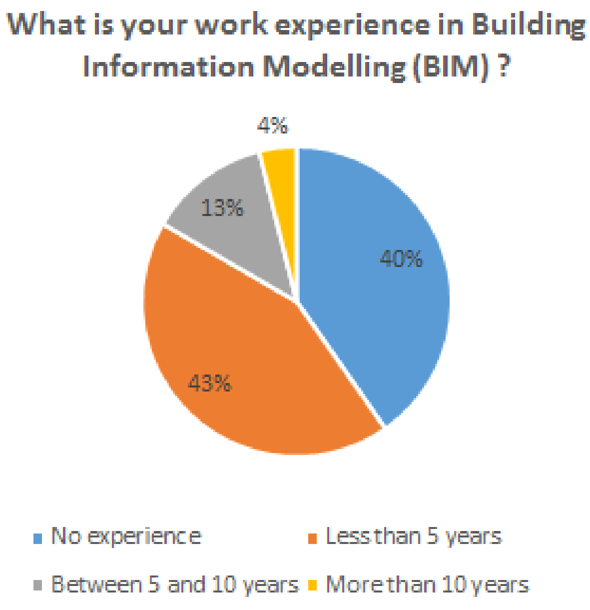


Figure 5.7 Respondents' BIM experience

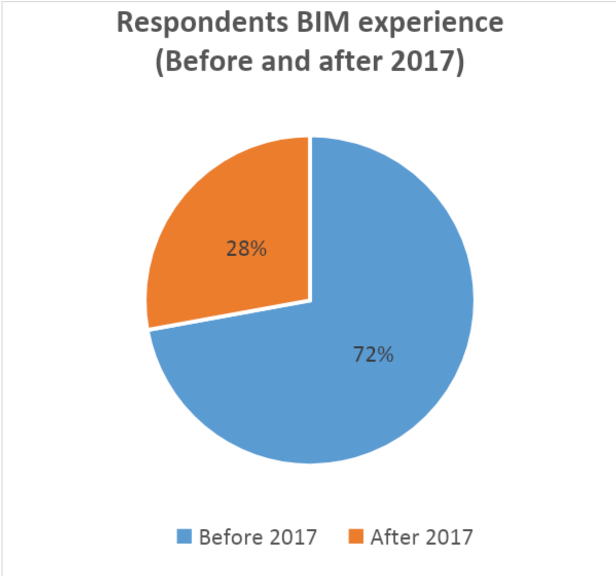


Figure 5.8 BIM experience (Before and after 2017)

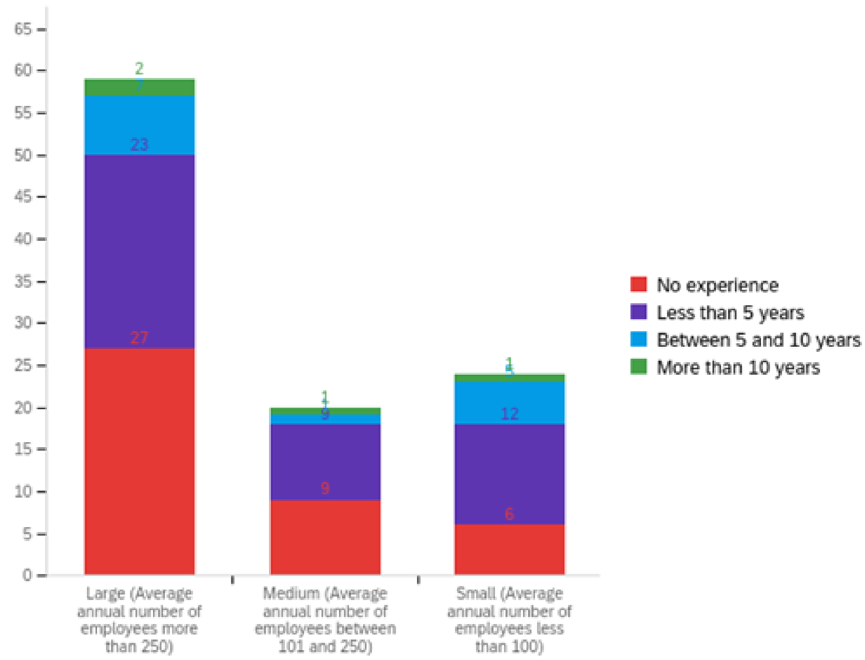


Figure 5.9 Respondents' BIM experience according to company size

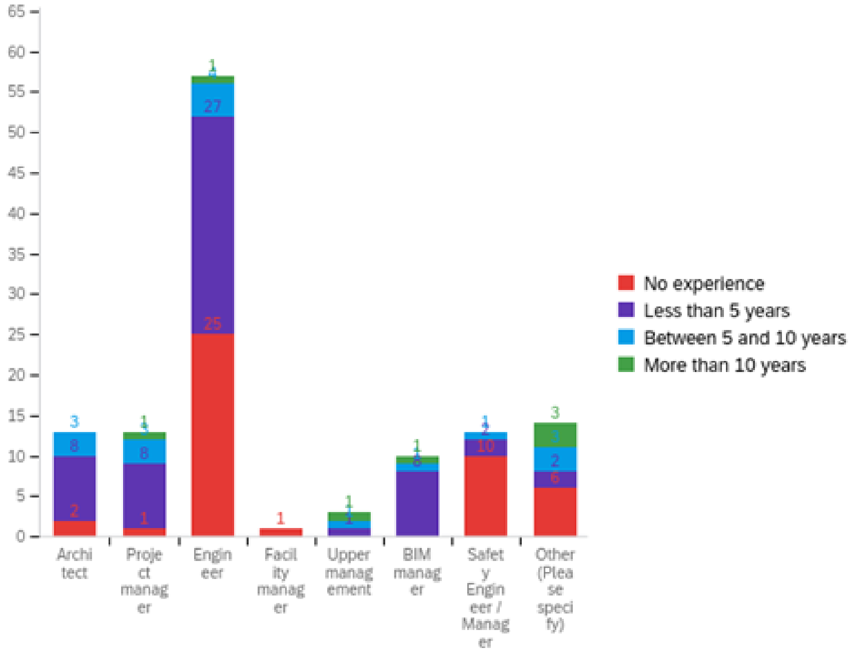


Figure 5.10 Respondents' BIM experience according to their roles

5.4 SM during BOM

In this section, industry professionals were asked about their perception of safety management during BOM. According to the survey result, the most common hazards during building O&M are falls from height and hazards from electrical equipment, which were selected at 32% and 21% respectively. Some less by 18% and 13% were chosen to be struck by an object and hazard from rotating objects respectively while only 10% were sleet hazard from being caught between objects. Among the other two options, one of the respondents mentioned falling objects during façade works. The second respondent indicated himself as a safety engineer who works in a large design/construction/facility management company and provided five following hazards: 1. Ergonomic (long term). 2. Tripping, slipping, falling on the same level. 3. Burns from hot surfaces 4. Frostbite when working in extreme conditions. 5. Diseases from bacteria in HVAC systems and other responses such as: 'thermal burns, electrical shock, building fire, food poisoning', 'falls, trips, pinches, slips", "they are mostly minor injuries due to slips, falls and trips, or pinching of the upper extremities and "Eye hazard, the hazard of toxic gasses and liquids". In the survey 24% strongly agreed about the possibility of hazard avoidance through design, 42% somewhat agreed and 25% selected options neither agree nor disagree while only 8% and 1% selected somewhat disagree and strongly disagree answers. Thus it was revealed the dominant agreement among industry professionals that most of the possible hazards during building operation and maintenance could be avoided through early design considerations because 68% of respondents were in the positive level of agreement, 25% were in the neutral level, and only 9% in the opposite level of agreement.

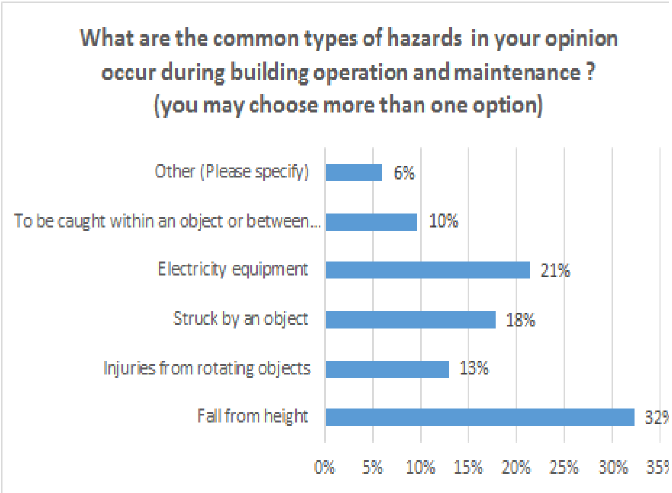


Figure 5.11 Common types of injury during building operation and maintenance

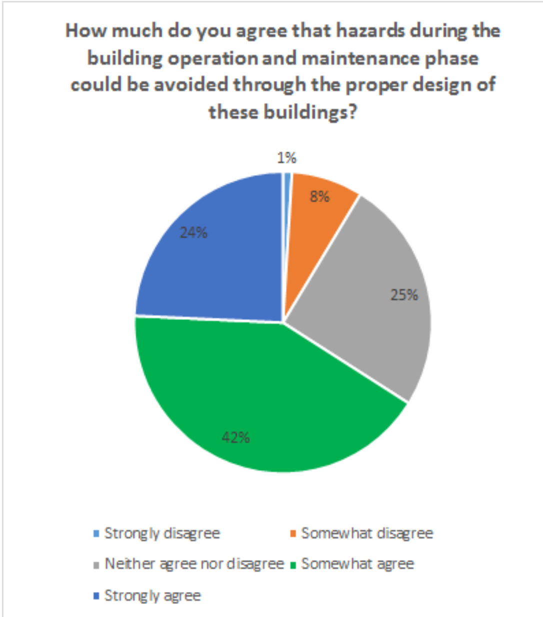


Figure 5.12 O&M hazards avoidance through DFS

During the survey, the strong belief of the professionals that safety was majorly considered in their companies was also observed. 55% indicated that they were 'completely considered', 24% "mostly considered', 13% "moderately considered" while only 6% and 2% of respondents mentioned that safety during BOM is "slightly considered" and "not considered" in their companies. Some studies state that maintainability issues with building elements can cause difficulties during BOM (Akanmu, Olayiwola, & Olatunji, 2020), and generally, maintainability is not considered during the design phase. The survey revealed that respondents primarily agreed with the statement that maintainability problems may cause safety issues during BOM because 42% answered "strongly agree", 38% "somewhat agree" 17% "neither agree nor disagree" while only 5% indicated "somewhat disagree" and only 1% mentioned, "strongly disagree". In the next question, survey participants were asked to select the common maintainability issues during BOM and mainly selected the options of issues with accessibility of building elements 31%, 21% inaccuracies in elements design, then 18% and 15% indicated inadequate ceiling space in ceiling for HVAC elements and insufficient space in the mechanical room and. At the same time, only 9% and 6% mentioned difficulties with the AHU filter service and other issues. Among other options, 13 descriptive questions were provided. Two respondents responded that they were not competent. A respondent from a client company and one from a construction company both typed the reason "poor quality of work', while two design company respondents typed ‘difference between design and construct building due to changes made according to the client’s request’ and “poor quality of construction materials. Two-three were mentioned competency of the operating company, one respondent stated that incompetency of operating company, the second stated that mainly the competence of the staff, the design of the building and equipment suitability for work while the third indicated about Lack of a plan about the organization of building operation. Among the responses were also quite comprehensive answers such as “Poor-quality protective equipment is purchased to save the budget and the incompetence of workers in the field of safety, as well as the fear of being fired, if they refuse to do unsafe work”, “Lack of consideration for future, not focusing on compliance with the later operation, design according to the principle, they will approve it and that's okay, closeness to new changes, excessive economy, ignoring existing operational problems” and “It’It’It’It’It’s hard to give a precise answer because there are so many situations. During the design, the layout, location, dimensions, and accessibility of equipment are always taken into account; however, it happens that even this does not help if used incorrectly, there are a lot of human factors”.

However, one respondent who indicated himself as an engineer from a large construction company with 3-10 years of work experience answered that all the considerations for O&M are provided in his company.

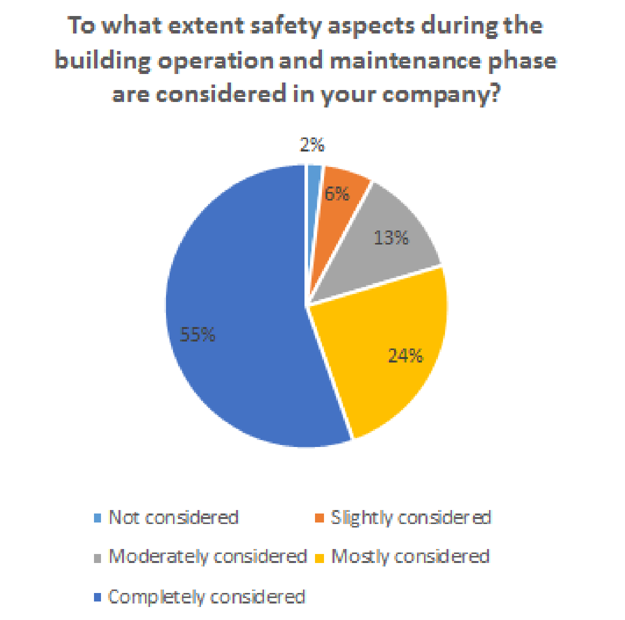


Figure 5.13 Safety considerations in the companies

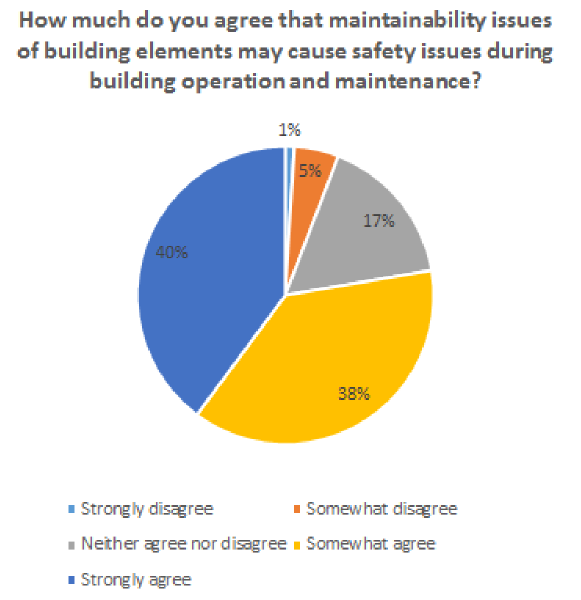


Figure 5.14 Maintenance of elements affects possible safety issues

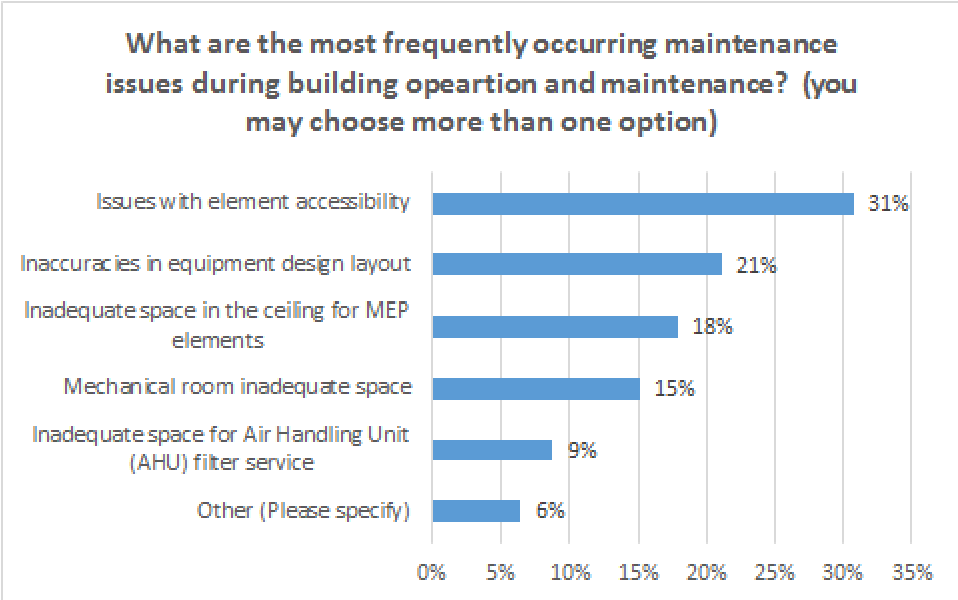
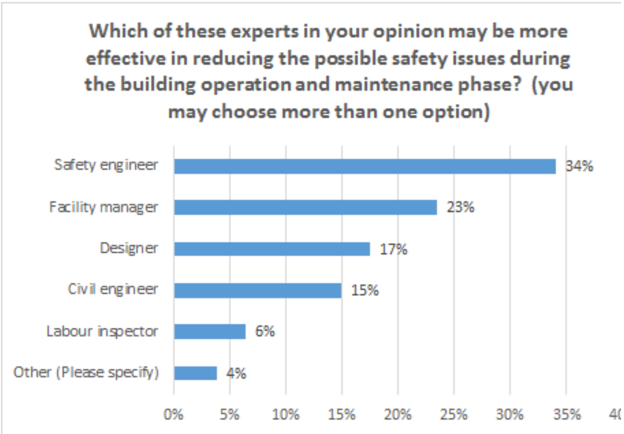


Figure 5.15 Most common maintenance issues during BOM

During the literature review, several studies investigated the importance of the involvement of various nondesign specialists in the design process to facilitate safety considerations for BOM. Thus firstly the respondents were asked about which of the expert's involvement mostly facilitates safety during BOM. In most cases, safety engineers were selected for 34% and facility managers for 23%, while some fewer designers were selected for 17% and civil engineers for 15%, and at least labor inspectors for 6%. As can be seen from figure 5.18 where the recommendation of the expert's involvement answers was distributed according to the respondent's roles in the company, the involvement of safety engineers and facility managers was mostly recommended by every specialist in the industry. Among other options were recommended the involvement of such experts as the general director, project manager, health and safety engineer, engineers participating in the operation and maintenance, (KSK) An apartment owners' cooperative (an organization that was created by residents of a house or several houses that have a common yard and communications) also were provided more descriptive answers as: "Issue has to be resolved primarily at the design phase. All discipline engineers have to conduct model reviews and identify access requirements: HVAC, Mechanical, Electrical, Instrument, etc. Only after that, Facility managers etc can effectively run the building operation and maintenance", "The designer does not have experience in operation and repair, maintenance engineers are not designers, there is a need to somehow combine their experiences, knowledge and skills", "Process safety, fire and gas protection, HVAC and Instruments combined". In addition, a strong agreement among respondents on the positive effect on the safety performance during the BOM phase in case of participation of these experts in the design phase, selecting 50% and 41% strongly in agreement and somewhat in agreement with this statement.



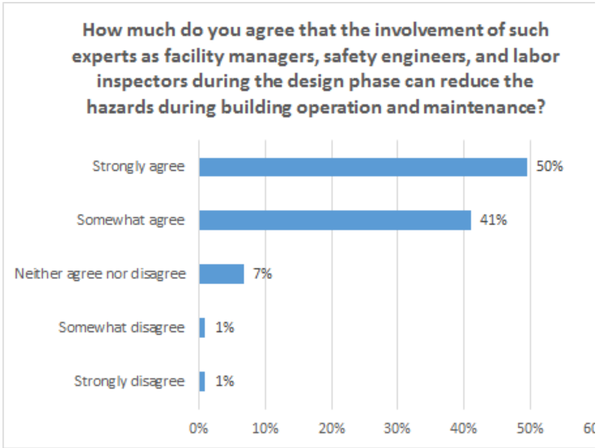


Figure 5.16 Non-design specialists' involvement in the design process

Figure 5.17 Affect of nondesign specialists' involvement in the design process

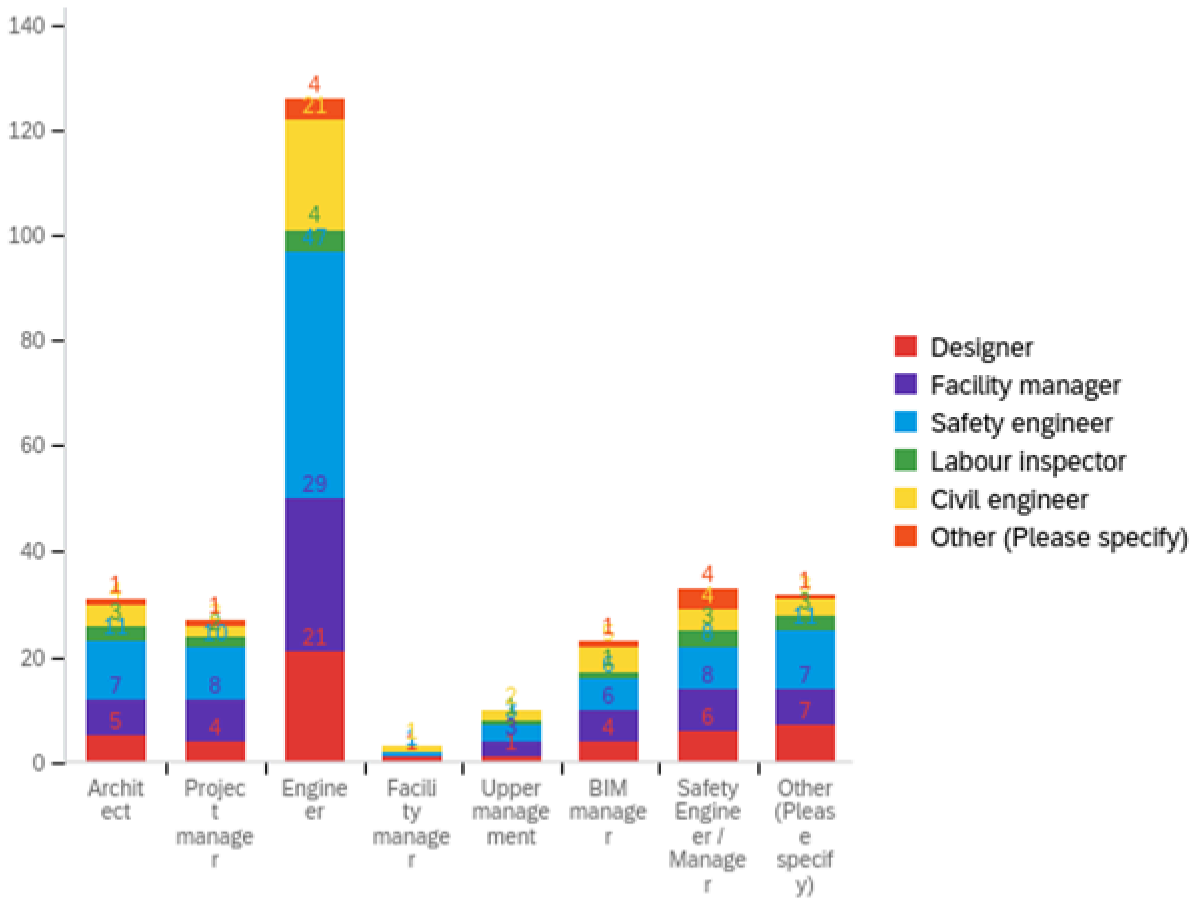


Figure 5.18 Experts' involvement during design phase recommendation from industry professionals - by respondents' roles in the company

5.5 BIM application for SM during the O&M phase in buildings in Kazakhstan

In the next section were asked about the BIM application practices of the respondents. It was found that in most of the cases, the professionals use the BIM for visualization (27%), coordination (18%), quantity management (16%), project scheduling (13%), and almost equally for SM, FM, --and resource planning by approximately 7-8%. The prevalence of using BIM for visualization purposes among industry professionals was also observed in the previous studies. For example, in the study of Akhanova and Nadeem (2016) more than half of the respondents strongly agreed on the reasoning behind the usage of BIM for visualization purposes while in the questionnaire survey provided by Akhmetzhanova et al. (2022) respondents also 52 times 116 selected the dominant usage of BIM for "Modeling and visualization of building structures" option. The low usage of BIM for SM during O&M was noticed in the following question as 40 % of respondents answered that they never use BIM for it and only 14%, 10%, 9% and 26% answered that they use it; most of the time, about half the time and sometimes, respectively.

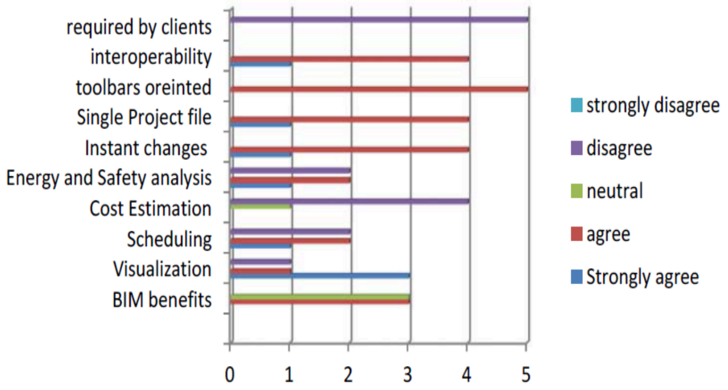


Figure 5.19 Reasons for using BIM in a company's practice

Akhanova, G., & Nadeem, A. (2016, October). The current state of building information modeling (BIM) and total building commissioning and study of its applicability in Kazakhstan. In *Proc. of the 33rd CIB W78 Conference*.

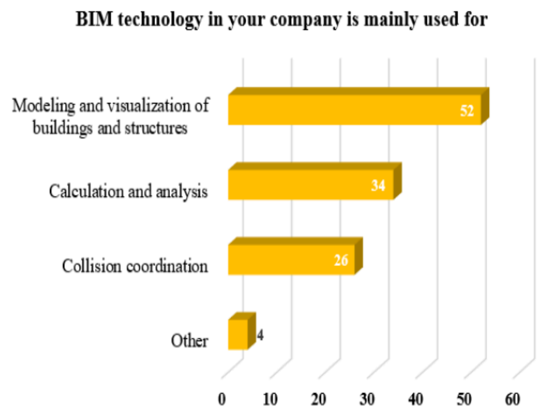
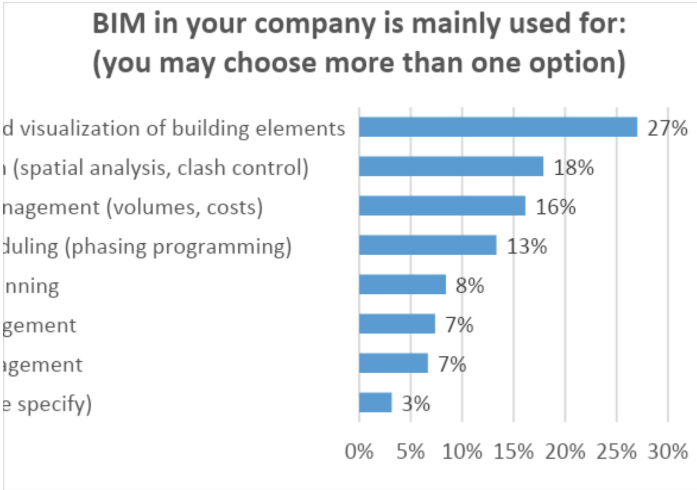


Figure 5.20 BIM utilization in construction companies and design organizations.

Akhmetzhanova, B., Nadeem, A., Hossain, M. A., & Kim, J. R. (2022). Clash Detection Using Building Information Modeling (BIM) Technology in the Republic of Kazakhstan. *Buildings*, *12*(2), 102.



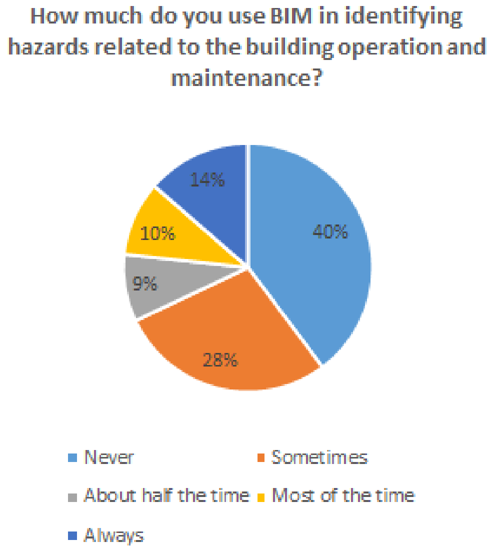
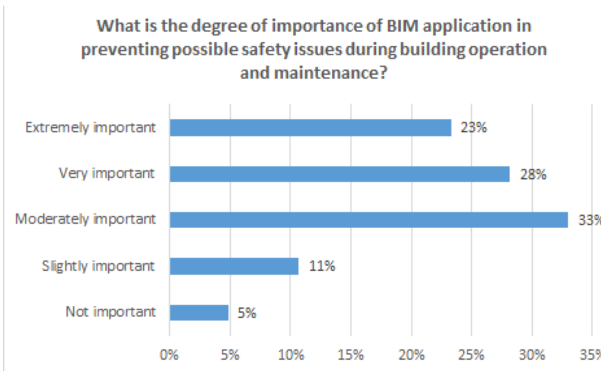


Figure 5.21 BIM application purposes

Figure 5.22 BIM application for the identification of hazards related to the BOM

Even the BIM application for safety consideration among the survey participants was low. However, it was noticed that respondents dominantly believed that the degree of importance of BIM application for preventing possible safety issues during BOM Is quite high because they selected majorly “extremely important” 23% and “very important” 28% answers. As the most effective stage for BIM usage in reducing BOM hazards, specialists indicated the mostly design phase at 42%, then the construction phase at 27%, and only thirdly O&M at 17% phase highlighting the importance of preventing possible safety issues ahead before the O&M phase. 14% of the respondents indicated implementation in the predesign phase is crucial.



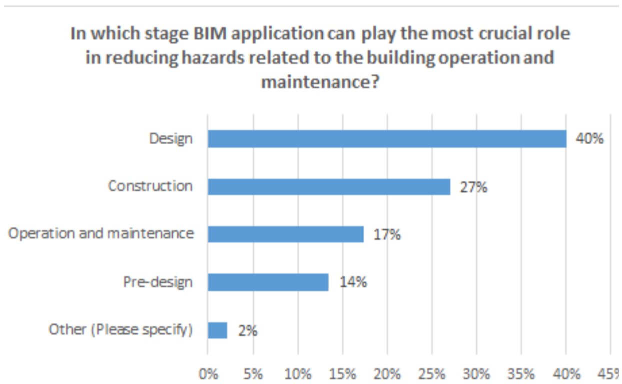


Figure 5.23 Importance of BIM application for SM during BOM

Figure 5.24 The most appropriate stage for BIM application for reducing BOM hazards

Then survey participants were asked to categorize according to their importance the various BIM implementation approaches applied during the design and O&M phases to identify possible safety issues related to the BOM. Importance was measured from extremely important to not important definitions which correspond to values from 5 to 1. The results revealed that the respondent perceives the BIM model walkthrough in the BIM software and Automated safety checking procedures as the most effective as they mentioned 44% and 43% for "very important option" and 28% and 27% for "extremely important" options. Thus their average importance values were the highest among other procedures and comprised 2.87 and 2.86 which is quite close to the very important (value=3) definition then the third importance value reached O&M activity simulation comprising an average importance value of 2.47 which is closer to the moderately important value. Regarding the O&M phase, the respondent indicated that using BIM-enabled CMMS systems (average value 2.64) and Building automation systems (average value 2.58) has greater importance than other tools. This survey results highlight the importance of usage of BIM tools in the context of BOMS because all the asked BIM-enabled tools reached an importance value higher than 3 (moderately important) that exemplifying specialists' belief that usage of BIM technologies both in design and operation and maintenance phases are important in reducing hazards during BOM.

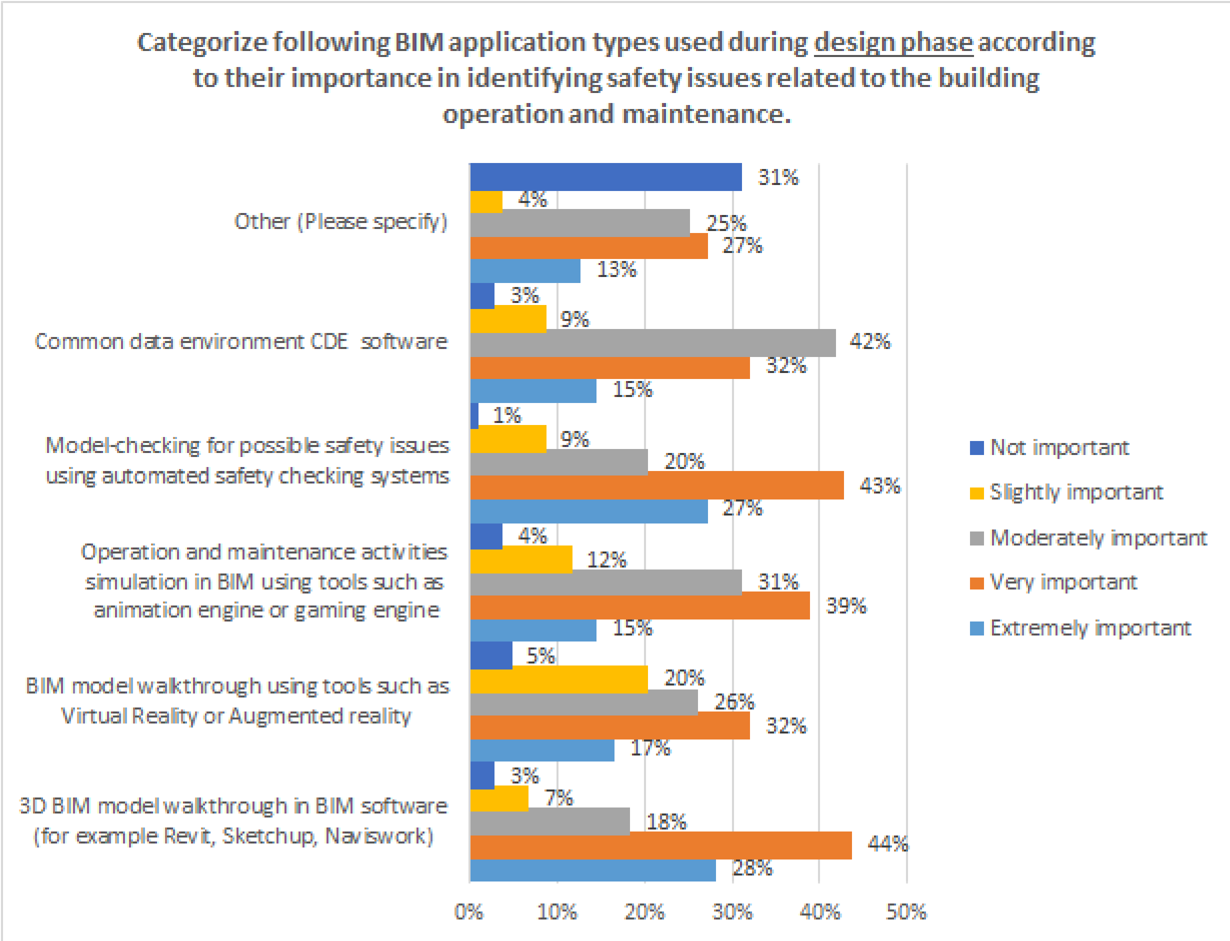


Figure 5.25 Categorization of BIM application approaches applied during the design phase according to their importance

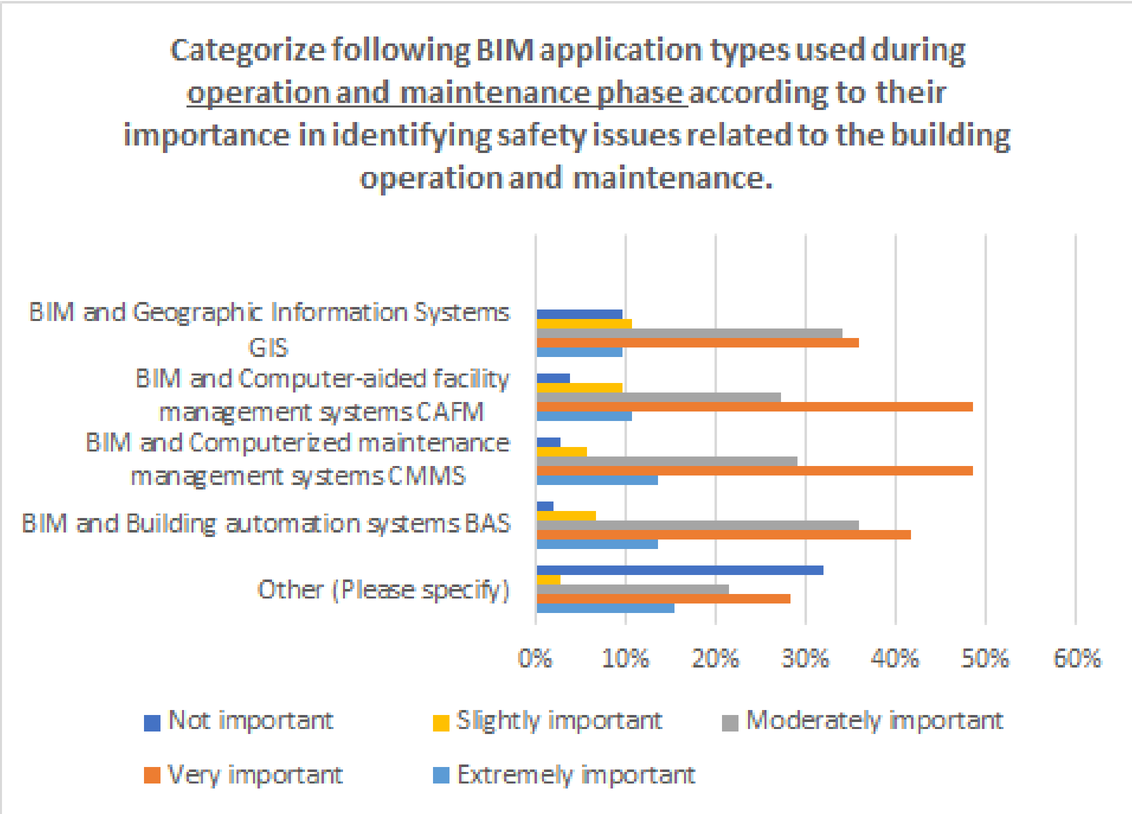


Figure 5.26 Categorization of BIM application approaches applied during O&M according to their importance

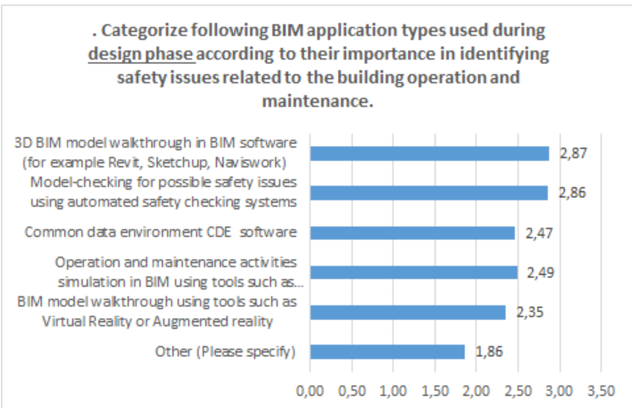


Figure 5.27 Importance of average values of BIM application approaches during the <u>design phase</u>

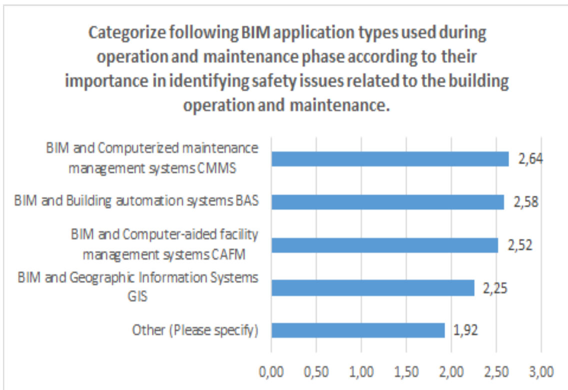


Figure 5.28 Importance of average values of BIM application approaches during the O&M

5.6 Barriers and recommendations for the application of BIM for SM during O&M phase in buildings in Kazakhstan

In the last two open questions, respondents were asked to provide their opinions on possible application difficulties and future effective strategies in the context of the survey topic.

These questions were not mandatory for completing the survey and respondents had an opportunity to skip them. However, among 103 participants half provided descriptive answers (55 answers for the 19th question and 48 for the 20th question) thus showing high involvement in the survey.

In the first question about difficulties that may occur during BIM application in the context of BOMs in Kazakhstan, 17 of 55 responses mentioned that the lack of BIM qualified specialists could be a crucial barrier, then 6 times have mentioned the difficulties associated with costs of implementation. According to the participants, the lack of vision from the customer on saving money in case of BIM application, the high price of BIM software, and additional expenses for the transition of the company to BIM design are the main triggers of difficulties associated with cost. Equally, four times were reported about the issues with additional design/construction/operation handover processes, also about the issues with differences between the design model and built building, and that there is no clear statement on who will recover additional expenses for BIM implementation. According to the built documentation, the respondents informed that frequent changes in the design cause additional work on the constant updates model. Three respondents mentioned the problem of the mentality of local people and their unwillingness to change toward new technologies and the closeness of local design specialists for usage BIM as most of them used to work on 2D drawings while one of the respondents also stated that there is a need to create a safe design culture and change the way of thinking of Kazakhstani engineers and all construction project participants. Several respondents also mentioned the human factor and reported that there is an unwillingness among participants to understand the importance of considering the safety in all the stages and the absence of a clear picture of who will approve the accordance of the project to the safety requirements.

Moreover, several participants mentioned the poor usage of BIM among the operating participants and their lack of BIM experience. Also was mentioned the possible difficulty with lack of time, a hurry in completing a design, and the necessity to increase design time for usage of BIM and this kind of consideration in it. One of the respondents stated that 'BIM is not developed in the country. The maximum is used to avoid collisions, produce quick specifications, or even worse, just for visualization. At the same time, another answered as 'Lack of material base, ready-made families, standard solutions'. Two respondents provided more descriptive answers, stating, "the main problem in operation approach, including injuries, and the human factor, both from the operational side of the organization, and occupants and from the visitors. BIM systems are only suitable for highly complex and unique buildings with a high level of staff training. For example, modern automation and dispatching systems operates without BIM technologies and allow efficient maintenance of buildings" and "At the moment, most of the software solutions in the framework of automating the operation of facilities do not work with the BIM model or interact in an extremely limited mode, and also do not provide integration with engineering systems monitoring systems (SMIS) and engineering structures monitoring systems (SMIK). This circumstance does not allow for the full safe operation of buildings and structures in real-time".

In the second open question on effective BIM application in the context of the topic, the necessity of introducing BIM subjects in the middle and high education organizations and providing specialist preparation has been mentioned as most of the existing BIM courses in the country are quite superficial. According to one respondent, early addition of BIM education in the phase of specialists' preparation will increase general interest among industry participants in BIM application. One of the respondents recommended providing the preparation of specialists in safety management during the operation and maintenance. Three times were mentioned the activity of state governmental enterprise of design projects examination. For example, respondents stated that they should increase their quality of work, be more tolerant of the minor things that are not important in the 21st century, and adhere to the existing Kazakhstani BIM Set of Rules that they usually ignore. Two times, the introduction of BIM as an obligatory tool for examining the design projects was recommended. One time, its introduction was mentioned to make it mandatory for the operation phase. One of the respondents in his response indicated that a recommendation was 'Creating incentives for the development of this industry. Many projects tend to be short-term, and design in this case becomes too costly. It is necessary to find a market approach for the development of the BIM cycle". Three times have mentioned the necessity to implement advanced training for engineering staff and maintenance personnel in this direction. Also, among the answers, it was stated to provide a BIM model change at the end of the construction and introduce additional costs to the project budget to these works. Two respondents indicated the necessity of increasing the design cost and introducing incentives in this sphere. In contrast, other respondents recommended increasing awareness of BIM benefits for the clients whose awareness causes their unwillingness to pay additional expenses. Among the responses associated with the Kazakhstani regulative base, there were recommendations for the Introduction of the corresponding set of rules and standards, the introduction of a single regulated bim standard in design/construction/operation, and the creation of design criteria. One of the respondents indicated that he could not answer as he did not use BIM while another respondent stated that he couldn't understand the BIM application in the operation phase. There were several more descriptive responses among the responses, for example, 'it is needed to competent implementation of BIM not only in design but also in construction, then in operation. The designer works according to the same standards as the builder, and then management. BUT in practice, builders are economical on many things, and during construction they already make mistakes, believing that something is not important. And during the operation, they turn a blind eye to so many things. The farther phases, the less strict they are with all rules and regulations" and "He must already accompany BIM Manager as a separate specialist at the FEED or detail design stage. In Kazakhstan, this position is at the engineers' mercy; there is no structural philosophy. There is just a self-trained semi-specialist who works how they think by trial and error. Well, it is necessary that the customer is also interested in BIM. There must be an incentive for this law in Kazakhstan because the design for the customer is mostly like an extra waste 'or 'Firstly, it is needed to study the problem, how critical is it? Collect data, statistics on critical cases in the operation and maintenance of buildings. Formulate criteria in the form of a standard and regulations." "

Chapter 6

Discussion and recommendations

The questionnaire survey results confirm previous studies that most Kazakhstani AEC industry companies began to use BIM after 2017. It could be correlated with the approval of the BIM adoption concept in 2017 and associated with its measures applied in the country. Regarding the BIM experience, one tendency was noticed, the share of respondents who have BIM experience of fewer than 5 years was approximately three times more than the share of respondents with 5-10 years, and similarly, the share with BIM experience between 5-10 years was almost three times more than those with more than 10 years.

One of the questionnaire survey goals was also to study respondents' opinions on general aspects of safety management during building operation and maintenance. One of the important questions of this part was identifying the respondents' opinions about the design for operation and maintenance safety, asking how much they agree that the safety issues could be prevented through design. To this question, they indicated high rate of agreement giving promising potential to this direction. Then as the importance of the design for operation and maintenance safety were identified in the next question became clear that fall from height and electricity equipment are the most frequent types of the hazards occurring during this phase and this implies to make additional focus to these type of hazards during the model safety checking procedures. Also, in the open questions, participants mentioned that during the operation and maintenance phase, minor hazards such as ergonomic hazards, Tripping, slipping, and falling on the same level, highlighting the importance to avoid neglecting this kind of hazards due to their low severity.

Furthermore, the survey results imply that you should pay attention to the maintenance aspects of the building elements because most of the respondents agreed that maintenance issues might cause additional safety issues. Among the most common maintenance issues mostly were selected option of issues with building elements accessibility. This kind of difficulty could be helpful for automated checking when the elements repeat a lot of time throughout the model, and manual checking its accessibility could be too time-consuming. This type of checking was graphically simulated in the experimental part of the study when a similar approach as in the study of Liu, R., & Issa, R. R. (2014) used the Solibri model checker using the logic free space before objects checked their accessibility.

During the experimental part, it was found that when reviewing the building model, it is possible to identify the building elements that can lead to injuries; however, in the absence of stimulation of the processes associated with the element, it is difficult to identify the exact probability and danger of the process. However, it should be noted that this simulation of the process showed high effort and time consumption. Therefore, it can be assumed that the most efficient approach would be to use process simulation to create rules for a library of automated checking systems. This simulation can be used to simulate the processes and check the list of processes in a building. However, it is most useful to simulate it based on reports of incidents of injury that are available to the labor inspectorate. All necessary records for the simulation are available for further analysis. Henceforth, since Kazakhstan implies the use of a BIM model throughout the entire period of the project, if there are accidents in the building, it will be necessary to create a dynamic simulation in the BIM platform and try to create rules for automatically checking the building of the BIM model so that in the future these cases will not be repeated. Each case should be recorded in the labor inspection, not in paper form. However, electronic form so that each participant in the system has access to the further development of automatic checks. The simulation could be the most comprehensive when it is created at the end of the case investigation when all the needed data are stored.

One of the key steps in facilitating safety management during building operation and maintenance is gathering comprehensive data for constructive analysis and forming rules and regulation bases. In Kazakhstan, one of the mandatory design documentation chapters is "construction safety management" where the information about how SM would be provided during the construction is provided. Similarly, under the development of the AECOM industry, the chapter on "O&M safety" would be provided where the building as an asset item would be provided with its manual and instructions on how to use it. However, there are enough data to create such a comprehensive standard and regulation base. Under the literature review, it was identified that there is no clear data on injuries and fatalities division according to their relation to the BOM phase. Data on injuries and fatalities are provided for work-related cases in Kazakhstan due to the special procedure of the investigation under which work-related traumatism cases are investigated, and data are stored. For example, the injuries and fatalities in Kazakhstan are majorly divided into work-related and non-work-related, and in the case of work-related traumatism (WRT) there is a special investigation procedure performed. The WRT case investigation provided by the local labor inspector was specially formed and stored. Then local authorities of labor inspection periodically send forms about occurred work-related injuries and fatalities in the region which are formed based on the reports of the case investigations. This Kazakhstan gathers from their respondents and creates special annual bulletins under which the trends of reducing or increasing traumatism under certain criteria. But in the bulletins, the special division of the injuries was not found according to their relation to the operation and maintenance. Thus, under review of the labor inspection investigation report form understudy, an example of recommended change of the cases report form where the occurred cases are divided according to the category of the intended safety knowledge database that will be used for automated safety checking rules and regulations library and manual model walkthrough check list. It is expected that this categorization of the occurred injuries and fatalities will enable the development of the analysis and later O&M safety rules creation. The necessity of creating a separate standard base for O&M was mentioned several times by the survey respondents.

In the literature review, the predesign and design procedure of the construction projects was observed and identified that there are key important processes affecting the safe BO&M being provided not only in the design phase but also during the pre-design phase. As two of three important processes relate to the pre-design phase, it could be assumed that it is also advisable to provide a certain checking procedure for these activities based on the usage of BIM. However, currently, it is not clear regarding the first important process that city network supplying enterprises performs their checking in the BIM, and also regarding the second important process is whether the conceptual design is checked by the stakeholders considering the safety of BO&M.

Even though there are two important processes in the pre-design phase, government expertise in design projects provides the most important decisions during the final third step. BOMS rules and regulations should check all the design considerations. As was provided previously, forming the separate standard and regulative base for SM during BOM will encompass several developments. Under the questionnaire survey, the design phase was indicated as the most crucial stage for SM consideration for BOM and among the different BIM application approaches the BIM model walkthrough and automated safety checking were indicated as the most effective tools. Also, a=most of the respondents agreed on the importance of involvement, such as safety engineers, facility managers, and civil engineers during the design phase. Thus recommended methods for model checking for BOMS are automated BIM model safety checking and BIM model walkthrough by the safety specialists and facility manager. Thus the generated rules and regulations could be an appropriate base for automated safety checking systems and checklists for manual checking by different specialists. Also recommended animation of the WRT cases could be a substantial trigger for the development of automated safety checking systems thus decreasing the scope of manual checking and gradual facilitation of the automation of the processes.

The survey results also revealed that a major part of the respondents agreed that the involvement of nondesign specialists such as safety engineers, facility managers, civil engineers, and others during the design phase may reduce the hazards during building operation and maintenance. This approach is used in the integrated project delivery contract scheme when AES/FM industry professionals collaborate on the project from the initial part (Sacks et al., 2018). However, Kazakhstan currently practices the design-bid-build DBD scheme with such crucial benefits as a fixed cost for the customer. However, it is the most challenging for BIM application (Sacks et al., 2018). However, the participation of stakeholders from other phases is already practiced in Kazakhstan. For example, the main expert of the design company participates in the execution processes as a supervision expert from the design company who checks the execution of the construction process following the design. The involvement of such design specialists in the construction phase is executed by assigning a special fun allocation that is calculated according to a certain percentage of the project cost. The same approach is used for technical supervision experts, also called quality supervision expert involvement. These design supervision and technical supervision experts participate in the whole construction process until the building is accepted to the operation phase. Thus it is could be recommended to use a similar approach for the other specialists' involvement in the design process and their participation in the whole cycle of the construction project. Based on the provided study, it is possible to recommend that the facility managers, together with the maintenance staff, participate in the creation of the BIM plug-in and state expertise experts will check the BIM model for possible safety issues. Develop a clear inspection procedure and make changes to the regulative documents for Kazakhstan in this direction. It is assumed that the specialists of the design project examination should have needed knowledge and experience of BIM model checking skills they have a lack of knowledge about the period of operation and possible problems regarding the operation and general safety consideration skills therefore, based on the suggestion of previous works on the possible involvement of facility managers to review the BIM, and based on the survey results when the respondents indicated the safety managers as the specialists who has the most crucial experience in this direction it can be recommended that facility managers and safety engineers work together with experts of expertise in the role of experts or to create a safety database and creation automated checking plugin and manual model walkthrough checklist.

Conclusions

This research encompasses a literature review of topic-related fundamental concepts, and a review of BIM implementation approaches applied during the design phase for early BO&M safety issues identification and their experimental testing under BIM software. Under the provided literature review, there are three key BIM application approaches: Experience-based, semi-experience-based, and rule-based approaches. Under their experimental tests, it was concluded that the experience-based approach shows low efficiency if there is now a comprehensive checklist and experience in facility management and safety management. It was also concluded that the semi-experience-based approach shows relatively high experience-based efficiency. In contrast, the rule-based approach is suitable for repetitive safety issues due to automation of the checking process but is highly dependent on their rules library and limited with coding opportunities among the BIM platform and checking plugin.

In the study also was provided a questionnaire survey was provided, and in the results could be concluded that the main opinions were as follows:

- Most of the respondents began using BIM after 2017
- Most of the hazards occurring during the BO&M could be prevented by design, and the most frequent hazards occurring in this phase are: fall from height, hazards from electrical equipment, and such minor hazards as slips, fall at the same level tripping.
- Safety management for BO&M in their companies is primarily considered.
- Maintainability difficulties can cause safety issues during BO&M, and the most crucial maintainability issue is the accessibility of building elements.
- The design phase is the application of BIM for safety management of safety during BO&M and the most appropriate stage for its application to reduce possible hazards.
- The participation of facility management and safety specialists during the design phase can facilitate the possible identification of BO&M hazards.
- BIM in their companies is mainly used for modeling and visualization purposes and quite rarely for possible BO&M hazards identification.
- The key barriers in the BIM application for SM during building operation and maintenance are lack of qualified specialists, difficulties associated with the cost of BIM implementation and frequent changes of design during construction, and excessive work associated with the necessity of updating the model with as-built documentation.
- The key strategies in the BIM application for SM during building operation and maintenance are: preparation of BIM qualified specialists from high school organizations and providing training courses for industry professionals, preparation standard and regulative base for safety management during BO&M, increase awareness among clients about BIM benefits to motivate them to use BIM and introduce BIM application incentives by the government.

Previously, there were no studies reviewing the BIM application for safety considerations related to BO&M. The study was addressed to evaluate how BIM application can facilitate safety management during building operation and maintenance in Kazahstan and majorly contributed to studying the Kazakhstani industry professionals' perceptions of BIM application in the observing topic gathering their opinions on the possible barriers and strategies and providing recommendations under the analysis of the survey results.

Limitations

The limitation of the study is that the literature review is limited only to online data available from science direct, Google Scholar, and Kazakhstani local sites of government agencies and regulatory document posting sites. If regarding the experimental part, then it is limited to a low experience of the researcher in the context of the building operation and maintenance safety. Also with the tools available on this platform, since there are no programming skills to add additional coding to the BIM platform to increase its capabilities in the direction of the checking procedure. Regarding the simulation part of the experimental study, it is limited by the accessible model libraries of Sketch-up base, which was integrated into the BIM model created in Revit for better illustration of M&R activities. In addition, the simulation was performed in static mode, so the dynamic characteristics of the processes could be missed. Regarding the part of the survey, it is limited to a small number of response letters and a little percentage of the completed surveys, since the topic under study is very specifically focused and requires a lot of concentration when answering, which may have affected the small coefficient of the completed responses. The survey results could be limited by the low BIM experience of the respondents because most of them had BIM experience of less than 5 years and low awareness of BIM from participants who had no BIM experience at all.

Future work

Among the application approaches reviewed in the study, the most promising direction in the field of safety could be highlighted in the early identification of possible problems during the design stage, and in particular by checking the BIM model with automated safety checking systems and the BIM model walkthrough with a comprehensive checklist. However, as was identified, the possibilities of checking by these systems are primarily restricted by the coding capabilities of BIM platforms and checking plugins. Also, the depends of the checking procedure efficiency mainly on the library cohesiveness under which the checking is performed. Therefore, it is recommended to provide a study on the possible improvement design of safety knowledge in types of rule databases both collected from different standard regulations and accident data. DFS data could be reviewed from local standards or local labor inspection accident data or foreign standards or such foreign OSH departments as OSHA or WSH. After the creation of a comprehensive database, it is recommended to provide a study on investigating the possibility of integrating into automated safety checking plugins thus testing the possible increase of checking instruments of these systems. Although the introduction of these rules is restricted by the coding capabilities of these systems, the remaining checking criteria should also be analyzed for the creation of checklists for provision walkthrough model checking. Also, during the study, two important processes in the pre-design phase that can affect the later safety condition of building maintenance, it is recommended to provide a study on identifying the real influence of these processes on future safe building O&M.

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Appendices

Appendix A

NAZARBAYEV UNIVERSITY

English

Application of Building Information Modelling (BIM) for Safety Management during Operation and Maintenance phase in buildings in Kazakhstan

Invitation for Participating in a Master Research Survey

Dear Esteemed Respondent,

My name is **Dastan Kopeyev.** I am a second year master student of the **Department of Civil and Environmental Engineering at Nazarbayev University.** I am conducting a master thesis on the topic "BIM application for safety management during building operation and maintenance phase in buildings in Kazakhstan".

My research supervisor is **Dr. Abid Nadeem**, **Department of Civil and Environmental Engineering, Nazarbayev Universiity.**

You are invited to participate in this research study. Your paticipation in this study is voluntary. It will help us to learn about the current state and perceptions of Kazakhstani industry professionals about BIM application for safety management duing buildings operation and maintenance in Kazalhstan.

This suvey consists of 21 questions and will typically take no more than 10-15 minutes to complete. We appreciate giving us your precious time.

No personal information will be asked in this questionnaire. The information and the resuts obtained from this study will be kept anonymous. We would like to share the research findings with you at the end of the study if you wish to know the outcome of our research.

If you need any clarifications about this study, please contact me at:
Dastan Kopeyev mob. +7+775-740-66-26
email. dastan.kopeyev@nu.edu.kz

By completing this survey, you are consenting to participate in this study.

We are very grateful for your participation in this study.

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Background Information of Respondents

1. Indicate your organization type (you may choose more than one option)

- ☐ Engineering survey
- ☐ Design
- ☐ Construction
- ☐ Facility management
- ☐ Client
- ☐ Other (Please specify)

2. What is the size of your company?

- ◉ Large (Average annual number of employees more than 250)
- ○ Medium (Average annual number of employees between 101 and 250)
- ○ Small (Average annual number of employees less than 100)

3. What is your role in the company?

- ☐ Architect
- ☐ Project manager
- ☐ Engineer
- ☐ Facility manager

- [ ] Upper management
- [ ] BIM manager
- [ ] Safety Engineer / Manager
- [ ] Other (Please specify)

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4. What is your work experience in the Design / Construction / O&M industry ?

- No experience
- Less than 3 years
- Between 3 and 10 years
- Between 10 and 25 years
- More than 25 years

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5. What is your work experience in Building Information Modelling (BIM) ?

- No experience
- Less than 5 years
- Between 5 and 10 years
- More than 10 years

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Safety management during building operation and maintenance

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6. What are the common types of hazards in your opinion occur during building operation and maintenance ? (you may choose more than one option)

- [ ] Fall from height
- [ ] Injuries from rotating objects
- [ ] Struck by an object
- [ ] Electricity equipment
- [ ] To be caught within an object or between objects
- [ ] Other (Please specify)

---

7. How much do you agree that hazards during the building operation and maintenance phase could be avoided through the proper design of these buildings?

- ○ Strongly agree
- ○ Somewhat agree
- ○ Neither agree nor disagree
- ○ Somewhat disagree
- ○ Strongly disagree

---

8. To what extent safety aspects during the building operation and maintenance phase are considered in your company?

- ○ Completely considered
- ○ Mostly considered
- ○ Moderately considered
- ○ Slightly considered
- ○ Not considered

---

9. How much do you agree that maintainability issues of building elements may cause safety issues during building opeartion and maintenance?

- ○ Strongly agree
- ○ Somewhat agree
- ○ Neither agree nor disagree
- ○ Somewhat disagree
- ○ Strongly disagree

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10. What are the most frequently occurring maintenance issues during building opeartion and maintenance? (you may choose more than one option)

- ☐ Issues with element accessibility
- ☐ Inaccuracies in equipment design layout
- ☐ Mechanical room inadequate space
- ☐ Inadequate space in the ceiling for MEP elements
- ☐ Inadequate space for Air Handling Unit (AHU) filter service
- ☐ Other (Please specify)

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11. Which of these experts in your opinion may be more effective in reducing the possible safety issues during the building operation and maintenance phase? (you may choose more than one option)

- ☐ Designer

- [ ] Facility manager
- [ ] Safety engineer
- [ ] Labour inspector
- [ ] Civil engineer
- [ ] Other (Please specify)

12. How much do you agree that the involvement of such experts as facility managers, safety engineers, and labor inspectors during the design phase can reduce the hazards during building operation and maintenance?

- Strongly agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Strongly disagree

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BIM application for buildings Operation and Maintenance Safety

13. BIM in your company is mainly used for: (you may choose more than one option)

- ☐ Modeling and visualization of building elements
- ☐ Coordination (spatial analysis, clash control)
- ☐ Quantity management (volumes, costs)
- ☐ Project scheduling (phasing programming)
- ☐ Facility management
- ☐ Resource planning
- ☐ Safety Management
- ☐ Other (Please specify)

14. How much do you use BIM in identifying hazards related to the building operation and maintenance?

- ○ Always
- ○ Most of the time
- ○ About half the time
- ○ Sometimes
- ○ Never

15. What is the degree of importance of BIM application in preventing possible safety

issues during building operation and maintenance?

- ○ Extremely important
- ○ Very important
- ○ Moderately important
- ○ Slightly important
- ○ Not important

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16. In which stage BIM application can play the most crucial role in reducing hazards related to the building operation and maintenance?

- ☐ Pre-design
- ☐ Design
- ☐ Construction
- ☐ Operation and maintenance
- ☐ Other (Please specify)

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BIM application for buildings Operation and Maintenance Safety

17. Categorise following BIM application types used during design phase according to their importance in identifying safety issues related to the building operation and maintenance.

	Extremely important	Very important	Moderately important	Slightly important	Not importar
3D BIM model walkthrough in BIM software (for example Revit, Sketchup, Naviswork)	○	○	○	○	○
BIM model walkthrough using tools such as Virtual Reality or Augmented reality	○	○	○	○	○
Operation and maintenance activities simulation in BIM using tools such as animation engine or gaming engine	○	○	○	○	○
Model-checking for possible safety issues using automated safety checking systems	○	○	○	○	○
Common data environment CDE software	○	○	○	○	○
Other (Please specify)	○	○	○	○	○

18. Categorise following BIM application types used during operation and maintenance phase according to their importance in identifying safety issues related to the building operation and maintenance.

Extremely important	Very important	Moderately important	Slightly important	Not importar

	Extremely important	Very important	Moderately important	Slightly important	Not importar
BIM and Building automation systems BAS	○	○	○	○	○
BIM and Computerized maintenance management systems CMMS	○	○	○	○	○
BIM and Computer-aided facility management systems CAFM	○	○	○	○	○
BIM and Geographic Information Systems GIS	○	○	○	○	○
Other (Please specify)	○	○	○	○	○

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Respondent recomendations

19. What kind of difficulties in your opinion may involve in BIM application for safety management during building operation and maintenance? (You may skip this question)

20. What are the strategies in your opinion would be effective to facilitate BIM application for safety management during building operation and maintenance? (You may skip this question)

21. It is an optional question. If you wish to receive our survey results at the end of the study, please provide us your name and email address in the text box below.

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