Integration of Mixed Reality and Lean construction in the execution phase: To perceive better execution process for construction projects and participants

Master thesis

International Master of Science in Construction and Real Estate Management

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I would like to thank my parents; whose love and guidance are with me in what-ever I pursue. They are the most important and distinguished asset in the world to me. I wish to thank my loving and supportive sisters, Solmaz and Elnaz.

BABAK SHAHMEHR

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Joint Study Programme of Metropolia Helsinki and HTW Berlin

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Master Thesis for Mr. Babak Shahmehr
Student number s0562625

Topic: Integration of Mixed Reality and Lean construction in the execution phase: To perceive better execution process for construction projects and participants

Introduction:

Construction projects development are divided into different phases, these phases shape the process of reflecting the project objectives into a detailed design and plans for the project's execution. The execution phase is the phase where the detailed plans are constructed. This phase involves the use of information, resources, and methodologies to construct the planned project. Managing the interactions among the inputs in the execution phase is challenging and insufficient management practices can lead to reduce the project value and increase the possibility of waste generated. Therefore, efforts where dedicated to integrating the lean construction theory within the execution phase to handle the issues of value and waste. From the perspective that implementation of lean construction theory requires supportive tools in visualizing the various factors affecting quality and waste. The author proposes the integration of mixed reality tools within lean construction theory to achieve better visualization, therefore, to perceive better execution process.

Background:

Virtual reality tries to change user's perception of around world with an artificial 3D environment which is produced by a computer. Also, augmented reality integrates images of virtual prototypes into a real world. AR technology increase user's perception of a virtual object with a real world. While Mixed reality presents a combination of reality and virtuality. For example, a virtual reality generated a virtual environment which is placed on its related physical world, or augmented reality application (Li, Yi, Chi, Wang, & Chan, 2018).

Li and his colleagues in 2018 reviewed many articles about VR/AR in construction safety and they figured out significant application domains regard ng the VR/AR in safety

construction which are included safety education and tra ning, hazard identification, and safety inspection and instruction.

Riexinger and his colleagues believe that MR is able to connect digital information and virtual objects with the on-site real-world environment. They found that used cases of MR are in preliminary step, but it is obvious that MR applications are capable to increase benefits for daily work on site in the construction environment. MR tools are able to prevent errors and improve quality which work performance will be optimized. The developed MR solutions increase the competences of users and stakeholders on site for self-inspection and self-instruction activities by an efficient and effective way (Riexinger, Kluth, Olbrich, Braun, & Bauernhansl, 2018).

Objectives:

The aim of carrying out this study is to figure out the benefit that mixed reality can add to the implementation of lean construction within construction execution phase. In addition, identify the improvements from integrating the mixed reality/lean construction within execution phase to perceive better execution process for construction project and participants.

Questions:

This research will cover and clarify the doubts related to the below highlighted questions;
What are the challenges in construction execution phase?
How mixed reality can be integrated with lean construction in the execution phase?
What is the value added to the lean construction by integrating mixed reality?
How can mixed reality/lean construction perceive better execution process?
What are the challenges and limitation of integrating lean and mixed reality?

Methods:

Achieving the aim of this study required the use of the following two research methods;

- Organizing a literature review on Mixed Reality and lean construction within execution phase.
- Analysis of different case-studies where MR/Lean construction is implemented to perceive better execution process for construction projects and participants.

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August-September 2019: Proposal and review of literature
September-October 2019: draft literature review
October 2019: review research methods literature and agree on research strategy
November 2019: agree on different case-studies
November-December 2019: analysis case-studies and data
January 2019: writing of results and review of the report
January-February 2019: completion of first draft of project report
February 2019: final writing of project report

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Access to library and academic sources.

References:

Li, X., Yi, W., Chi, H.-L., Wang, X., & Chan, A. (2018). A critical review of virtual and augmented reality (VR/AR) applications in construction safety. Automation in Construction Volume 86, February 2018, Pages 150-162, 150-162.

Riexinger, G., Kluth, A., Olbrich, M., Braun, J.-D., & Bauernhansl, T. (2018). Mixed Reality for On-Site Self-Instruction and Self-Inspection with Building Information Models. 51st CIRP Conference on Manufacturing Systems, Procedia CIRP 72 1124–1129.

30.08.2019

Signature of the Supervisor

1. Abstract

Construction projects development are divided into different phases, these phases shape the process of reflecting the project objectives into a detailed design and plans for the project's execution. The execution phase is the phase where the detailed plans are constructed. This phase involves the use of information, resources, and methodologies to construct the planned project. Managing the interactions among the inputs in the execution phase is challenging and insufficient management practices can lead to reduce the project value and increase the possibility of waste generated. Therefore, efforts where dedicated to integrating the lean construction theory within the execution phase to handle the issues of value and waste. From the perspective that implementation of lean construction theory requires supportive tools in visualizing, simulating, and predicting the various factors affecting quality and waste; the author proposes the integration of Mixed Reality tools within lean construction theory to perceive better execution process.

The aim of carrying out this study is to figure out the benefit that Mixed Reality can add to the implementation of lean construction within construction execution phase. In addition, identify the improvements from integrating the Mixed Reality/Lean construction within execution phase to perceive better execution process.

The study's goals achieved by organizing a literature review on Mixed Reality and Lean Construction concept within construction execution phase. Also, five different case studies are analysed to identify Mixed Reality technology, Lean Construction theory, and implementing of them in construction execution phase. The author proposed specific questions and asked from professionals in fields of Mixed Reality and Lean Construction to cover parts of the main study questions.

The author was able based on this study to identify challenges related to both fields (Mixed Reality and Lean Construction), analyse the required knowledge/tools/skills that has to be involved to perceive a proper implementation of Lean Mixed Reality, identify the benefits that Lean Mixed Reality can add to the execution phase management, and finally determine the challenges/improvement suggestions that Lean Mixed Reality implementation can face.

Key words: Mixed Reality, Lean Construction, Construction Execution Management, BIM, Lean Mixed Reality.

2. Table of Contents

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4. List of Tabulations

5. List of Abbreviations

2D	2 Dimensional
3D	3 Dimensional (Design)
4D	4 Dimensional (Time)
5D	5 Dimensional (Budget)
6D	6 Dimensional (Facility Management)
7D	7 Dimensional (Sustainability)
8D	8 Dimensional (Safety)
AI	Artificial Intelligence
AR	Augmented Reality
AV	Augmented Virtuality
BIM	Building Information Modelling
HMD	Head-Mounted-Display
HSE	Health, Safety, and Environment
JIT	Just in Time
KPI	Key Performance Indicator
LWS	Lean Work Structuring
MEP	Mechanical Electrical Plumping
MR	Mixed Reality
QR	Quick Response
RE	Real Environment
VDC	Virtual Design Construction
VE	Virtual Environment
VR	Virtual Reality

1. Introduction

1.1. Research purpose

The aim of carrying out this study is to figure out the benefit that mixed reality can add to the implementation of lean construction within construction execution phase. In addition, identify the improvements from integrating the Mixed Reality/Lean construction within execution phase to perceive better execution process for construction project and participants.

1.2. Research Question

This research will cover and clarify the doubts related to the below highlighted questions;

- What are the challenges in construction execution phase?
- How mixed reality can be integrated with lean construction in the execution phase?
- What is the value added to the lean construction by integrating mixed reality?
- How can mixed reality/lean construction perceive better execution process?
- What are the challenges and limitation of integrating lean and mixed reality?

1.3. Research Methodology

Achieving the aim of this study required the use of the following two research methods:

- Organizing a literature review on Mixed Reality and lean construction within execution phase.
- Analysis of different case-studies where MR/Lean construction is implemented to perceive better execution process for construction projects and participants.

2. Construction project management

In this section, the author aims to define the concept of construction project management based on previous researches, highlight the phases of construction project especially execution phase, explain the main challenges faced in execution phase; this will help in understanding the concept of construction project management and identifying the related challenges.

2.1. Project management

The aims of project management are to perform a project to meet project requirements based on budget, schedule, and quality at the acceptable risk, safety and security levels (Shadan & Fleming, 2012). The project management definition according to Project Management Institute (PMI, 2013) is '' Project management, then, is the application of knowledge, skills and techniques to execute projects effectively and efficiently. It's a strategic competency for organizations, enabling them to tie project results to business goals – and thus, better compete in their markets'' (PMI, 2013).

The three pillars of project management to fulfil to ensure its success is illustrated in figure 1 (PMI, 2013).

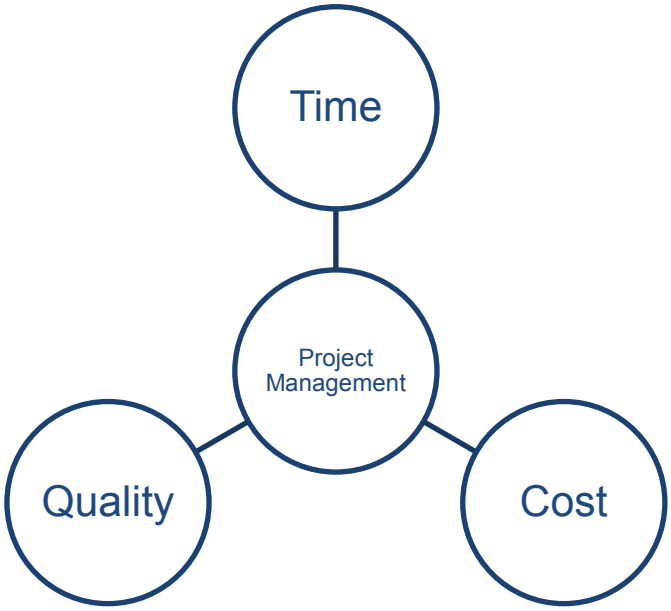

Figure 1 Project management pillars. Adapted from: (PMI, 2013).

- Time; projects must be delivered according to the schedule. The schedule is known as the time needed to complete the task. Task schedules are often the most frequent project supervision in the development of projects. This is expressed in missing deadlines, incomplete events, and late donor statements. Proper control of the schedule requires careful identification of the tasks to be performed, accurate estimation of their duration, the sequence in which they are to be performed, and the allocation of people and resources.
- Budget; projects must be delivered within the planned budget. Budget or costs approved for the project, including all expenditures required for the execution of the project. In development projects, managers have to balance between not running out of money and not spending, because many projects receive funding or grants that have contract terms with a' use or lose' approach to project funds. Poorly implemented budget plans could result in a last-minute rush to spend the allocated funds.
- Quality; projects are defined to fulfil some standards and specifications which shows the project quality, any failures at the delivery time will cause project defects. Quality is characterized as delivering project results on the basis of explicit or implied needs and expectations of project recipients and donor agencies in order to meet stakeholder satisfaction. It also means complying with quality standards that are either imposed by the donor, local government (such as laws and regulations) or professional standards.

These three pillars are main aspects of the project management. The whole idea of the project management concept is to comply these pillars by organizing a certain balance while using specific tools and techniques.

2.2. Construction Project Phases

Projects are like systems that are complex and dynamic, and all of them encompass phases. According to the Project Management Cycle book there are six major phases for each project which is shown in figure 2 (PM4DEV, 2015).

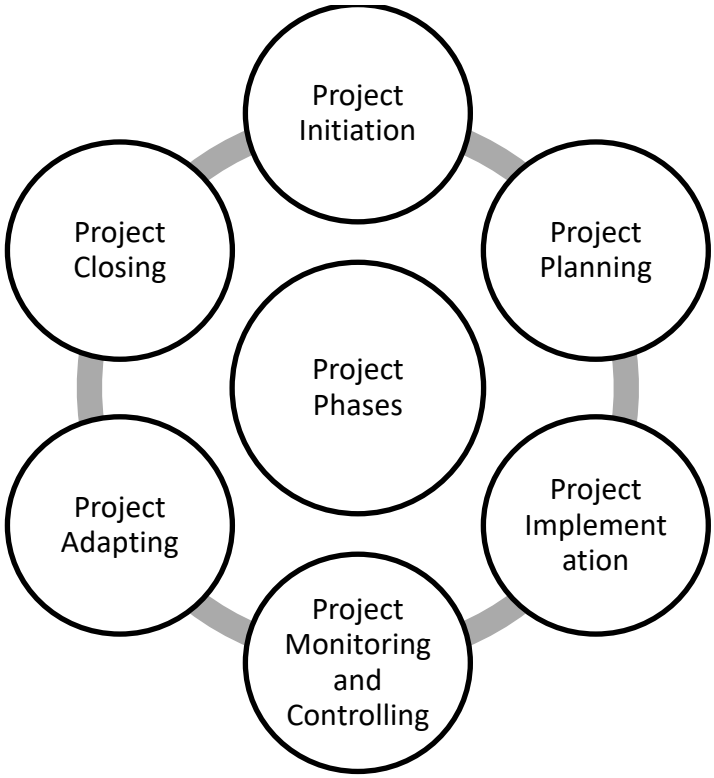

Figure 2 Project Management Phase. Adapted from: (PM4DEV, 2015).

2.2.1. Project Initiation

The initiation phase includes the definition of project purpose, project concept or idea, and timeframe to show when goals are expected to be met, for example, developing a new building, renovating an existing clinic, or building a new road. In this phase, the project type, the main goals of the project, and the approximate budget should be considered. During the initiation of a review of the issue, it identifies the methods that the project will use to achieve its benefits; in addition, the company has established that the project is consistent with the organization's strategy, mission and vision. Key decisions of this process are the acceptance of the project idea as well as the authorization of the project proposal.

This decision is based on the values and goals of the company and takes into account available resources, local needs and government interest. Approval of the project concept requires documents reflecting the criteria of the funding agency. The project is or is not approved or authorized at this stage or may need further review or

changes to the proposal; it is not uncommon for the donor and the company to participate in lengthy discussions on the final budget of the project.

The authorization of the project proposal is made by the company or the supporter when the company refers to a bidding process such as the Request for Proposal or the Request for Assistance; the approval of the proposal opens up the project for the beginning of the second phase of the project, Project Planning. (PM4DEV, 2015).

2.2.2. Project Planning

When the plan is accepted and the funding has been authorized, the project is finally prepared to start. The first stage is the preparation of project plans which involves two separate components; the development of the proposals that are needed as part of the proposal which is the core planning and the preparing to plan the execution of the project that is the cooperation of planning.

Detailed planning documents that were originally produced as part of the project proposal are core planning. The first duty of the project manager is to prepare the project plans in more detail, including the comprehensive project budget and time schedule. Developing plans are plans to handle the scope, timeline, budget and project quality.

Facilitation Plans include the creation of plans to handle other facilitation processes needed to handle the project, including staff, stakeholders, details, risk, and contract management plans.

In the planning phase, more details are created to support the concept. The main tasks are defined and then are prioritized based on importance to the project. The estimated budget is determined and a time-frame is created therefore all project team members and stakeholders are aware of budget and time for the work (PM4DEV, 2015).

2.2.3. Project Implementation

Project implementation allows users to take the appropriate actions to ensure that the tasks in the project plan are accomplished and that the outputs of the plan are generated. Implementation usually occurs once the final project proposals have been

accepted by the company. The project manager proceeds by creating a team and the initial costs of the project, which can include the procurement of office equipment, vehicles and other services necessary to start the project. Implementation encompasses integrating the people and other resources needed to carry out the project plans and to achieve the desired results of the project or process.

The implementation phase also comprises activities like providing project guidance, developing the project team, endorsing project scope, assuring quality, creating progress reports, purchasing the required resources and taking corrective action.

The implementation phase is defined as a project plan into actions. It means that project carry out the actions with specific aim to meet objectives of the project plan and deliver products or services. In this phase, different tasks and responsibilities are defined for each project team members. Therefore, more details are exposed, the budget plan is revised, and the schedules are defined (PM4DEV, 2015).

2.2.4. Project Monitoring and Controlling

Project monitoring is about assessing the project progress against project goals, based on the schedule and taking corrective action to get the project back on track. Monitoring is carried out throughout the project stages of the life cycle of the project. The emphasis is on monitoring the four project shortcomings of scope time, budget and quality. Project monitoring starts with planning and completes with evaluation. The monitoring step also looks for new opportunities that may improve the possibilities to achieve the project goals. Monitoring helps indicate unexpected consequences, establishes a discipline that helps observe how the project situation is evolving, and how the primary assumptions of the project have changed.

In the project monitoring and controlling phase, the goal is to ensure that the project procedures are based on time, budget, within scope with minimum risk and this phase is a continuously process during the project life (PM4DEV, 2015).

2.2.5. Project Adapting

Adapting is considering corrective action which uses observations from the monitoring process to tell what needs to be changed or adjusted. Adapting includes an

overview of the changes required and their effect and importance to the project and project constraints.

The project adapting is the step that adjust the plan with minimum changes to achieve goals. The adjusted plans are created and implemented and changes in requirements needed to be considered to modify the main plans and to ensure the project is performed in a smooth way (PM4DEV, 2015).

2.2.6. Project Closing

Once the planned objectives have been reached and all deliverables have been generated, the closing phase of the project is met. There may be occasions where a project is closed before all deliverables have been completed. This could be happened by changes in management strategies, lack of availability of funds or security factors that make it difficult for the project to run.

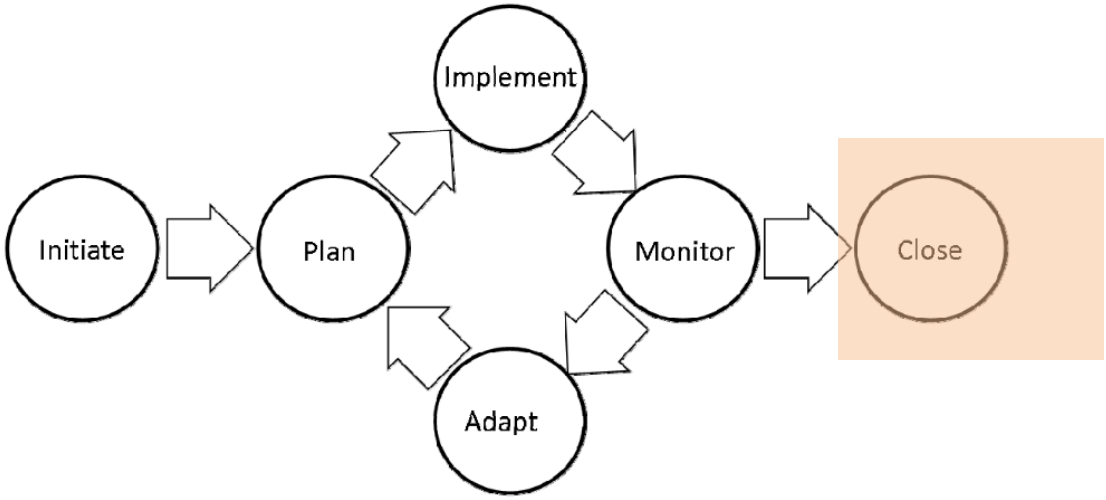

Figure 3 Closing Phase in Project Management Cycle. Source: (PM4DEV, 2015).

The project closing is the last phase of the project as shown in the figure above that shows the planned objectives have been considered therefore all deliverables like services and products are ready to transfer to the clients (PM4DEV, 2015).

2.3. Execution Phase

The execution project phase is clearly the take action of performing activities and tasks that carrying out the production of the project deliverables. Activities and tasks

fulfilled must be completed effectively and efficiently. Therefore, the basis for successful project delivery is the project plan. The project team during the execution phase must continuously monitor and control its performance to ensure that everything is based on the project plan (CPM , 2006). The execution phase is illustrated briefly in figure below.

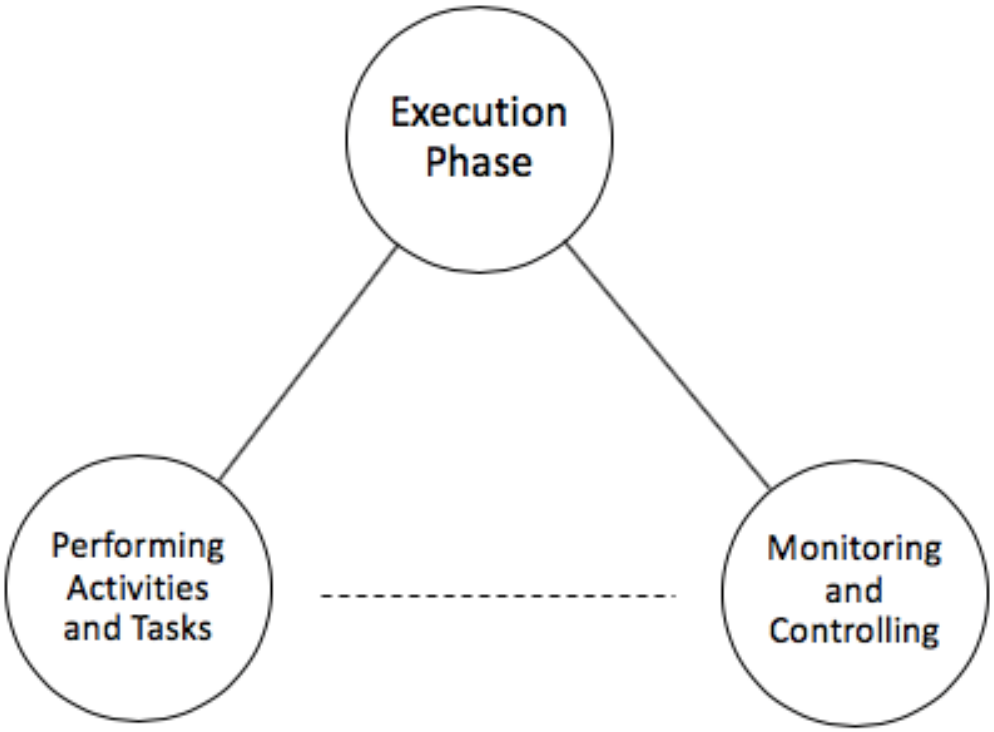

Figure 4 Execution Phase. Adapted from: (CPM, 2006).

2.4. Main Challenges in the Execution Phase

The aim of a project management is to balance the main three pillars of the project management and it is successful when the project is delivered on time, with certain budget, and based on the agreed quality but some challenges may happen failure to achieve these aspects.

Different challenges occur and effect on the project life cycle and cause problems, additional costs, delays and defective execution of works. In this section the author aims to focus on the main challenges in the execution phase based on different studies;

According to Kumaraswamy the effect of variation on the project execution was studied in 1997 and he pointed out that variations happen due to many reasons, for example the most common reasons of variation are due to site conditions, client changes, design errors, unforeseen ground conditions, uncertainty in contract documents, external events and interferences (Kumaraswamy, 1997).

Yates in 1998 studied the major concerns disrupting construction works and came up with the main challenges to project execution in the conclusion. He noticed that vagueness in contract documents, variation, severe weather condition, delay in possession of site by contractor, delay in issuance of drawings and design information, delay by other contractors, and delay due to miscoordination are the main challenges (Yates, 1998).

Mitropoulos and Howell in 2011 also mentioned that improper early planning may cause certain problems in project execution and highlighted that contractual problems, project uncertainty, financial issues, and cultural matters must be discussed in the primary planning stage to avoid of problems, disruption and additional cost to the project (Mitropoulos & Howell, 2001).

Many studies in construction projects have carried out that the lack of communication is a major problem; communication between different teams can be included contractors, subcontractors, design teams, and stakeholders. This lack of communication in the construction field can affect inefficiency, delay, quality, cost, and project schedule. Also, poor communication effects on project coordination between design and operation teams (Dahmas, et al., 2019).

Main challenges in execution phase are shown as figure below;

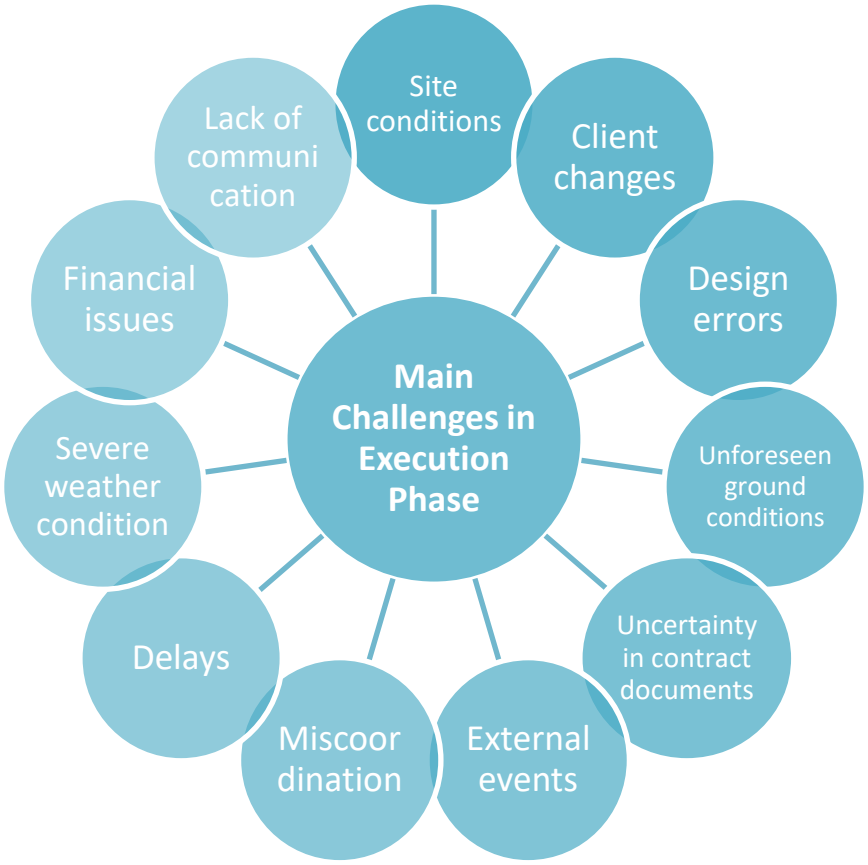

Figure 5 Main challenges in execution phase. Source: Author.

3. Mixed Reality (MR) and Lean construction

3.1. Concept and background of MR

The concept of Mixed Reality was driven by the invention of the Augmented Reality interface which was developed in early 1960s in Sutherland. Although, the AR interface first implementation was around 1990s by Caudell and Mizell. Caudell and Mizell carried out their research at Boeing Corporation to achieve a system to train workers installing wiring harnesses in planes.

Later on, in 1994 Milgram and Kishino presented an environment which can be describe as a non-disturbed virtual environment. MR technology helps us to better understand phenomena by integrating real-time display technology. In Figure 4, augmented reality, the phenomena between virtual reality and pure real environment are

immersed in the virtual reality of the user and are immersed in the computer-generated virtual environment (Che Mohd Yusoff, et al., 2011).

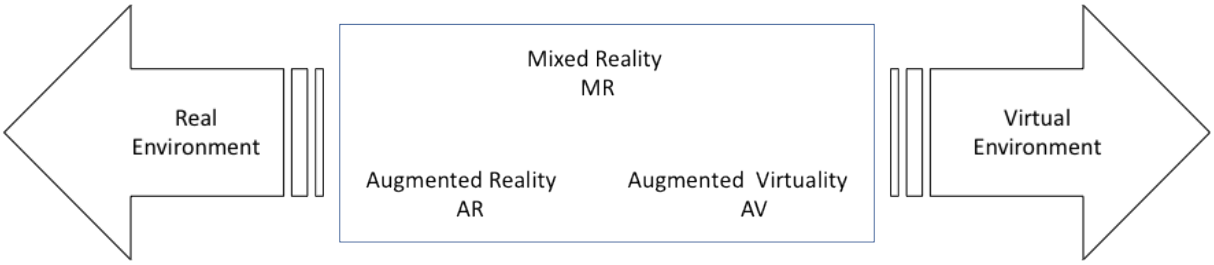

Figure 6 Reality-Virtuality Continuum. Extracted from (Behzadan, et al., 2015).

Mixed Reality as presented in figure 4 includes augmented reality (AR) and augmented virtuality (AV) and can be divided into real and virtual environment. Augmented Reality environment merges real and virtual objects within real time and notes in three dimensions. In the AR, users exist in real world and use a computer-based device or an advanced camera which enable them to visualize and interact with a virtual model.

Augmented reality is the technology in which virtual objects are placed in a real environment, along with other real objects. AR integrates physical surroundings with computer-generated information in real-time (Wang & Schnabel, 2009). The best advantage of using augmented reality is that to increase ability to see how details and features fit on the site. An AR system explanation is extended within the definition of an MR system that integrates digital and physical entities (Che Mohd Yusoff, et al., 2011). The popularity of the videogame Pokémon Go which has attracted whole the world is an example of it to perceive and clarify AR definition. While an augmented virtuality is a term that to identify synthetic systems with imagery added in the real world. AV, which is explored less than AR, places real-world elements on virtual environment.

Also, real environments (RE) include direct or indirect (through a video display) visibilities of a real sense. While virtual environments totally are based on computer-generated environments and those non-existing objects are demonstrated on a device, therefore, end-users interact within a technological interface in real-time. (Flavián, et al., 2019). Users can work with the real environment (3D) within receiving modelled information or computer-generated about the task. The perception of the users about

the real environment is increased by displays that show information the user cannot acquire directly without help (Wang, et al., n.d.).

As stated above, Milgram and Kishino's (1994) view of MR included any plane where real and virtual elements were presented together in a single display, thus considering AR and AV as part of MR. Jeon and Choi (2009) also noted that the terms AR and MR were used interchangeably in the literature. Yung and Khoo-Lattimore (2017) draw attention to clearly delineating the terminology related to VR / AR in order to avoid current confusion (Behzadi, 2016).

3.2. Current MR Technology in Construction

According to Ahmed in 2018, AR and VR technologies can solve issues related to construction management effectively and efficiently. It has shown that Mixed Reality is used as a visualization tool in different steps of the construction project for example scheduling, training for workers, progress tracking, safety, defects, quality, time, and cost management (Ahmed, 2018).

Mixed Reality lets you add real environment elements to the system, so you can add a variety of virtual elements to your environment. One of the useful applications of this technology is the ability to instantly teach the building crew that they can receive instructions and view them on their displays with augmented reality. This will minimize the amount of errors and mistakes caused by carelessness of employees, which can improve efficiency and at the same time reduce construction costs.

Also, Augmented Reality allows the user to be fully aware of the environment in which they are located and to add new information to the environment. Augmented Reality can change the way a building is built. Workers can use headphones like the DAQRI Smart Helmet in the works and have the building plans they need to monitor constantly, and easily and without need for paper maps in their proper place. Workers can aware of other workers' work locations, equipment, and heavy services. Problems and risks that occur quickly can be forward directly to workers' headsets, allowing them to solve the problem before they are compromised and ensure safe safety.

It is noticeable to say that people responsible for a building under construction may be hundreds of miles away or in another country. They may only be able to visit the building under construction once or twice during the work. At the same time, it is important for builders that customers have a clear understanding of the construction situation.

Augmented reality is generally in search of a specific goal. This can be anything, but it's usually a two-dimensional image printed on a movie poster. When the augmented reality application detects the target with its camera, it processes it and adds image and sound to it. For example, you see the poster of a movie, and when you look at the poster from the screen, you see augmented reality instead of poster images. In Augmented Reality, you communicate between the real and the virtual world, but in the virtual reality you don't communicate between the real and the virtual world.

Virtual reality is a simulation and modelling of the real world that you only see through a computer system. In virtual reality, all perceptions of reality are virtual, and there is no interaction with the real, and if there is, it is virtual. In augmented reality you communicate with the real world when you use it, when you put augmented reality glasses on your head it captures the surroundings through a camera built into it, and you use the features that this camera has in It empowers you to make a virtual change to that reality through the camera. For example, you shoot with augmented reality glasses from your home wall, and with the virtual features that the camera gives you, you can change the colour of your home wall to choose the best colour and in the future the colour that is right for your home painting.

According to Behzadi in 2016, in the construction industry, a 3D model is being used as augmented reality in front of the user's eyes and then it causes to learn new experiences unlike any seen before. By offering this virtual environment people involved are able to practice and learn before actually carrying out any physical construction activity. This will enhance the efficiency of construction workers which will positively reflect on their productivity. On the other hand, it will minimize possible waste of time and material as involved people have practiced these tasks virtually and learned how to avoid unnecessary problems which generate waste. For instance, the Augmented Reality applications in construction projects for increasing the user’s visualization is shown in the figure below.

Figure 7 Augmented Reality applications in the construction projects. Source: (Berlo, et al., 2009).

Mixed Reality proposes new and existing advantages to the construction in many cases like scheduling, communication, man-labour hours, and safety (Behzadi, 2016). In the construction, the scheduling perspective will be developed by Augmented Reality that illustrates a planned structure to enhance visualization of progress. One more vital use of Augmented Reality is monitoring project progress during execution phase as proved by Wang et al. creating a Virtual Construction Environment by using Augmented Reality tools allow engineers and management team to track elements of progress and compare it with actual works carried out on-site (Wang, et al., 2013).

According to author experience, Augmented Reality also can be used during the early stage of scheduling to visualize the flow of resources among site activities. By creating this visualization proper implementation of resources can be obtained, avoidance of clashes among project trades, and an optimum usage of resources can be determined.

Communication as well is one major aspect during execution phase, the use of Augmented Reality here introduces the possibility of visualizing all related data for construction elements while walking around on-site or even sitting in the office. For instance, if the project team are conducting a site-walk they can review the details and aspects related to a certain column; wearing Virtual Reality Google or DAQRI Smart Helmet, this will eliminate the use of all paper drawings and documents which will make

it smoother and more efficient to track and control project progress, review quality aspects, and assign actions to responsible people (Behzadi, 2016).

According to Meža, et al., the main challenge in developing an Augmented Reality data base for project information is that the enormous amount of project related data and updates which means more people are assigned to maintain the data entry process (Meža, et al., 2015).

Following the advance of technology and the proposals of using these technologies within the construction projects to overcome challenges related to labour force and labour productivity, Augmented Reality has proven to be an efficient tool to bridge the gap between the BIM model and the actual work carried out on-site. This is reflected on three main levels;

- Virtual training and workshops for construction site activities
- Communication, coordination, and guidance of labour work
- Monitoring, tracking, and controlling labour's productivity

Developing a virtual environment using augmented reality tools with the aid of the BIM model to conduct trainings and workshops for labours before actual execution on-site will lead to improve awareness of the construction activities, minimize possible mistakes which generate waste, and reduce the time wasted during the learning process of each individual task. This also can provide a visual platform of communication and coordination which will act as the main guidance for workers. The Augmented Reality tools will offer the possibility of visualizing planned productivity vs. actual productivity on-site which will improve the monitoring process and precisely generate control plans. All of that will reflect on the labour's productivity and minimize the waste of time and effort which means cost savings (Behzadi, 2016).

In the construction, safety has more importance to everyone who is participated in the project. Due to more accidents in this industry, many companies invest a lot of money into safety and trainings. Augmented Reality can reduce the cost of training for human safety. For example, using Augmented Reality tools on cranes will provide appropriate methods to select suitable cranes and location of them into different projects for project managers and it helps to reduce time of training for safety. Also, Augmented Reality tools develop work quality and reduce probability of accidents. The goal of

using this technology is trying to get a picture of real view to users during different stages before starting the actions in the construction projects (Behzadi, 2016).

Mixed Reality including Augmented Reality and Virtual Reality provides a unique tool for users with offering a 3D perspective that can be used in real-time and used efficiently and effectively to discover and analyse possibilities and simulations of the construction process (Woksepp & Olofsson, 2008).

Mixed Reality tools give an opportunity for users to navigate freely in real-time and interface and communicate with virtual objects in a 3D environment which is a Virtual Environment. This navigation increases the ability to move around and find some features in the virtual environment, and also users can interact and have the ability to control the virtual environment, for example, manipulate a virtual object and see the result of it (Woksepp & Olofsson, 2008).

Using Mixed Reality by increasing the visualization can help to improve communication and collaboration during the planning, design, and execution phase. In the planning phase by increasing the awareness of planners about interaction between different activities and resources. In the design phase by enhancing communication between designers during conceptual design and also in the execution phase by increasing safety and reducing the possibility of waste and hazards. The research results indicated that the Mixed Reality model helped the decision-making process and make a good representation of the future workplace (Woksepp & Olofsson, 2008).

In some cases, Mixed Reality was used as a tool to improve communication between constructors, non-constructors, and subcontractors on-site. It helped them to reduce possible waste and construction issues in the production phase which decrease construction costs dramatically. For example, many subcontractors used Virtual Reality before installation steps of different items like drainage, ventilation, and elevator shafts. The communication between those subcontractors and employees who work in the construction site and office provided by the virtual environment. This could able to show different elements which were theory and practice on-site. In construction projects, the benefits of using Mixed Reality in the planning phase and in the execution phase like on-site logistics are identified as saving time and avoid of reworks (Woksepp & Olofsson, 2008).

Mixed Reality tools are explained as a method to develop and improve the information, communication, visualization, and realizing in construction projects. Augmented Reality and Virtual Reality provide a 3D view for the users that can be manipulated in real-time. It can help to collaborate and simulate the construction processes (Woksepp & Olofsson, 2005).

In another research in 2006 by Westerdahl et al, showed that employees of a company shared their experiences of a Virtual Reality model in their workplace. The results showed that they had a good understanding of their future workplace and also Mixed Reality model helped them in the decision-making of the design process as well (Westerdahl , et al., 2006).

4D in Mixed Reality increases the ability to use a process that combined schedule information and spatial data. This method combines 3D models in a specific time and facilitates the analysis of various strategies before starting work on-site. In this 4D model, the project participants are able to review the planned and actual progress of the project in any time of the project. It helped them to have effective visualization of the project and analyse the problems related to process, construction schedules, and construction operations on-site (Woksepp, 2007).

Woksepp carried out that Virtual Reality as a Mixed Reality tool can be helpful and used to define options in design, simulate activities in construction, review design, increase communication and collaboration between team members, and indicate clash detections. He believed that the Virtual Reality tools has some benefits as followings;

- Cost reduction
- Risk minimization
- Efficient communication between stakeholders
- Earlier error defection (Woksepp, 2007).

VR as a Mixed Reality tool can show a design solution in the construction model to avoid errors. Using a VR model in the design phase to solve the transportation way, which is blocked by marked pipes, is shown as figure below.

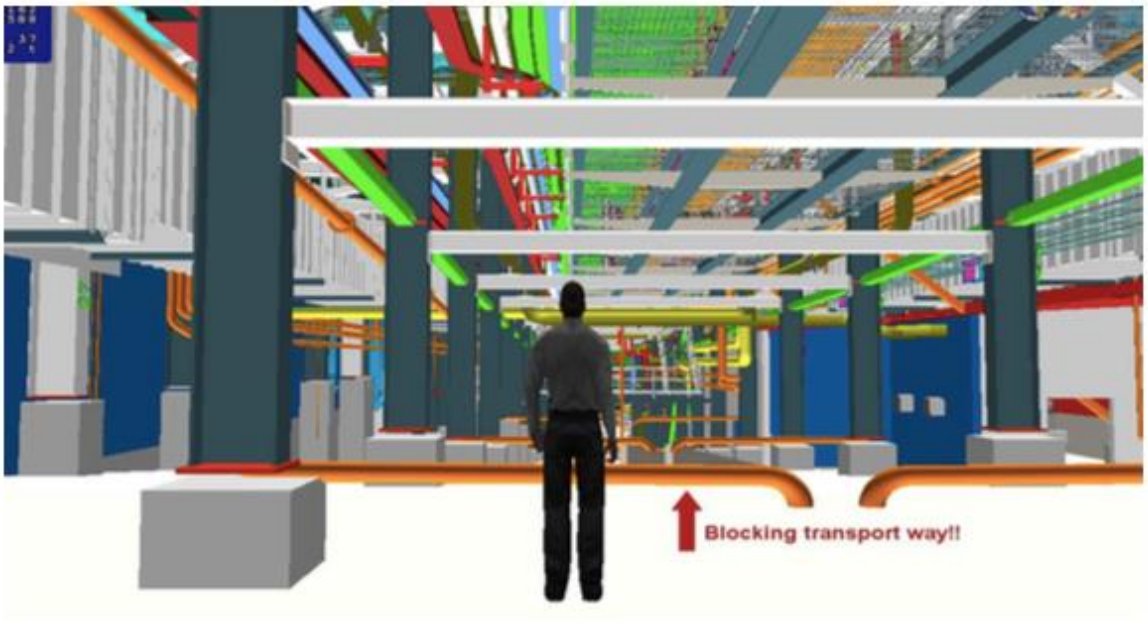

Figure 8 VR model in construction project. Source: (Woksepp, 2007).

Vilela Cruz in 2018 studied Mixed Reality concept in the architecture, engineering, and construction industry and explained that Virtual Reality is integrated on a virtual environment completely while Augmented Reality is using in real world with virtual elements. Three characteristics of Augmented Reality is pointed as followings;

- Is combined in the real-world with virtual elements
- Is integrated in the real-time
- Is defined in three dimensions

Augmented Reality is referred to virtual objects within a real environment in a real time which creates a mixed world. By using Augmented Reality, users are able to bring information to the construction sites. In construction sites, Augmented Reality is used through different application on smartphones or tablets. BIM model is brought to the site by Mixed Reality tools which increase the visualization while workers are in the real location and the digital model at the same time. These applications increase the ability of employees to have a better visualization of area like piping systems or electrical and mechanical systems. Employees can send warning information to avoid any hazard and to increase safety purposes on-site.

He mentioned that the Augmented Reality tools have more possibility to be used on-site in construction projects compared with Virtual Realty devices which are more effectively used in the planning design phase (Vilela Cruz, 2018).

3.3. Five case studies showing current use of Mixed Reality technology in construction

3.3.1. Construction Operation and Procedures

Case 1 A: Advanced Virtual Reality Applications and Intelligent Agents for Construction Process Optimization and Defect Prevention

Project brief:

Asgari and Pour Rahimian studied the effect on work optimization and waste minimization from implying Mixed Reality using different tools on the inspection, monitor and control process on construction sites to improve the process itself and determine possible high risks and defects.

During their study, they presented the use of different sensors during the execution process to monitor and report materials' quality aspects. One example was the use of special sensors (Smartrock2) placed within the concrete formwork to report some prosperities such as humidity, temperature, maturity monitoring of concrete and predict the strength of concrete. In terms of safety they presented DAQRI Smart Helmet to prevent injuries and alert from possible hazards on construction site (Asgaria & Pour Rahimian, June 2017).

By using Augmented Reality tools can enhance safety and able to show details for having a better decision making before start of the project. In figure below, using an Augmented Reality tool is shown before starting the operation phase of a construction project.

Figure 9 An augmented Reality tool in the construction operation. Source: (Meemim Inc., 2018).

Challenges:

The major challenges that limit the use of mixed reality tools within construction to enhance the logistics, health safety environment (HSE), and workers efficiency in operation were defined as;

- Dynamicity of construction products
- Unsafety and unsuitability of construction sites for high-tech monitoring system
- The disintegration of construction project teams
- Slow and error-prone construction project data collection systems

Findings:

Asgari and Pour Rahimian summarized their findings under the followings;

- Relying on optimal use of artificial intelligence
- Cybernetics and complex adaptive systems
- Development of a real-time intelligent observational platform
- Self-organized sensor (agent) network, for capturing and reporting real-time construction site data (Asgaria & Pour Rahimian, June 2017).

Therefore, in order to make up for the deficiency of the process monitoring system used in the construction site, augmented reality technology can be applied to the site as technical images, important information, and design changes to be applied to the site as virtual images. By checking the work contents in real-time through the 3D model in the construction site, it is possible to reduce the rework due to unexpected results, thereby reducing the construction cost and reducing the construction period, and real-time communication between the site workers and the project manager is possible.

In addition, people who do not have knowledge, like stakeholders, in the construction field can visually check and share information easily. Therefore, the construction project is expected to be transparent and easy to understand. As an example, the site employees can check the construction site and the augmented 3D model, proceeds with the plan, and if it does not match, send the current status to the project manager away from the site and receives the revised information. By adopting augmented reality, it is possible to intuitively view three-dimensional models in the construction site, as a result of that reducing problems caused by construction failure. Thus, efficient and planned use of resources and optimization of allocation and rework and process delays can be minimized (Asgaria & Pour Rahimian, June 2017).

Using an Augmented Reality tool to increase visualization and reduce the possible defects in the construction operation are shown in the figures below.

Figure 10 Augmented Reality in the construction operation. Source: (Avatardigital, 2019).

Figure 11 Using the Augmented Reality in the construction operation by employees. Source: (Alder & Suerth, 2019).

Figure 12 Using the Augmented Reality by employees on-site. Source: (Fusionpeople, 2019).

Case 1B: Virtual experiment of innovative construction operations

Project brief:

Li et al. studied the effect of Virtual Reality as a Mixed Reality tool on construction operations. According to Li and et al., the planning for construction operation phase is a complicated step which include planning of required materials, drawings, resources, safe working place for labours, and sequence of works. They believe that using the Virtual Reality for construction planning can increase the understanding of the construction process. Also, Virtual Reality creates a virtual environment with objects in the real-world and provides an ability for users/planners to interact with the objects.

Mixed Reality can minimize the waste of the time during the planning phase and avoid a lot of rework in the construction phase. It helps construction planners to evaluate and validate the project's planning. In this study, they presented a Virtual Reality system to create a reality construction environment for planners to familiarize themselves with the physical construction process (Li, et al., 2003). Figure below shows the installation of elements in a virtual environment, so the employees have a better understand of the installation in the operation phase and also, they can reduce the extra time for installing and save more cost.

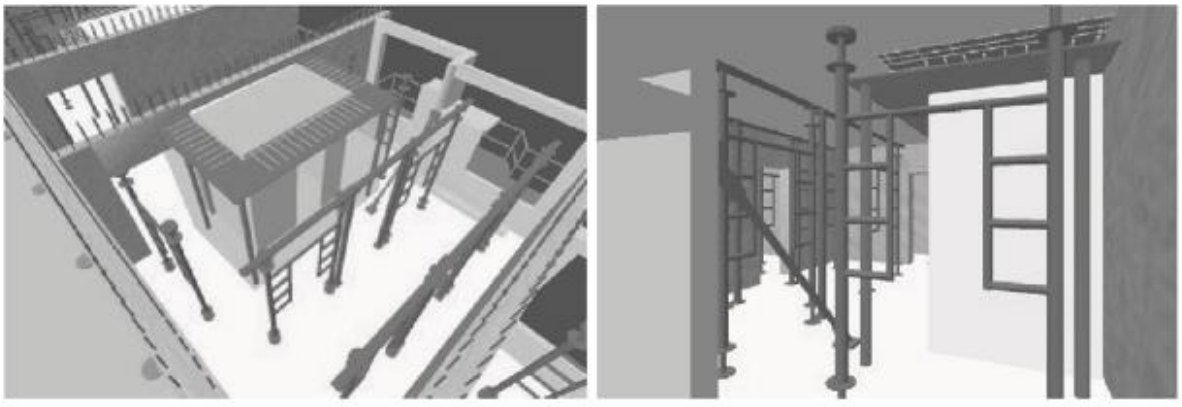

Figure 13 The visualization of elements in a virtual environment. Source: (Li, et al., 2003).

Mixed reality can increase visualization during construction operations. The visualizing of the concreting activities, building elements, and required labours during the construction operation are illustrated in the figure below.

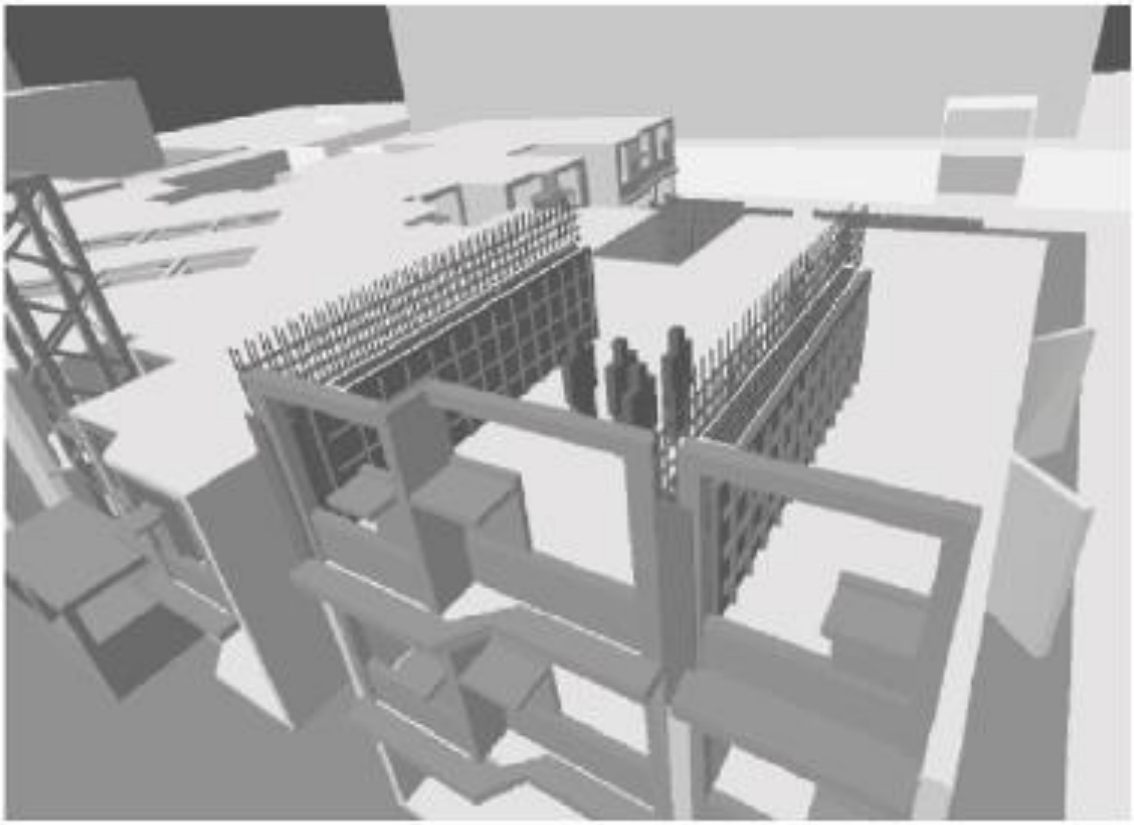

Figure 14 The visualization of concreting operation. Source: (Li, et al., 2003).

Mixed Reality tools and applications are able to help planners and project managers and also as figure below show them different capabilities by different options. For example, the main operation option, plant operation option, and the status option of the project are able to help them.

So, they can just by clicking on each Option/Window; interact with the virtual environment in different positions and elevations, view the virtual environment form the plant operator, and realize the progress of the construction works of each activity (Li, et al., 2003).

Figure 15 The site operation environment. Source: (Li, et al., 2003).

Advantages and Challenges:

As an advantage, this Virtual Reality system makes a safe and inexpensive option for construction operations which avoids wasting resources and saves time. They believed that the system increases the user's understanding of construction operations which is included proportionality of the planning sequences and deployment of required resources.

As a challenge, the proposed system can only simulate main building objects and processes, therefore, there is a need for more work to provide a realistic environment for simulating construction operations (Li, et al., 2003).

Conclusion:

Virtual Reality system provides the planners with a visual aid in a similar scale to actual works for the construction processes and operations as well as a full control on the time frame; so, the planner can examine the construction processes and

operations in slow motion, fast motion, or even pause to get specific details. This can support the planners in having a precise vision of the construction works to be done, therefore, proper resource estimation, durations estimation, associated cost, and sequence of works. This can be even done during the interaction with the virtual environment, where planners are actually able to rectify resources, durations, and etc. simultaneously.

3.3.2. Health Safety Environment:

Case2:

A critical review of virtual and augmented reality (VR/AR) applications in construction safety

Project brief:

Li and et al. reviewed Virtual Reality and Augmented Reality applications in construction safety because of high possibility of hazard to workers in the site. They believed that it is hard for many companies to make sure their employees are supported and protected from injuries and death by accident. Therefore, using Mixed Reality can get the opportunity to increase visualization of complex workplace situations by make a virtual environment. In this study they reviewed a wide range of journals and classified Virtual Reality and Augmented Reality technology characteristics, safety scenarios, and evaluation methods. They focused in implying the Mixed Reality tools to;

- Hazard identification
- Safety training and education
- Safety instruction and inspection (Li, et al., 2018).

Increasing awareness of safety terms by using a Mixed Reality tool in the construction site is shown in the figure below.

Figure 16 Increasing awareness of safety terms by using a Mixed Reality tool in the construction site. Source: (Raafat, 2018).

Challenges:

Here are some major causes of accidents in construction but not limited to;

- Risky and hazardous site environment

Construction site happens to have a lot of activities and people working in the same time and with poor management and safety control; an increasing potential of having near misses, incidents, accidents, and fatalities become possible.

- Unsafe workers' behaviours

As known workers on construction site come from different countries with different cultural backgrounds which might create conflicts and misbehaviour during the execution of the project. Such events will affect the safety and health environment on-site.

- Unsafe working sequence

Construction tasks are complex and require a proper understanding for both the methodology of execution and the sequence of work.

- High-risk equipment operation

Complexity of construction site includes the different types of machinery and equipment operating at the same time which might create a hazardous environment for workers if not managed properly (Li, et al., 2003). In figure below the marked areas are the view safety zone.

Figure 17 AR-based wearable glass for construction safety. Source: (Ahmed, 2018).

Conclusion:

Therefore, they introduce the following areas of improvement to overcome the aforementioned challenges;

- Working environment
- Worker's behaviours
- High-risk equipment
- Work sequence

The main idea they based their approach on is to focus on using Mixed Reality to increase the safety awareness of workers by training them how to identify safety hazards, how to treat them, how to avoid similar hazards in the future, setting up a visual standard regulation for workers behaviour on-site and ensure its well understood. On the other hand, the use of Mixed Reality tools to visualize and plan the operation of machinery and equipment along with the sequence of work and ensure people in charge are aware of it (Li, et al., 2003). In figure below, AR-based construction crane safety application is illustrated.

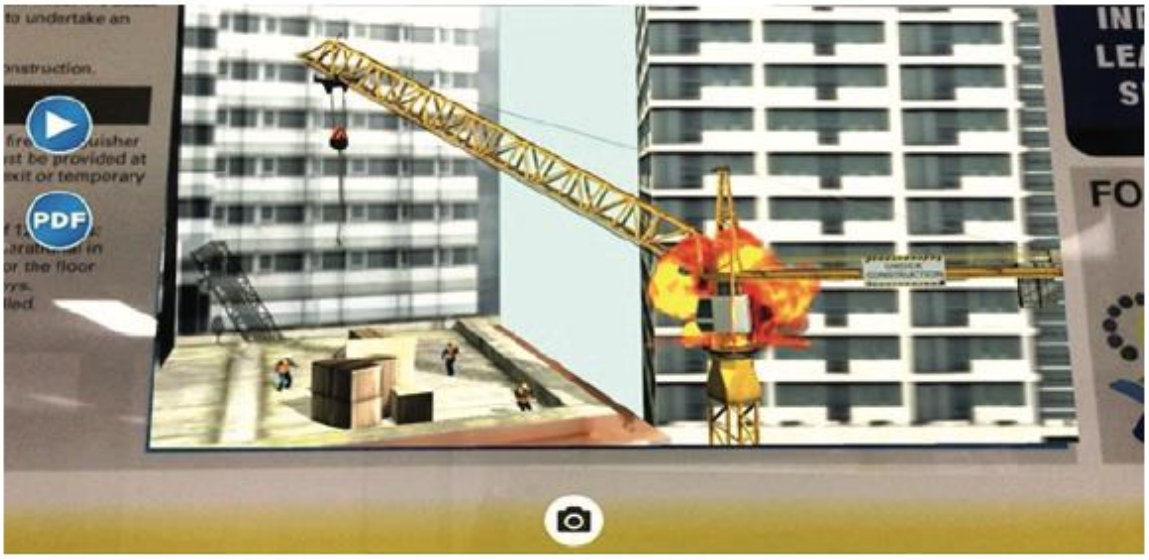

Figure 18 AR-based construction crane safety application. Source: (Ahmed, 2018).

Therefore, the application of visualization technology by using Mixed Reality Tools has the potential to improve the effectiveness and efficiency of safety management activities and it can increase the clarify of hazards and risks in the construction projects. Virtual reality and augmented reality are effective technologies to complete the lack of information in sharing and utilizing safety management information. As an example, users can select the risk factors related to the work, select the parts that the hazardous risk factors can affect the workers, and input them to the virtual site by using Mixed Reality Tools (figure below); so, the awareness of employees will increase, and the probability of the risk will be reduced. Also, it can be used as a training tools for increasing the awareness of workers at the construction site.

Figure 19 Mixed Reality in safety. Source: (Moduluc, 2019).

The hazards assigned to the virtual sites is depicted in the figure below. Then, the HSE officer can show these risky places to the employees and workers to apply necessary actions to stop and avoid possible hazards.

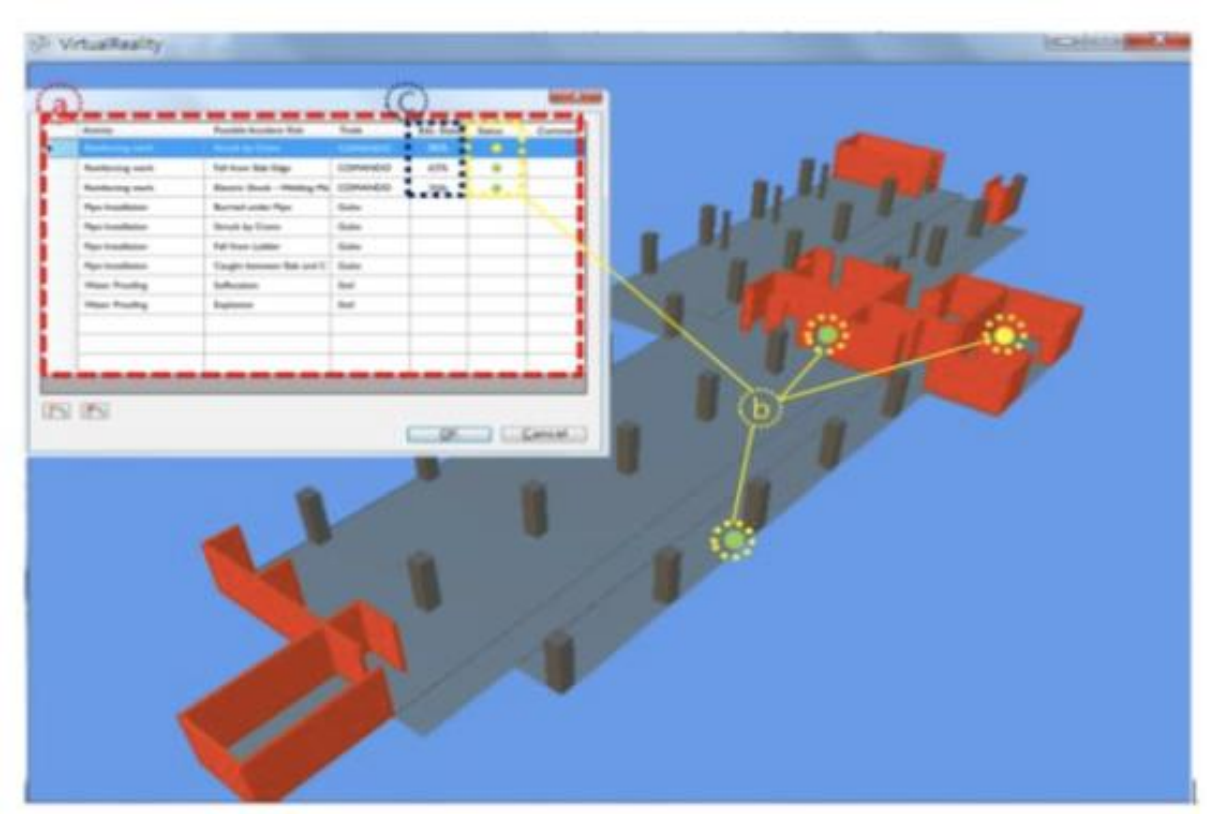

Figure 20 Hazards assigned to the virtual site. Source: (Li, et al., 2003).

3.3.3. Construction Logistics

Case 3A: Augmented Reality in Logistics

Project brief:

Cirulis and Ginters in 2013 studied the basic logistics' elements to improve possibilities in handling, storage, and transportation phases which is related to manpower and resources. They believed that by using Augmented Reality to visualize processes in logistics the rate of error will be reduced, and also decision-making time will be optimized. Integrating objects as a 3D model on a Head-Mounted-Display (HMD) or tablet is more realistic. Augmented Reality can be used to locate a worker and improve its location in the virtual environment (Cirulisa & Gintersa, 2013).

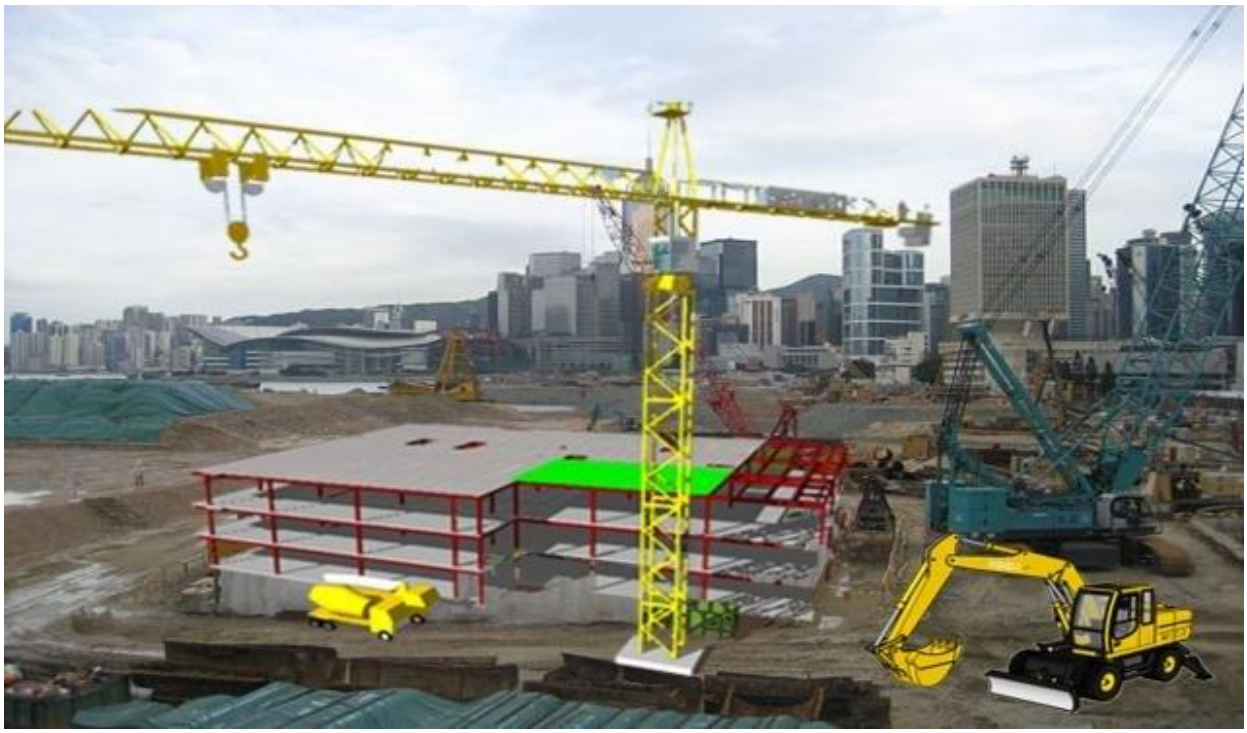

Figure 21 Augmented Reality in Logistics. Source: (Rohani, et al., 2012).

Challenges:

They explained that the major challenge in logistics is the cost of wearable devices. In other words, using Augmented Reality tools for the purpose of logistics could be only cost efficient if applied to large scale projects, in this case the efficiency added to the project execution process as well as the savings in time and cost would be higher than the cost of using the Augmented Reality tools (Cirulisa & Gintersa, 2013).

Conclusion:

One important factor that Augmented Reality offers is a visualization of detailed project's elements and the interaction among them with minimum efforts. This will influence the accuracy of the details in the logistics plans as well as reduce the possibility of mis-coordination, errors, and waste in the plan. All of that will lead to improving the master logistics project plan, and on the other hand, it gives the opportunity to test and visualize the established logistics plan before even moving to the execution on site. The other important factor is the training element; where Augmented Reality tools offer logistics trainings in line with the master logistics project plan for individuals involved

in project execution phase, this will impact the efficiency of the individuals as well as reduce the possibility of mis-coordination, errors, and time waste by individuals (Cirulisa & Gintersa, 2013).

Case 3B: Using Augmented Reality to Plan Virtual Construction Worksite On-site Logistics

Project brief:

Wang in 2007 studied using Augmented Reality to plan virtual construction worksite. So, he figured out that planning for worksite by using Augmented Reality will minimize possible errors and reworks. AR can improve the architecture visualization, process of design, processes of building construction, and logistics management system. Virtual information can be brought by Augmented Reality into real world view of users to get better visualization of position of critical elements (Wang, 2007).

Challenges:

Although implementing Augmented Reality in construction shows positive potential of improvements, some issues and challenges which Wang found are as presented below;

- Preparation of reality model

In order to apply virtual information into the real-world environment, Augmented Reality needs to obtain a description of the real environment precisely.

- Extraction of industrial domain knowledge

2D drawings are presenting information more than 3D models in the construction due to lack of well-organized 3D database; which supports information source. So, there is a lack of efforts to create an Augmented Reality database with appropriate formats.

- Technological limitations

Technical limitations are the main barrier to Augmented Reality systems, for instance, AR needs accurate long-range and trackers that user and the surrounding objects' location will report in the environment.

- Social concerns

For transferring AR technology there is a lack of motivation where people usually are afraid to accept new technology and also, AR is a determined cost-effective solution (Wang, 2007).

Conclusion:

Augmented Reality can affect construction logistics and the implementation of the AR system in the planning phase assists people and minimize the potential of the errors which occur in the planning phase for logistics. On the other hand, the efforts, time, skills, knowledge, and budget required to develop the Augmented Reality environment is holding back the idea of implementing AR in the field of logistics (Wang, 2007).

3.4. Challenges of using Mixed Reality technology

According to researches and case studies which are studied in previous section; the main challenges and limitations by using Mixed Reality tools in execution phase are as following table;

Table 1 Main Challenges by using Mixed Reality Tools in Execution phase. Source: Author.

Main Challenges by using Mixed Reality Tools in Execution phase

Operation

- Dynamicity of construction products
- Unsafety and unsuitability of construction sites for high-tech monitoring system
- The disintegration of construction project teams
- Slow and error-prone construction project data collection systems (Asgaria & Pour Rahimian, 2017).
- More work to provide a realistic environment for simulating construction operations (Li, et al., 2003).

Safety

- Risky and hazardous site environment
- Unsafe workers' behaviors
- Unsafe working sequence
- High-risk equipment operation (Li, et al., 2003).

Logistics

- Cost of wearable devices (Cirulisa & Gintersa, 2013).
- Preparation of reality model
- Extraction of industrial domain knowledge
- Technological limitations
- Social concerns (Wang, 2007).

In addition, three main challenges by using Mixed Reality in construction projects are as followings;

- Additional cost; Using Mixed Reality technology requires a cost to operate in the execution phase including hardware and software. Working with a VR, AR, and XR system can be expensive especially on a small scale of the project.
- Additional time; Implementing Mixed Reality technologies take time because it needs to prepare hardware, software, cod reader, and training which add more time to implement this technology in the projects.

- Limited skills and knowledge; The challenges could be more complex when there is no knowledge or skills to use the Mixed Reality technology (Quad Cities Manufacturing Innovation Hub Playbook Series, n.d.).

3.5. Lean Construction Theory

Lean construction is the most common approach lately in the construction field, in this chapter, the author will shed the light on; firstly, the history of Lean principles concept, secondly, Lean Construction and its characteristics, and finally, Lean Construction techniques.

3.5.1. Background

Back into the 80s, production industry was booming as the world economy were growing rapidly. Despite that, achieved profit was not promising as expected for different reasons but most importantly the amount of waste generated through the production process. This triggered an alarm that waste is a serious issue in production, and it has to be dealt with and sorted out. Not until 1987 where engineer Ohno in Toyota has set up the basis of Lean theory in production relying on the Just in Time (JIT) delivery method to reduce the waste in production process, time, and handling. His idea was to run the production line based on the demand. In other words, shutting down the production line when there is no demand, this was a bit weird for the workers at Toyota which they believed that more production means more profit. (Howell, 1999).

3.5.2. Lean Construction Definition

Lean Construction is a theory based on Lean manufacturing concept. It is about managing and developing the construction process to ensure full delivery to the customer in-line with project value. There are two major terms that Lean Construction targets in project development; value and waste. Value is reflected by the three main elements of project management; quality, time and cost. On the other hand, waste is reflected by time and cost mainly.

Koskela in 2002 based on The Foundation of Lean Construction, defined Lean as “A way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value” (Koskela, et al., 2002).

Reducing waste generation, optimizing construction processes, focusing on valuable works, and achieving better communication and coordination throughout the project life cycle supports the concept of Lean Construction and ensures a proper delivery process as per the requirements of the Client (Ansah, 2016).

Two major practices in construction are supported by Lean construction; (Howell, 1999)

- Planning: the project goals are achieved by specifying clear strategies. These strategies are supported by different processes during the project development.
- Controlling: ensuring that the project development is in-line with the delivery plan and forcing corrective actions when necessary.

Planning is an important practice in construction to define efficient processes and methodologies which lead and manage, perform and control the project. Planning assigns different resources to the project based on the requirements, also estimates cost and defines the sequence and workflow. The lean Construction concept focuses on two main areas; increasing the value of the work and reducing the possible waste in the resources which is the main point of the planning step.

Scheduling is defined as a process to reflect the planned works into different tasks with specific resources, the work sequences, and costs. A master schedule is the output of the planning process and for the monitoring and controlling purpose used by involved parties. The main aspects of Lean Construction must consider in the planning step are;

- Milestones planning; the project phases should be determined to support quality, time, and cost point of view.
- Resources; optimization of resources to avoid extra costs.
- Cash-flow; considering positive cash-flow for client and contractor to secure the funding.
- Workflow; work sequence should be considered as a smooth continuous work to avoid possible delays, clashes, and interruptions.

- Execution monitor and control; on-site activities are in-line with master schedule of the project, so deviations are identified, analysed, and reflected into the revised schedules.

The purpose of planning and scheduling is to optimize project resources; it can be achieved by ensuring a clear and smooth continuous workflow is planned. It can be reached by implementing different techniques like location-based planning, takt-time planning and pull planning. To have a properly monitor and control in the execution phase, the last planner system technique should be considered (Koskela, et al., 2002) and (Ansah, 2016).

Lean thinking changes the classical management style from a supply based to a demand based, a maximized flow to an optimized flow, and a quality driven to a value driven. Further next, Lean Construction as any other theoretical approach relies on practical tools and techniques to support its main characteristics through execution process.

- **Characteristics of Lean Construction**

The main characteristics of Lean Construction which add benefits to the project are described as followings;

- **Value of Work**

The value of the work is the maximum possible value that is achieved by meeting the expectation of the clients and ensuring their satisfaction according to the best price and quality (Garrido, et al., 2009). The main goal of Lean Construction theory is explained as adding value to the clients and reducing the aspects which have no value (Shillito & De Marle, 1992). Lean Construction has two main aims; understanding the value of the project and organizing the processes that make sure the necessary value is met and reduce the effect of invaluable elements (Garrido, et al., 2009).

- **Minimizing Waste**

Waste generally is determined as invaluable products, services, processes, and activities that happen during a certain time in a project. Waste in construction is defined as all services and processes that use resources without increasing any value to the

project (Ansah, 2016). Shingo in 1984 defined the classification of construction wastes based on the cause of waste, construction systems, materials, construction operations, waiting time in transportation, oversupply, and defects. Koskela in 1992 also identified construction waste as construction reworks, design mistakes, changes in scope, execution defects, and oversupply of materials (Koskela, et al., 2002). According to Nikakhtar et al. in 2011, waste in construction is classified in figure below that shows the waste categorization based on Lean Construction concept; construction site, external factors, and construction processes (Nikakhtar, et al., 2015).

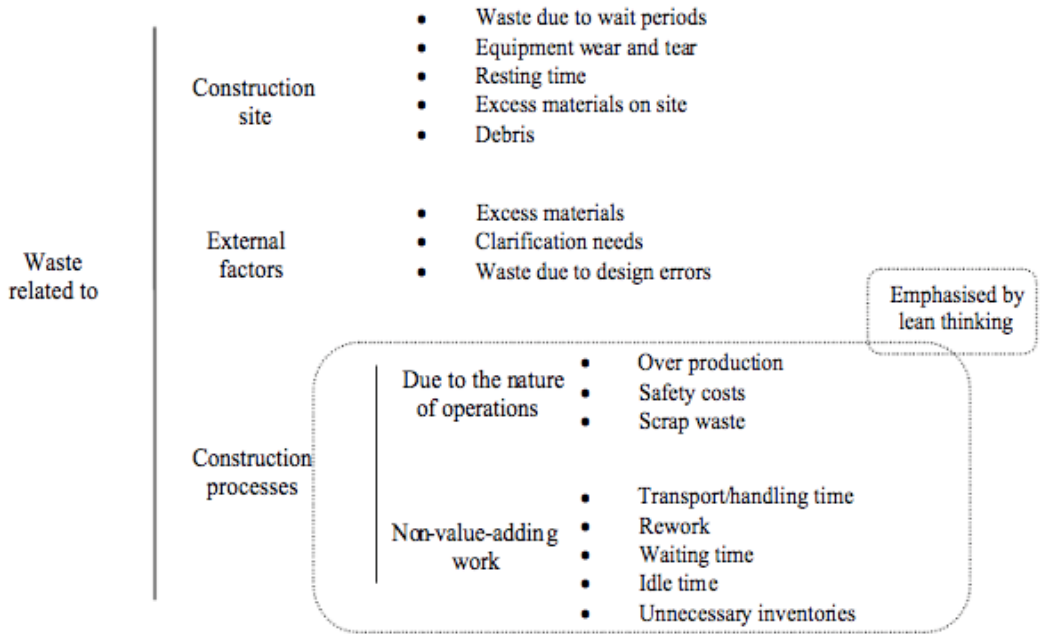

Figure 22 Waste classification considering the Lean Construction concept. Source: (Nikakhtar, et al., 2015).

In figure above, waste related to construction processes is a significant issue in the Lean Construction which is divided to two categories; waste caused due to nature of operations and waste caused due to non-value-adding works.

- **Optimizing Workflow**

A construction project includes many activities within a certain time and budget. Some interruptions occur in all construction projects like the pause of works, costs, and delays. Many factors affect the project workflow and make these interruptions which including design elements, permits, operations, resources, material supply, decisions

by management teams, communication issues, and other external components. Lean Construction's goal is to minimize these interruptions factors and define a smooth workflow. The workflow in construction, as figure below, is determined as carrying out information, processes, and resources like activities to achieve main goals in the project (Garcia & Fischer, 2016).

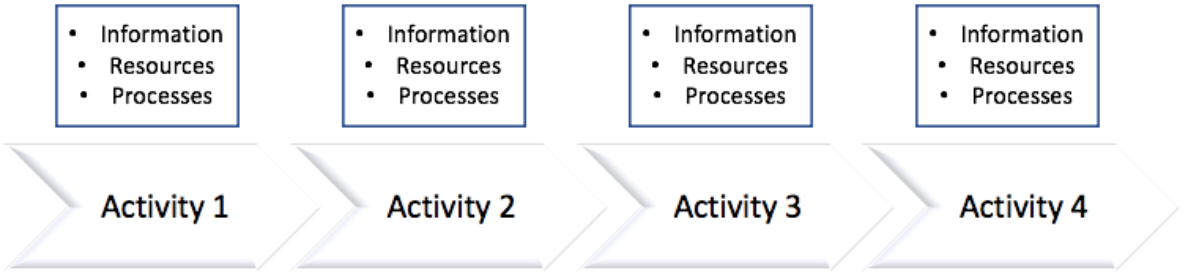

Figure 23 Optimized construction workflow. Source: Author.

- **Just in Time**

The Just in Time Concept was set up in the production industry by Taichi Ohno at Toyota, he believed JIT happens when changing the production system from an estimated demand to actual demand in order to reduce works in the process. Reduction in flow changes will be achieved by implementing JIT, resources were faced only when required which cause the elimination of extra handling and operation costs of resources.

There was a doubt to use the JIT concept in construction projects because construction has more uncertainty and different flow. The construction project is a schedule-driven process, this means if the execution goes perfectly therefore there are no problems to occur in execution. But, unfortunately, this concept is far from reality as construction execution is affected by many elements which cause delays and interrupt the work. One approach to dominate delay in the execution phase is utilization of buffers in construction projects. Schedule buffer and plan buffer are two types of buffers in construction schedule. Schedule buffer is the time gap for the resources required to implement a certain activity. Plan buffer is the buffer for the accessibility of the work front because of the construction work sequence (Ballard & Howell, 1995).

- **Reduce Cycle Time**

Cycle time is defined as a required duration to produce a product in the production phase. It is described in construction, as the required duration to achieve a set of tasks which are repetitive during the project like structural works, finishing works, and road works. Cycle time is defined by estimating the required duration to implement each individual task through set of activities. Each task relies on different resources and certain productivity to perform it. Therefore, the main key is the task productivity to reduce cycle time, while work sequence and construction methodology affect the cycle time as well. The main three elements which effect on activity cycle time are as followings;

- Productivity
- Construction sequence
- Construction methodology (Ridwan, 2016).

- **Making Improvements Happen**

Lean Construction concept control; the relations between processes and analysing each process itself. It can let users take construction activities and have an overview of all inputs and factors which affect a single process. During the construction projects, each activity is affected by three main factors; information, resources, and processes to implement the activity. Each factor, also, is affected by different sub-factors as figure below.

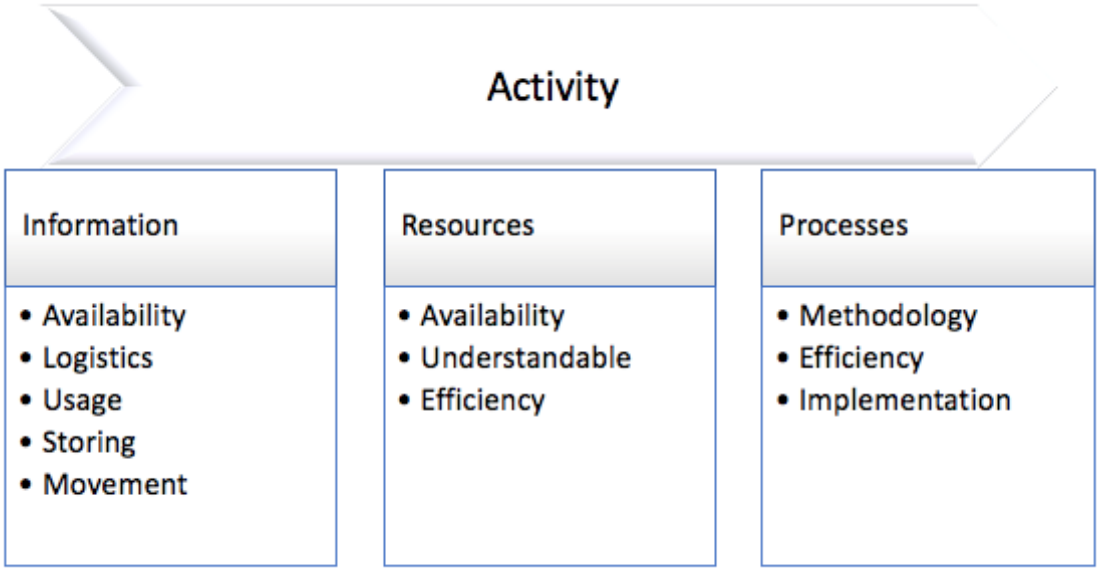

Figure 24 Factors and sub factors affecting a construction activity. Source: (Garcia & Fischer, 2016).

In every single sub-factor, the improvement can be considered. For example, by implementing JIT, the available resources can be controlled and organized and also improving logistics on-site minimize waste of time by managing the site access and the material allocation. This improves space management in or on-site and then reduces waste due to proper storage and resource movement. This can apply same to the information; to ensure the information is delivered on-time, within the needed efficiency, and in the proper form which is able to eliminate waste due to misunderstanding and wrong implementation. It affects processes by defining methodologies and make sure the proper and right implementation eliminates the defective execution of work and reworks (Garcia & Fischer, 2016).

- **Techniques and Methodologies**

The main techniques and methodologies that support the Lean construction concept to help the implementation process are explained as followings;

- **Lean Work Structuring (LWS)**

Lean Work Structuring defines the objective of a unique project from a lean point of view. In the construction, this concept applies as well by breaking down the project

to explain the value and possible waste. This LWS determines the Lean activities in the project and also the effect of each activity on the Lean aims set for the project (Ballard, et al., 2002).

- **Pull Planning**

In construction projects, Pull is using as the concept of executing based on downstream works. In the past, construction projects rely on the Push concept that means perform whatever is ready. The pull planning technique used to plan the activities' flow and information according to the downstream work request. The possible risks affecting cost, quality, and time should be considered by involving and collaborating all parties in the construction projects (Heery, 2015).

- **Takt-Time Planning**

This technique works aligned with the Last Planner System and the goal of Tack-Time planning is to generate an efficient environment that is suited for the Last Planner System's activities. A construction workflow is created by Tack-Time planning while the Last Planner System controls and stabilizes the flow. Tack-Time by creating a workflow construction zones organizes the work of the construction trades to ensure there is no trade clash with others and the work is completed during the plan (Frandson, et al., 2013).

- **Last Planner System**

Last Planner System explains the actual individuals performing the works on-site based on the plans and schedule. This system involves the on-site responsible person for performing the activity in the planning step. It helps to create a clear vision about what, how, and when the activities will be performed. Then, it can simply be monitored and acted in case of any errors happened. (Ballard, et al., 2002)

- **Kaizen and 5S**

Kaizen refers to a continuous improvement that involves all in the company including top management, supervisors, and staff. Kaizen is a Japanese theory of continuous process improvement that can be directly attributed to the origin of the Japanese words ' Kai ' and ' Zen', which translates roughly into breaking apart, analysing and improving the current situation. Improvement starts with the recognition that every

company has issues that can provide opportunities for improvement and change. This develops through continuous improvement including everyone in the company and depends on cross-functional teams (Gupta & Jain, 2014) and (Nowotarski, et al., 2016).

5s is including five terms in production that consist of a cycle; Sort, Set in Order, Shine, Standardize and Sustain which they are transferred to construction industry as identify status, remove unnecessary resources, eliminate inefficient activities and practices, organize and sort-out, and establish guidelines and standards (Ho, et al., 1995).

3.6. Lean Construction in Execution Phase

This part will focus on lean principles and techniques in the execution phase to make sure all daily tasks is achievable on the construction site. The goal of site management is implementing all resources including manpower, machinery, and material in the construction project which is achieved by having a clear plans, logistics, and supervisions. Handling all of these inputs and coordinating them is a challenge during the project which generate waste through activities on-site; material waste, safety problems, and improper productivity.

Therefore, Lean Techniques like Kaizen and 5S which effect on site environment, logistics, and work execution can be used in construction execution. The processed of Kaizen and 5S are explained as followings;

- **Kaizen:**

Kaizen refers to a continuous improvement that involves all in the company including top management, supervisors, and staff. Kaizen is a Japanese theory of continuous process improvement that can be directly attributed to the origin of the Japanese words ' Kai ' and ' Zen', which translates roughly into breaking apart, analysing and improving the current situation. Improvement starts with the recognition that every company has issues that can provide opportunities for improvement and change. This develops through continuous improvement including everyone in the company and depends on cross-functional teams (Gupta & Jain, 2014).

The concept of Kaizen seems to be that the people who carry out a certain task are the most knowledgeable of that task; therefore, by involving them and showing trust in their skills, awareness of the process is increased to its highest level. Involving all organization employees make a room for efficiency improvement and also it can encourage innovation and change (Gupta & Jain, 2014).

From this point of view, Kaizen is not only an approach to manufacturing competition but also it is related to everyone in the company because Kaizen's philosophy is focused on the idea that every individual has an interest in improvement. The idea of the Kaizen is to make process easier for people to work by taking them apart, learning and making improvements. The message is applied to everyone in the company, so that everyone is a participant. Rather than describing workers as a challenge, Kaizen points out that the process is a goal that employees will make improvements by realizing and improving how their roles fit into the process (Gupta & Jain, 2014).

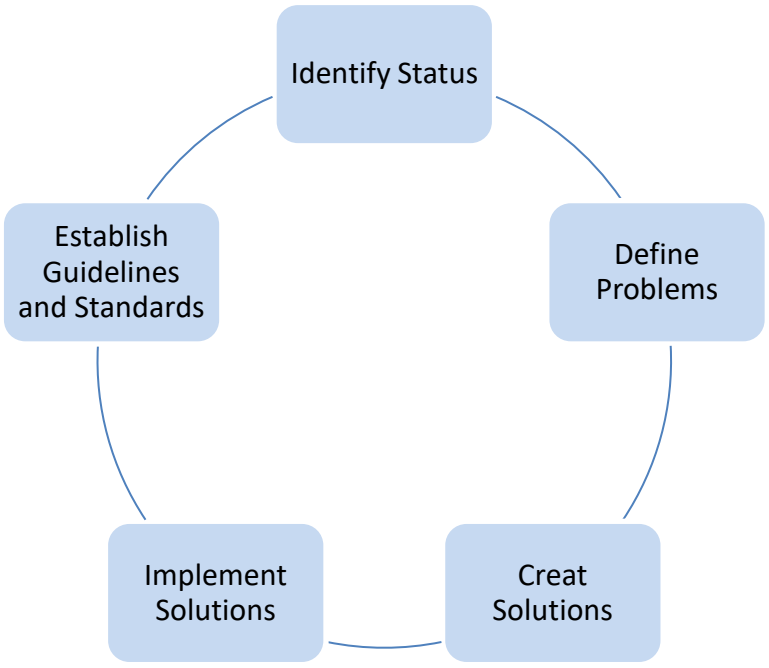

Figure 25 Kaizen cycle to improve construction processes. Source: Author.

Improving the quality of the process requires the use of different tools and techniques to be put in place and training for managers and operators that it can be provided and supported by Mixed Reality. Mixed Reality can increase the role of visual management as an idea and a tool that is promoted in Kaizen by individuals or team members that help people identify problems or encourage motivation.

Mixed Reality can help visual management by involving the clear display of tangible objects, schedules, charts, lists, records of performance. Therefore, both the management team and employees are continuously reminded of all the principles and elements. The visual controls make it easy and simple for everyone to recognize the state of a normal or abnormal situation. So, the management team can monitor and control progress and activities before the project starts in the execution phase to avoid any reworks, save time, increase the value of the work, and reduce waste. Also, Mixed Reality can increase awareness of employees from the workplace through some training and workshops.

The following points are highlighted by using Mixed Reality within Kaizen point of view;

- Improvement of safety
- Making critical information
- Increasing measurable results
- Increasing awareness of employees and end-users
- Reducing possible waste
- Improvement of quality
- Decreasing the reworks and save time
- Increasing communication and collaboration

Identifying a need is the starting point for improvement, therefore, the concept of Kaizen emphasis being able to aware of problems and then provide clues to recognize problems which means Kaizen is using as a problem-solving process. Next step of Kaizen is implementation of solutions and then it focuses on establishing standards and guidelines.

- **5S:**

5s is including five terms in production that consist of a cycle; Sort, Set in Order, Shine, Standardize and Sustain which they are transferred to construction industry as identify status, remove unnecessary resources, eliminate inefficient activities and

practices, organize and sort-out, and establish guidelines and standards (Ho, et al., 1995). In the figure below, the 5s cycle is shown.

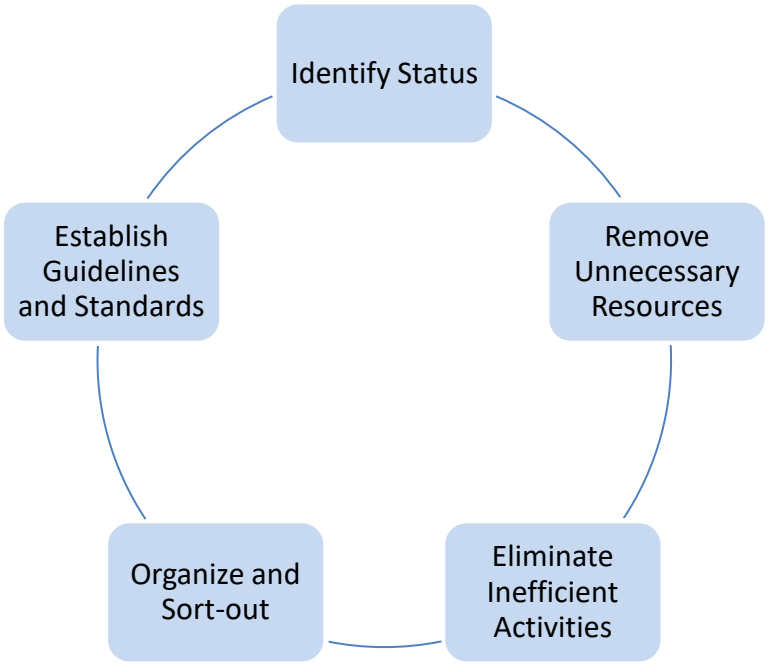

Figure 26 5s cycle to improve construction processes. Source: Author.

The first step in 5s is to identify the status of the work and all activities and sort all unnecessary resources and items which are not required in the area of the work and in the next step, eliminate these items and replace them into other places (Gupta & Jain, 2014).

It is noticeable to note that Mixed Reality tools can help to recognize the environment by visualizing the area and then monitoring activities to make sure that all resources are using in the right place.

Eliminate inefficient activities is the next step of the 5s cycle. In this step many pictures should be taken before and after to see the different of the process improvement. By organizing the processes in the next step, all activities and resources are clear based on a schedule and also the maintaining plan is created in this part. In the last step of 5s cycle, specific guidelines and standards are specified to have a simple process for each activity in the site to increase the improvement.

The site environment is identified as all factors affecting the working environment within the limits of the site; the allocation/interaction of employees, material stores, on-site warehouses, machinery and HSE factors.

As explained under lean construction techniques; kaizen and 5s are techniques to observe site issues, improve and ensure non-reoccurrence through project lifecycle; learning workshops, setting up standards and regulations, and implementing continuous site issues tracking. Site management can be improved by applying the Kaizen and 5s method in the analysis of on-site activities for different projects, and then using the results to provide site management plans; method statements, safety management plans, quality management plans, environmental management plan, human resource management plan, and logistics management plan. These plans will be shared with project participants, workshops will take place to discuss and spread the knowledge among the project team and updated regularly to fit project execution processes.

3.6.1. The Major challenges of integrating of Lean Construction Principles in execution phase

The Lean Construction is a new concept in the construction project which many challenges and limitations influencing the performance of this technology. Sarhan in 2012 figured out the main challenges affecting the implementation of Lean Construction that are related to (Sarhan & Fox, 2012) and (Bataineh, 2019)**;**

- Lack of awareness and understanding of the lean construction principles; issues in awareness of Lean Construction and implementation of it.
- Lack of top management commitment and support; which usually the results of the performance of Lean Construction concept can be realized in the long term and with a lack of patience, inefficiency occurs.
- Variable cultural backgrounds; where the various cultural trend reacts differently in the understanding of Mixed Reality and Lean Construction concept.
- Additional Cost, time and efforts; for implementing Lean Construction concepts, participants should dedicate more effort and time, so it is hard to ask them to spend more money and time to apply Lean Principles in the project.
- Improper implementation of lean construction techniques.

After identifying the possible challenges and limitation affecting of Lean Construction, there some proposed items to reduce challenges (Kawish, 2017) and (Bataineh, 2019);

- Workshops and training; carrying out some trainings to explain Lean Construction concepts and techniques as well as benefits of Mixed Reality technologies.
- Participants and users; Involving all users and participants in the decision-making process which can add more value to the project.
- KPI system; Setting up a KPI system to measure the efficiency of Mixed Reality and Lean Construction in the execution phase.
- Legislation; creating rules to follow and an implementation handbook that works as a leader to adopt the Lean Construction within Mixed Reality technologies.

3.7. Integration of Mixed Reality into Lean Construction in Execution Phase

In the previous section and based on researchers' papers in the field of lean construction, the author highlighted main improvements lean construction techniques can bring into the construction projects and specifically the execution phase. So, under this section the author identifies the possible connection of using Mixed Radiality tools for the purpose of supporting Lean Construction goals.

In order to identify the possible connection between mixed reality tools and lean construction goals the author defines two main elements which helps in analysing and connecting both techniques.

3.7.1. End users

One major aspect in studying the influence of mixed reality on the execution of construction projects is defining and analysing the end users which are involved in implementing and getting advantages from the different tools of it. The followings are

the main end users with direct influence and impact on using mixed reality within construction projects;

- **Client:**

A person or an organization which could be public or private with a certain idea of development to support defined goals and objectives reflected in a project. As a client the main concerns are achieving the project's objectives and goals by ensuring the main three pillars of project management are met; cost, time, and quality (Smith & Love, 2004) and (PMI, 2013).

Mixed reality can benefit the client by visualizing the project's progress in terms of cost, time and quality using a 5D BIM based model. This allows the client to visually track the expenditures throughout the project life cycle, therefore, achieve better control for project's funding. In addition to that using a 5D BIM based model presented by the use of different mixed reality tools takes the client in a virtual journey that accurately reflects project development which helps to minimize the conflict and simplify the process in case of any variation orders are requested.

- **Stakeholders:**

Stakeholders are any person or organization with a direct influence on the project or interests from the project such as; banks, government, investors, and society. Stakeholders are concerned in identifying their interface with the project in order to determine and track their profit and interest. Mixed reality by providing a visualization of the project development makes it easier to perceive full awareness of the project's progress (PMI, 2013).

- **Project management:**

Project management are the people who are in charge with ensuring that the project develops in a way that meets the planned criteria in terms of cost, time, and quality. This is achieved by maintaining proper coordination, cooperation and communication among all parties on board. Mixed reality provides a visual platform that can serve this goal and minimize the efforts required for the management process. Using the 7D BIM

model all aspects of cost, time, safety, and even sustainability can be managed visually at an early stage of the project execution (PMI, 2013).

- **Engineers:**

Engineers are responsible of monitoring and controlling all project aspects throughout project execution, starting from setting up detailed plans of construction methodologies, defining execution logistics, tracking down quality aspects, monitoring the productivity, and ensuring a healthy safe work environment is maintained. Using the 7D BIM model all previously mentioned responsibilities can be managed visually with less effort and better vision.

- **Direct manpower:**

Direct manpower is presented by the people who actually carry out the physical construction work on-site. Manpower's productivity is the main influence on the construction project development. When it comes to on site practices waste is defined as any effort spent without generated value; insufficient productivity, waiting time, reworks, faulty execution procedures, accidents, and injuries. Also, waste can occur from the excessive use of materials and/or surplus materials. Mixed reality can provide a visual tool for the purpose of training on-site manpower to ensure the following;

- Proper storing and house keeping
- Sufficient execution methodologies
- Plan, control and train manpower to maintain a Healthy, Safety and Environmentally working place
- Defining possible waste hazards and conduct visual workshops to eliminate it
- Proper workflow planning and productivity workshops
- Awareness by conducting workshops and trainings on timely basis

3.7.2. Virtual Environment (Using BIM to create environment)

BIM is identified as a collaboration that this collaboration to achieve project goals needs efficient ways of working. BIM helps projects in the construction field by improving communication and better understanding, leading to greater productivity, better quality, and cost certainty.

Planning in the construction project is a complicated task and difficult to predict because of several interrelated elements. Data are from different categories like geotechnical, architecture, structure, mechanical, electrical, and plumping which have to combine and avoid any possible clashes and improve health, safety, and quality of the works. By using BIM model different items are improved including; team collaboration, control of logistics, manpower allocation, the sequence of operations, scheduling, and value of the project (Gondar, et al., 2019). Followings are the main steps of developing a different dimension of BIM to create the required virtual environment;

- **BIM base design**

BIM has proven to be a great tool in different industries. However; in engineering and construction industry, it has become a major concept during different processes starting from design initiation till the operational phase. BIM is closely connected with designers and managers in the construction. BIM can help them to deliver a successful project and to understand the resources and processes are right in the project life cycle.

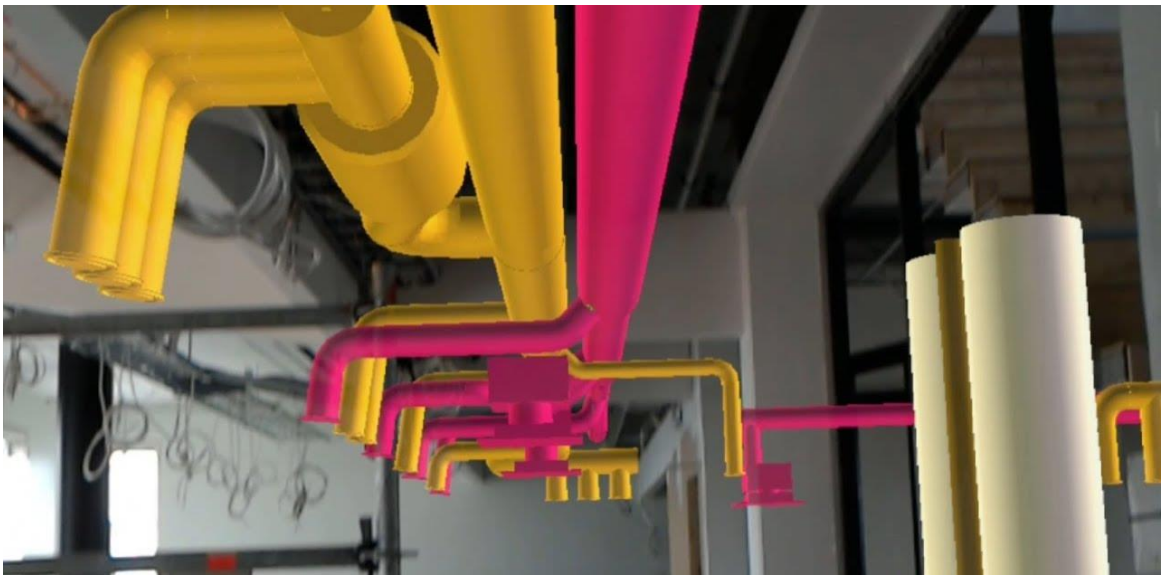

Figure 27 BIM on the construction site. Source: (Morozova, 2019).

BIM helps in exploring and evaluating project's constructability before execution. BIM technology on large scale projects and its integration with project cost and budget are highlighted.

Design initiation usually starts with a concept developed by an architect, that concept or idea will be transformed to a set of data and details reflected on dozens or even hundreds of separate drawings, this was the old concept of design decades ago, before the integration of BIM, old ways of design were time consuming, costly, improperly coordinated among stakeholders and limited in terms of complexity. Nowadays with the use of BIM tools among the field, process has become more efficient, highly coordinated, costless, and more dynamic. BIM based design rely on transferring the available set of data into a full detailed 5D model shared with all stakeholders incorporating all factors (based on the targeted level of details); aspects, specifications, concepts, materials, resources, costs, and time frames (Sharafutdinova, 2015).

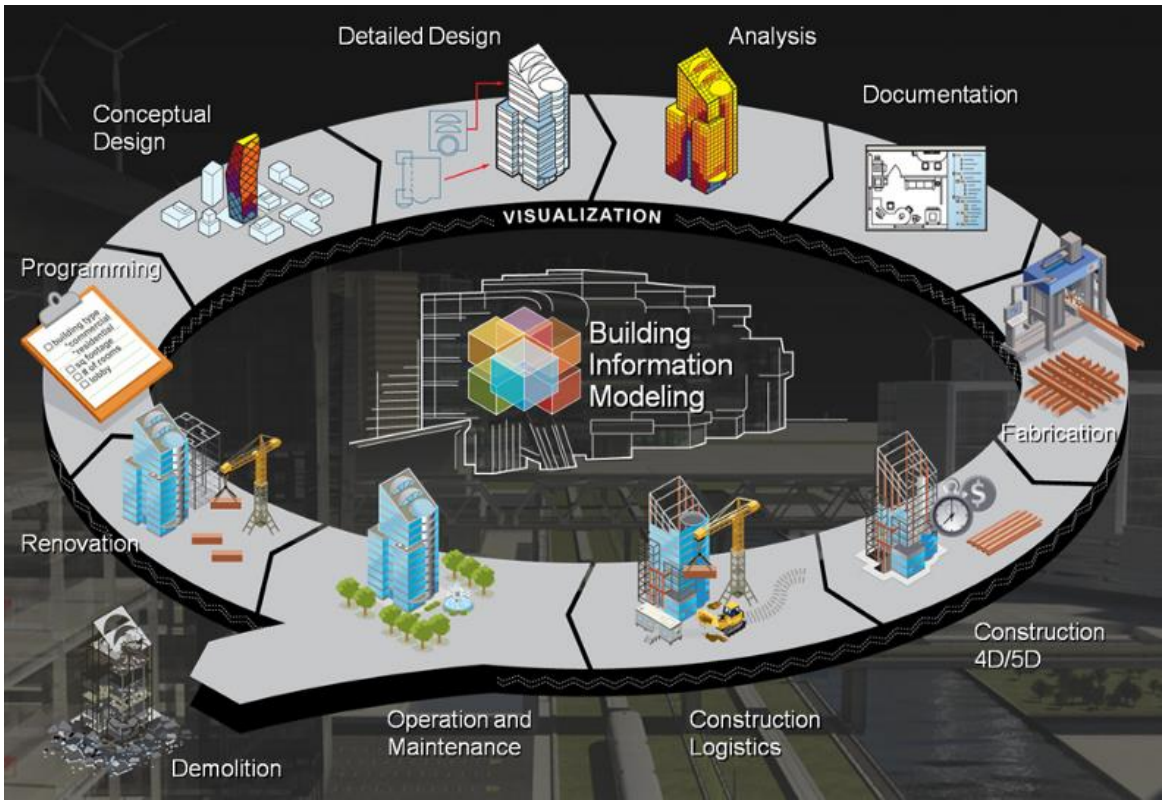

Figure 28 BIM Life Cycle. Source: (Parhiala, et al., 2014).

- **Data gathering and analysing**

This stage can be called as the design kick-off, it includes the conceptual design and analysis where gathering as much as possible details are required to fulfil the main design idea, here mainly what requested is to store the data in proper format -usually excel file is preferable to be used- to smoothly analyse and assign during the modelling stage, although BIM tools has given you the option of storing data, analysing and developing at the same time in a parallel perspective, which has provided kind of dynamic design concept (Sharafutdinova, 2015).

- **Modelling**

BIM can briefly be described as transforming all set of date related to the design in a virtual 3D model incorporating all systems together (structural, Architectural, MEP and etc.), creating a high coordinated model clarifies responsibilities and eliminate design risks, issues, and extra time/cost. The most interesting feature about using BIM

tools for modelling is the flexibility in adjusting and developing the design, furthermore the possibilities of generating highly complex designs which were impossible using drawings-based designs.

Many BIM software has been developed in the construction field, each software is preferable to be used in the different construction sector; for example, REVIT and ArchiCAD are preferable to model and design of the building, where Dynamo is mostly used for infrastructure and tunnels designs (Popov , 2016).

- **Setting Time Frame**

While generating a full detailed 3D model, the plan of execution can be incorporated in the model by setting the execution logic, assigning durations and setting up milestones, the output is called a 4D detailed model where it mainly represents the development of the design execution on the project duration. This process can be done by linking a developed project schedule with the 3D model using a specific tagging for each activity/element. BIM potentially influence time and save it to deliver the project (Wua, et al., 2018).

- **Cost and budget estimation**

One of the most significant factor when designing a project is to meet the specific budget set, bill of quantities gives you an acceptable estimation of the cost, usually, after the design is complete, unfortunately, it is so hard to estimate the project cost based on the drawings every single update, but with the use of BIM tools estimation process has become more accurate and flexible, assigning rates for material, equipment and resources on the model will give you the benefit of monitoring cost changes smoothly whenever design is updated, possibility of continuous budget monitoring during the design stage is useful to assure meeting the budget.

The cost estimation and monitoring model based on the BIM concept is presented by Elbeltagi et al. BIM model through visualization is able to add the color-coding to point the clashes, save significant time delays and cost wasting. Visualization increases the knowledge of the construction team to realize the project information, therefore BIM framework can be reflected as an effective and useful tool for cost

estimation and project monitoring. In this research, the cost estimation after design and structural analysis is divided into two steps; unit price data and quantity take-off (Wua, et al., 2018).

- **BIM level of details**

BIM level of details are shown as Followings;

- 3D Level of Details (Design/Model): Generating a full technical detailed model for a specific design.
- 4D Level of Details (Timeline): Assigning a schedule to the generated 3D model.
- 5D Level of Details (Budget): adding the function of cost time based to the model and possibility of generating financial representations against time.

3D, 4D, and 5D BIM breakdown are illustrated in figure below;

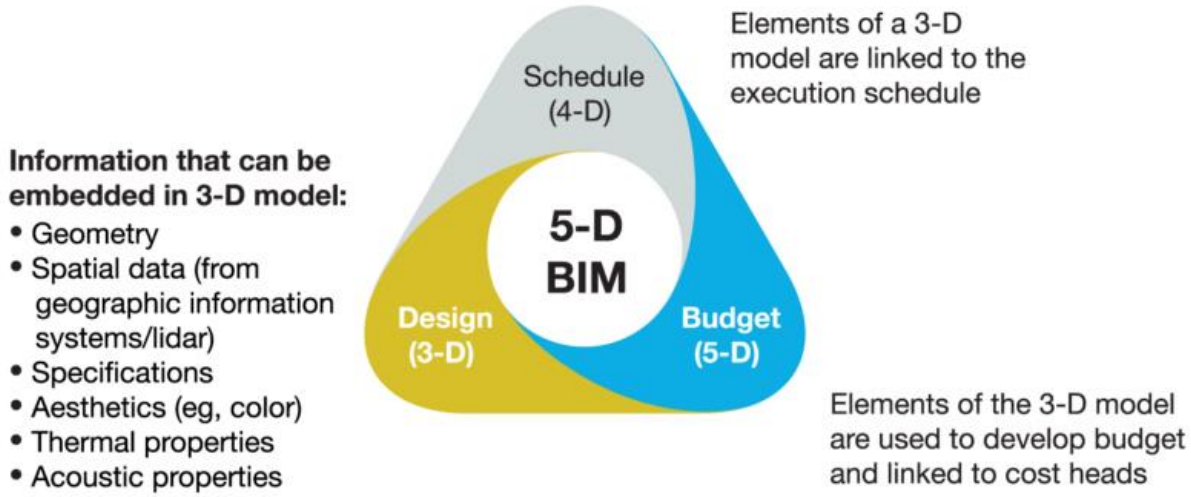

Figure 29 5D BIM breakdown. Source: (McKinsey&Company, n.d.).

- 6D Level of Details (Facility Management): Enables facility management to be considered, the project functionality and operational details.
- 7D Level of Details (Sustainability): it integrates the aspects of sustainability in your designed project.

- 8D Level of Details (Safety): Consider safety procedures for the project design and during the execution phase (CIC, 2015).

BIM Application during Construction Phase

Using BIM paves the way for different aspects for different users like designers, engineers, contractors, clients, and consultants. One model of BIM is 5D model which shed light on cost and budget estimation and some important outputs of BIM applications which are identified as the followings;

- **Material Take-off**

One of the most important outputs is using BIM for material take-off, which is basically a list of every single material used up to the deepest level of details in the project along with the exact quantity and the cost assigned. Estimators use BIM in the quantity take-off and reduce errors (Morgan Christian, 2017).

- **Solving Design Issues**

BIM is able to give opportunities to all participants including designers, structural engineers, MEP designers, and managers to coordinate and reduce possible errors. BIM allows you to easily check design factors in your project, it reflects high coordination among different construction disciplines by determining and avoiding clashes, misalignments, and others. It gives you flexibility in solving design issues or even changing a certain design within a project (Sharafutdinova, 2015).

- **Scheduling**

BIM helps users to schedule the project and optimize it in a 3D environment and also BIM increases the visualization so users can have a better view of the whole project.

Linking the BIM model to a developed schedule by using specific tags for each unique element/activity will provide you with a graphically presented schedule where

you can graphically monitor project progress clearly at different points of time (Jiang, 2011).

- **Logistics**

Logistics is included in transportation, material storage, equipment delivery, and distribution of resources that needs to coordinate. BIM can help for site coordination to better track and manage site logistics and layout, for example establishing an effective cranage plan or planning site accesses and routes along with the project (Whitlock, et al., 2018).

- **Safety**

BIM is identified as a technology to recognize hazardous areas and coordinate necessary safety provisions. BIM increases the level of safety in the construction site and planning activities. It also makes visualization of safety on the construction site to solve site safety problems. Site safety monitoring where safety managers call inspect safety procedures on the model.

In the figure below the safety's nets are shown as a new falling prevention solution to be applied during concrete casting formwork. So, visualization solution can be more helpful than other solutions in traditional modelling (Kiviniemi, et al., 2011).

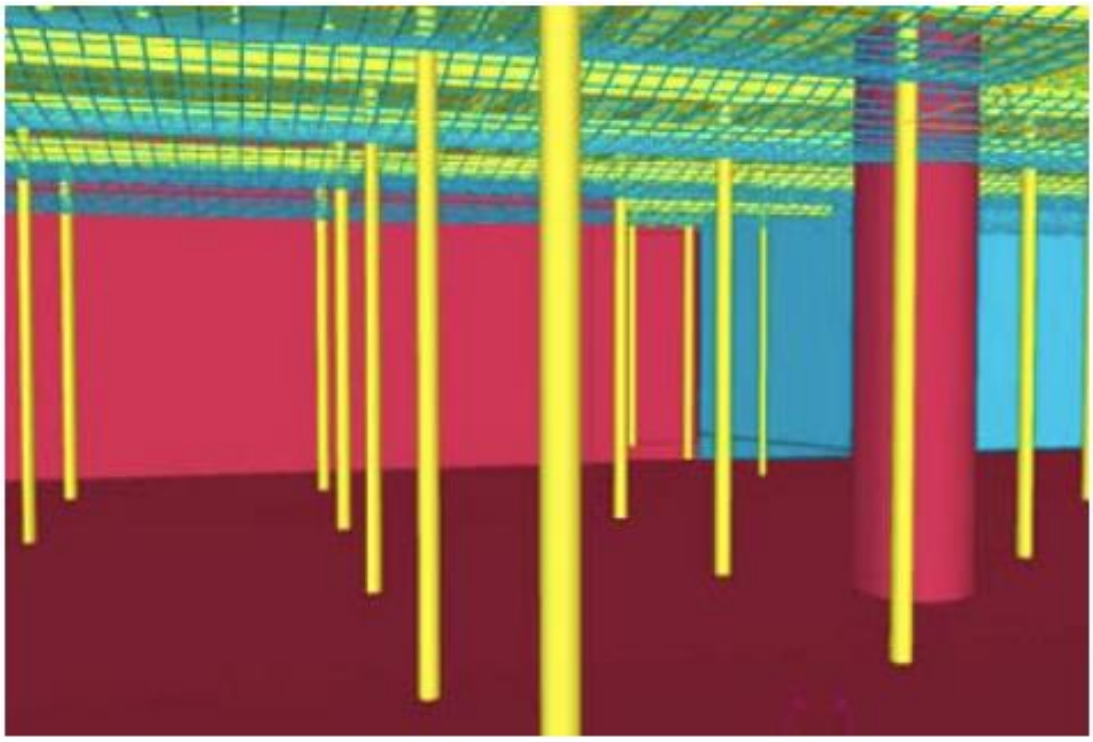

Figure 30 Modelling of safety nets for concrete casting formwork. Source: (Kiviniemi, et al., 2011).

- **Budgeting and Cost Estimate**

Projects are always achievable but a successful project is a project executed on time and within budget, using BIM technology allows to properly establish an accurate budget; assigning resources for each single element on the model, daily labour rates, equipment required, temporary services, land rental, extra charges, and cost buffers, the result will be a full accurate detailed budget as near as to be real and acceptable during construction, it will give you previous estimate for the project total cost and a proper breakdown with just a blink of an eye. Furthermore, having the 5D model will present you with the project cash flow where you can perfectly arrange your liquidity to meet that, loans in advance and sponsorships to cover if necessary (Wua, et al., 2018).

4. Author's Analysis and Findings

4.1. The Influence of Lean Construction Using Mixed Reality on Execution Phase

According to researches and case studies, after talking about the potential that Mixed Reality tools can support the application of lean goals within the execution phase and the important element of using BIM to support the whole interaction process, the author wants to shed the light on the fields of improvements that using Mixed Reality tools can bring to Lean Construction concept which are presented as figure below.

Figure 31 Fields of improvement of Lean Construction by using Mixed Reality in execution phase. Source: Author.

4.1.1. Operation

According to Li, et al., 2003, Lean Construction using Mixed Reality enhances the awareness of the construction process by creating virtual elements in the real world in the construction site.

Mixed Reality is able to minimize the waste of time during the operation. Construction employees can check the operation processes and be more familiar with the construction processes by Mixed Reality tools and applications which create reality construction elements on-site. For example, employees can check construction processes like fixing and position of scaffolding, concreting operation, wall installation details, defined location of elements for different operations, and fixing façade. Figure below shows that employees are using an Augmented Reality tools on-site to have a better idea to proceed operation step.

Figure 32 Using an Augmented Reality tool in construction operation. Source: (The Institution of Civil Engineers, 2019).

Visualization is a critical aspect of the construction operation field that highlights by using Mixed Reality tools. Some important factors that using Mixed Reality based

on Lean Construction concept improves the construction operation are defined as followings (O'Connor & Swain, 2013);

- Emphasize main project goals such as quality, reducing delays, and using the space efficiently.
- Look for improvements on the critical path processes
- Identify repetitive processes to reduce waste and increase quality (Li, et al., 2003).

4.1.2. Logistics

Logistics activities including handling, storage, loading, delivery, and transportation rely on human behaviours, mood, and decisions. Mixed Reality tools increase visualization to help logistics activities and improve execution of these operations with less mistakes. This technology also can develop communication skills during the operations in construction logistics (Cirulisa & Gintersa, 2013).

Using Mixed Reality tools can enhance visualization in construction logistics. For instance, those applications show the site access, delivery, loading, and storage location to responsible employees to have a quick action, save time, increase safety, reduce cost, and monitor material movement.

4.1.3. Safety

The safety term is a critical issue in construction projects. Using AR systems can help to reduce construction accidents and increase safety during the works (Ahmed, 2018). One example of using AR applications in construction projects is using a QR code reader safety report which can use in everywhere in the project on or off-site. Employees can report any small issues that they observed during the work and this can go through the mobile application and check by the responsible person then make related actions to avoid any further accidents and improve the related processes. Then, the right action and correct advices can convert to the QR and leave on the risky area, therefore, all employees who see this QR code reader can scan it by QR code reader and see the related information and correct actions to reduce possible accidents and errors. Safety term is manifestly connected to the training part, therefore, if we have a

proper training, the safety condition is secured. A VR construction safety training system is shown in figure below to increase awareness of possible risks and safety matter.

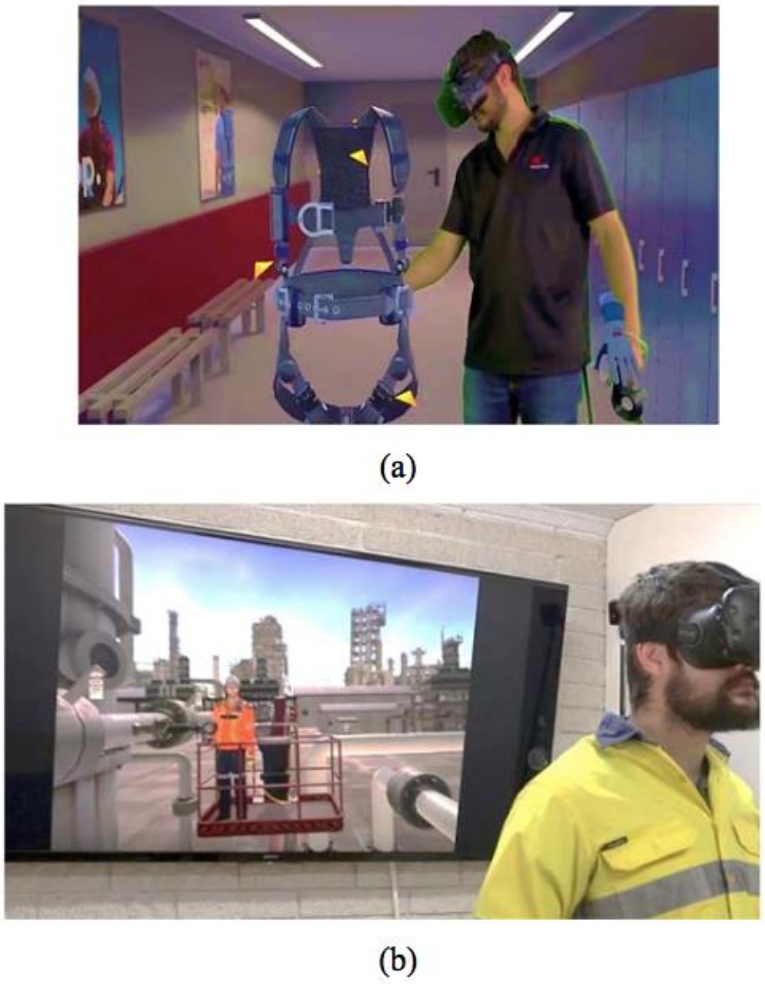

Figure 33 (a) Worker training on PPE and (b) Worker training on working at height by VR technology. Source: (Ahmed, 2018).

4.1.4. Scheduling and project progress tracking

Mixed Reality can clearly increase the aspect of scheduling in the construction projects; by visualizing the project progress. It can show effectively planned activities vs. actual activities. So, the progress tracking of different activities in the construction projects will be easy by using AR application (Ahmed, 2018). For example, employees can see the number of panels installed and number of panels that will install in next days, weeks, and months. It shows that how many panels are completed, how many panels are behind the project, and the reason for the delay of project.

Zaher et al. in 2018 studied the integration of mobile AR technologies with Microsoft Project and Primavera to increase schedule monitoring in construction projects (Zaher, et al., 2018).

Meža et al. in 2015 mentioned that AR on mobiles and tablets is the best option compared to the Gantt chart or other 3D models. They carried out construction activities that can be visualized and estimated on-site by using an AR application. Also, the proposed schedule of the activities and processes in the project easily represented by AR applications (Meža, et al., 2015).

Using the AR application increases tracking and monitoring of project progress which is a way to see differences with project progress in the schedule.

4.1.5. Communication

Communication is one of the most important fields in construction projects. AR systems can help users to access to information easily to make decisions in the different steps. These technologies also minimize cost and delays which happened due to lack of information, reduce complexity and difficulties for on-site information, and have better communication between participants involved in the construction projects.

In some cases, it can help easily to make decisions and advice some suggestion for improving the process of project (Behzadi, 2016).

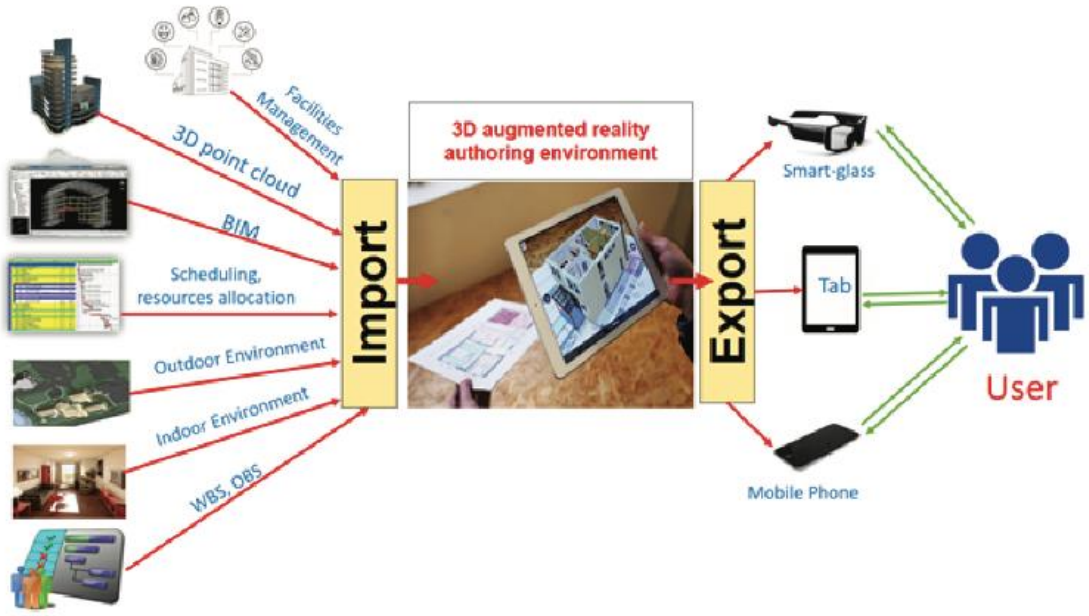

Figure 34 Construction field data and design information acquisition process using AR. Source: (Ahmed, 2018).

4.1.6. Quality and defect management

One of significant parts of construction management is quality and defect management. AR applications can help construction management to find possible defects during the inspection project time and reduce the duration of the project. AR technologies can improve the quality of the works and reduce defects by indicating the detailed actions for employees (Kwon, et al., 2014) and also a process of defect management is defined in the figure below by Kwon and et al. in 2014. For example, employees can see the process of installation of wall partitions properly and see the details of installation before any actions. So, AR applications prevent construction failures, increase quality value, and help to site managers to follow up activities on-site.

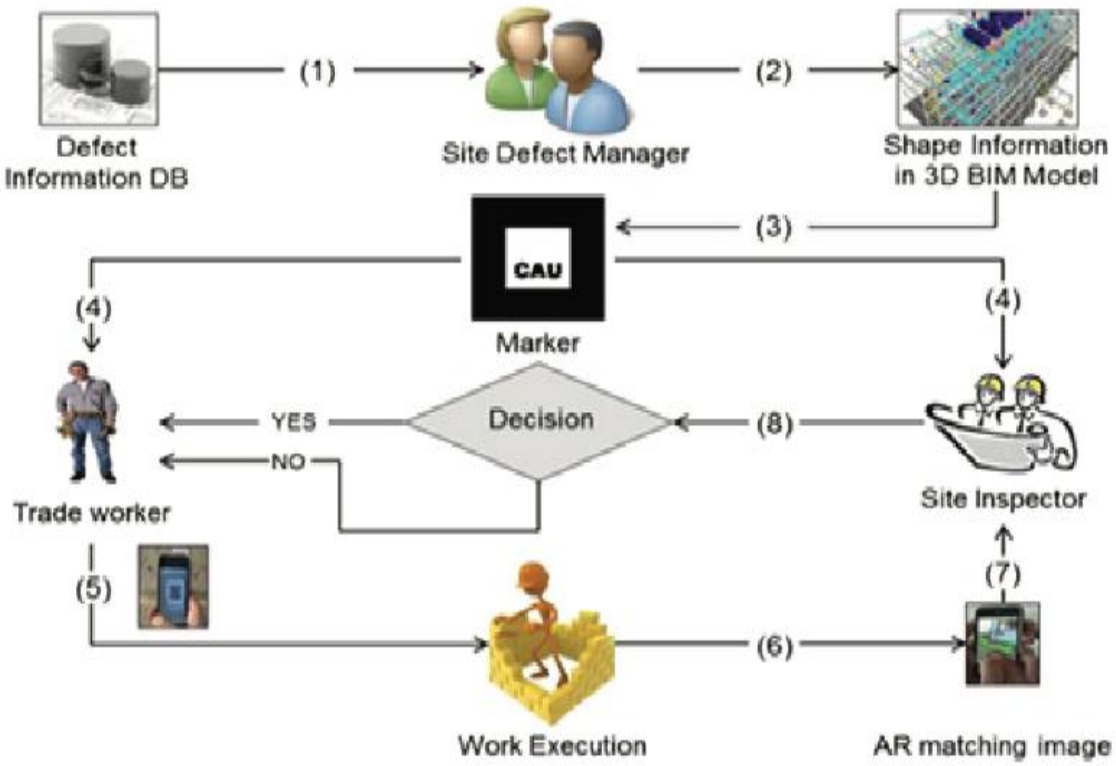

Figure 35 Process of defect management. Source: (Kwon, et al., 2014).

Mixed Reality technology is able to enhance the awareness of employees to avoid any errors and defects. As an example, in figure below, a detected clash between the ventilation system and the structure system is shown.

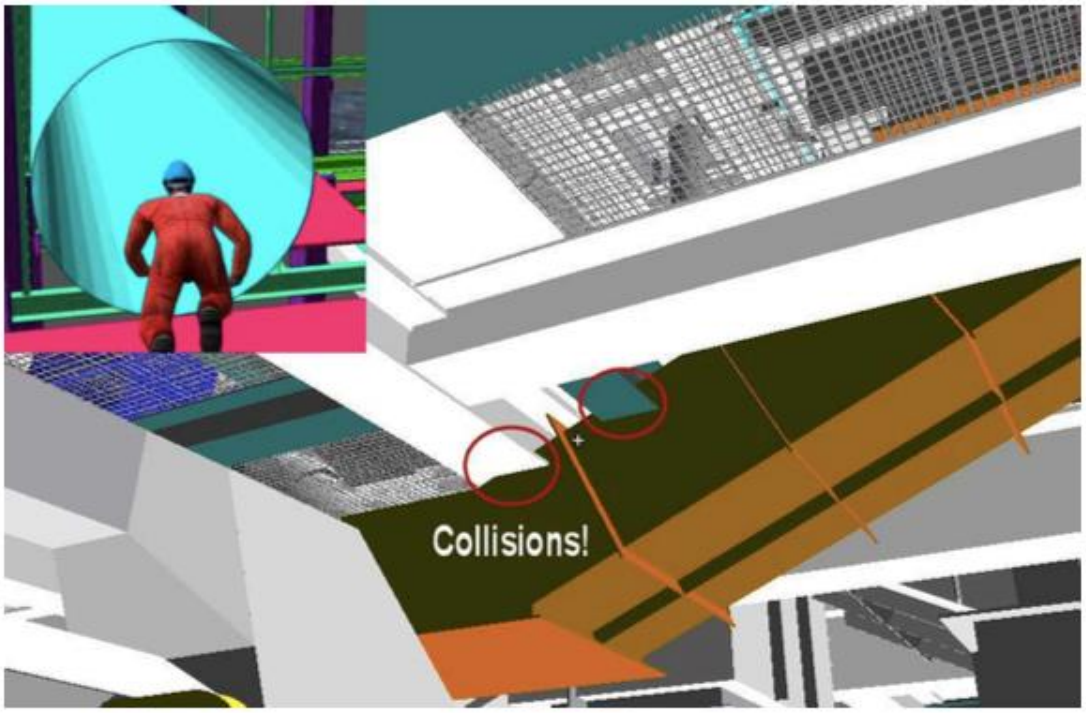

Figure 36 , A detected clash between the ventilation system and the structure system. Source: (Woksepp, 2007).

4.1.7. Time and cost management

Time and cost are another important issue of construction process. The main goal in each construction project is to reduce the duration of the project and save the cost of the construction. This should be monitored from the beginning of the project and is a continuous process. AR applications are defined for monitoring and controlling the projects in order to have projects on the schedule and budget. In the construction projects there are some activities that are time-consuming like site data acquisition, rework and defects inspection.

4.1.8. Employee training

Training is an important part before starting each project to increase quality of the works and safety of workers. By integrating Mixed Reality tools in training, those associated risks and hazards during the works will be discovered. So, appropriate actions

can reduce possible risks and save time before starting of the works. In figure below, operating heavy construction excavator is presented by VR system to the employees as a training before start of excavation. It can be used for operating the cranes, excavators, fork lifts, scissor lifts, and other construction equipment (Ahmed, 2018).

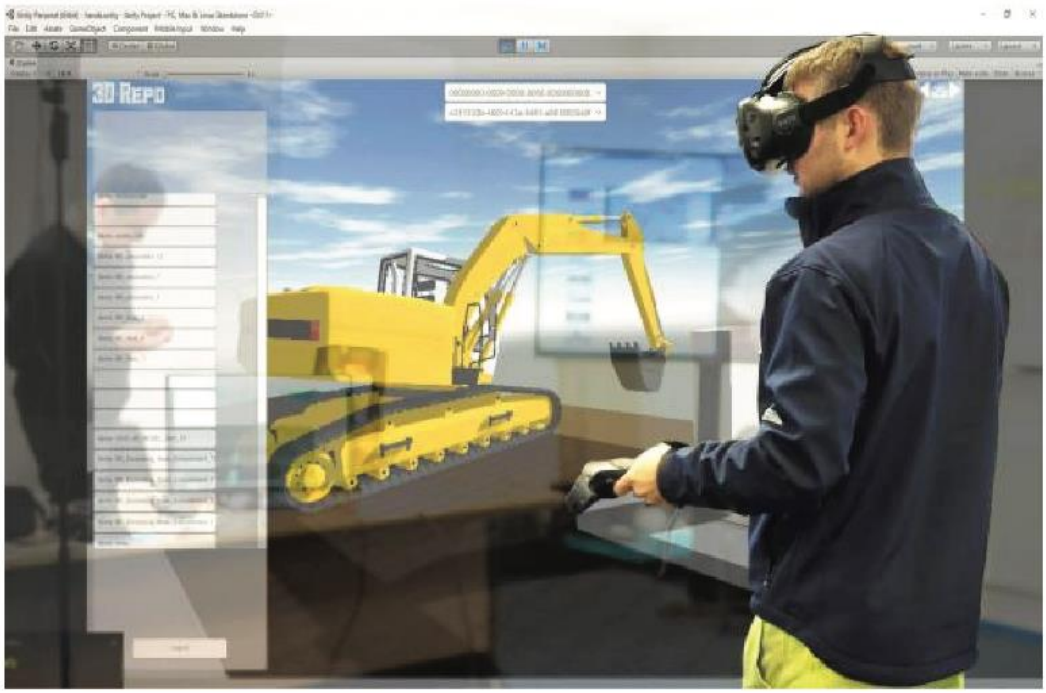

Figure 37 Using VR technology for construction excavator operating training. Source: (Kwon, et al., 2014).

Also, Mixed Reality tools can use for understanding of complexity of the project for the stakeholders. It is able to increase the efficiency of employees' training to avoid any possible risks and increase safety in the construction projects. Figure below shows a training course for employees before starting the work which used a Mixed Reality tool.

Figure 38 a training course for employees before starting the work which used a Mixed Reality tool. Source: (Anon., 2019).

4.1.9. Visualization

Mixed Reality can improve the visualization of the project before starting and increase the feeling of the real-world for all employees in different departments. They can visit inside and outside of the whole model before start of the project. This technology can save time and reduce efforts during whole phases. Visualization can use efficiently in planning phase by having good idea of the 3D completed model in construction projects (Kim, et al., 2013).

It also obviously helps responsible people to monitor the progress of each activity; figure below shows the amount of progress of the installation on-site.

Figure 39 Visualizing with Augmented Reality. Source: (Smith , 2017).

Figure below shows an Augmented Reality tool in construction for casting and concreting to have a better view of the project.

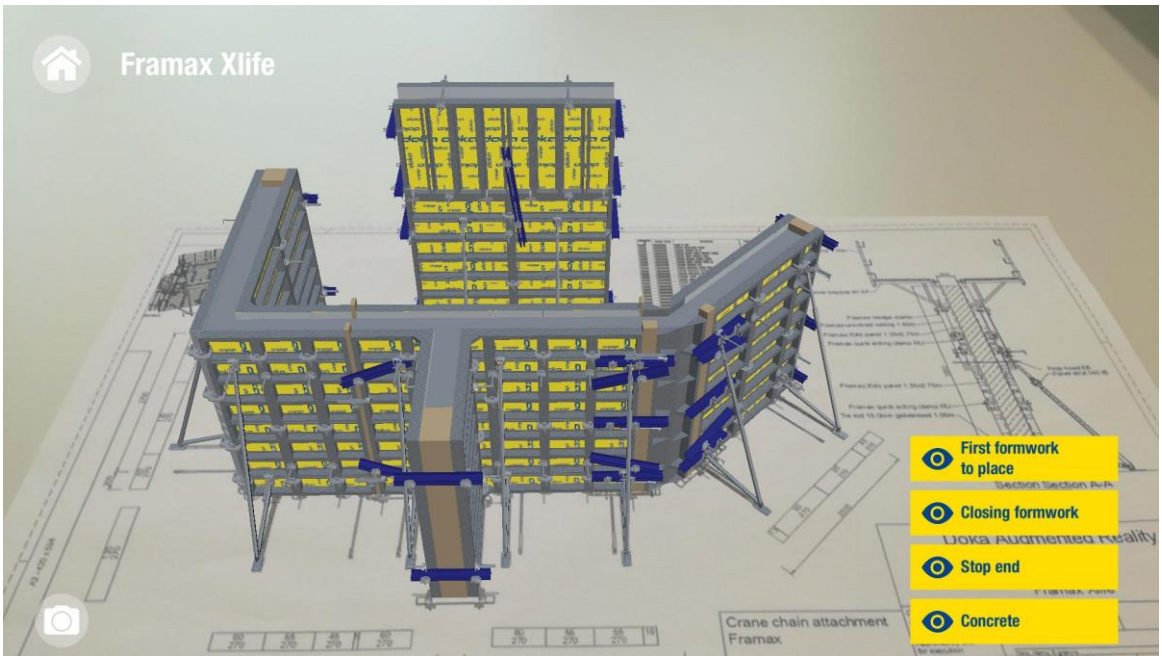

Figure 40 An Augmented Reality tool for casting and concreting in construction projects. Source: (Doka, 2019).

4.1.10. Simulation (Acting)

Augmented Reality technology can be used in different devices like smartphones and tablets to allow employees to view the 3D, 4D models, and virtual elements in the real environment. Mixed Reality and BIM are able to indicate construction information to the users to have a better visualization of the construction projects. This can be able to save time, optimize resources and minimize possible wastes (Zita Sampaio , 2017). Figure below shows a simulation of a construction operation by using a Mixed Reality application. Moreover, Mixed Reality can allow users to have a better visualization by simulating activities and add more improvements for the construction projects; compare different construction options, determine points of strength and weakness in the processes, interaction among workflow, analyse the interaction among work trade, minimize reworks and cost, reducing time and possible wastes, material delivery and storing, optimizing logistics and clashes among trades, material delivery plan, resource allocation, determine construction sequence, training, safety procedures, and working procedures.

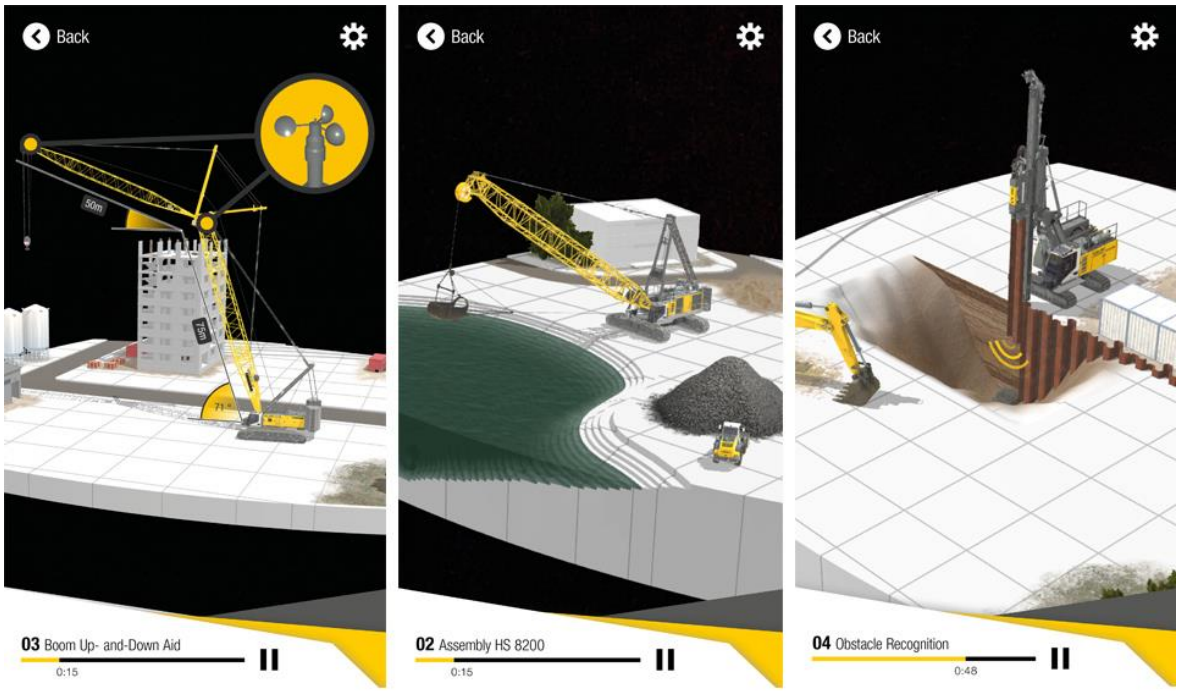

Figure 41 The simulation of a construction operation by using a Mixed Reality application. Source: (Liebherr, 2019).

Figure below shows the simulation of piping system on-site to allow employees to have a better comparison and choose among different options.

Figure 42 Simulation of piping system on-site. Source: (constru360, 2019).

4.1.11. Predicting

The Mixed Reality applications increase the whole view of the project on-site and are able to predict future activities to save time, enhance the quality of the work, and minimize the probable risk and wastes (Behzadi, 2016). These technologies by raising the visualization allow users to make an accurate plan for the execution phase and add more improvements and benefits for the construction projects; risk management, time-saving, cost-saving, clear area of waste, types of possible waste, cost overruns, time disruption, risk of errors, resources required, and liquidity.

4.2. The interaction between Mixed Reality and Lean Construction (Lean Mixed Reality)

Below is the Matrix that shows interaction between Mixed Reality and Lean Construction (Lean Mixed Reality) and possible benefits/outcomes that will be achieved once supportive tools are in place.

According to the previous sections based on researches and case studies, benefits of Mixed Reality are defined; visualization, simulation (acting), and predicting. Also, benefits of Lean Construction principles are explained; value of work, minimizing waste, optimizing workflow, Just in Time, reduce cycle time, and making improvement happen. The author figured out tools to achieve benefits of integration of Mixed Reality and Lean Construction principles which are presented in the table below.

Table 2 Mixed Reality/ Lean Construction Matrix. Source: Author.

Mixed Reality/ Lean Construction Matrix		Lean Construction					
		Value of Work	**Minimizing Waste**	**Optimizing Workflow**	**Just in Time**	**Reduce Cycle Time**	**Making Improvements Happen**
Mixed Reality	**Visualization**	• By visualizing the client requirements • Proper understanding of construction procedure • Visually analyse the construction process to determine valuable and invaluable factors • 3D BIM	• Surplus materials • Design errors • Clashes among the design	• Planning • 4D BIM • 5D BIM	• Construction work • Output	• Present construction sequence	• Safety hazards • Working environment • Storing • 7D BIM • 8D BIM
	Simulating (Acting)	• Compare between different construction options • Determine points of strength and weakness in the processes • Analyse the interaction among workflow • Analyse the interaction among work trade	• Reworks • Cycle time • Waiting time • Material delivery and storing • Overhead costs	• Logistics • Planning flow of trades • Clashes among trades	• Material delivery plan • Resource allocation	• Determine construction sequence • Productivity	• Training • Safety procedures • Working procedure • Logistics
	Predicting	• Risk management • Cost savings • Time savings	• Areas of waste • Types of possible waste • Cost overruns • Time disruption	• Risk of clashes among trades	• Resources required • Liquidity	• Time savings	• Future challenges • Time savings • Cost savings

4.3. Interview Professionals

In this section the author will analyse and present the opinions of professionals in the construction field; based on the interviews that he carried with them by asking key questions to evaluate the outcomes of the literature review. Interviewing is selected as a research method to gather opinions of Mixed Reality technology and Lean Construction concept and their effect on the execution phase. The interviewed experts' opinions are the foundations that the author based on his findings. From the perspective that the experts have the key knowledge of Mixed Reality technology and Lean Construction concept as related challenges are part of their daily work.

In this thesis there were 4 interviews conducted altogether. They were selected from different fields to raise understanding on the overall view. Interviewed experts are listed as following;

- Janne Salin, Head of VDC (Virtual Design and Construction) at YIT, Finland
- Amar Al-Saleh, Lean Construction expert at HTW Berlin, Germany
- Sinan Bataineh, Planning Engineer and Lean Construction expert at Yondr, Finland
- Omar Mabrouk, Structural Design Engineer at AFRY, Finland

This as well will help in proposing solutions in the ways of integrating Mixed Reality and Lean Construction concept in the execution phase. The structure of the interview consists of eleven questions, these questions are developed to gradually cover the concept of lean construction, mixed reality, the interaction between them, and finally how beneficially it can be during the execution phase. Presented below are the questions;

1. How likely would Mixed Reality elements (visualizing, simulating and predicting) during the construction execution serve the Lean goals?
2. How efficient can Mixed Reality be in construction execution phase?
3. How efficient can BIM to support Mixed Reality in construction?
4. How efficient can be Mixed Reality for construction training in line with Lean goals?

5. How efficient can be Mixed Reality for construction operation in line with Lean goals?
6. How efficient can be Mixed Reality for construction safety in line with Lean goals?
7. How efficient can be Mixed Reality for construction logistic in line with Lean goals?
8. How Mixed Reality serves the goal of Lean Construction in terms of reducing waste and optimizing value?
9. In terms of cost how likely would be using Mixed Reality to save cost by minimizing waste in comparison to the additional cost from applying Mixed Reality?
10. In terms of time how likely would be using Mixed Reality to save time by minimizing waste in comparison to the additional time and effort from applying Mixed Reality?
11. How likely the following group of people will adapt/appreciate the use of Mixed Reality to support Lean goals in construction?
    - Managers
    - Engineers
    - Supervisors
    - Direct workers

The intention of the author is to build his findings gradually which will fulfil the research objective. Therefore, the first concern is to analyse how likely would each output of mixed reality server the goals of Lean Construction. In reference with the interaction matrix presented in the earlier section. So, first question purpose is to evaluate ‘’How likely would Mixed Reality elements (visualizing, simulating and predicting) during the construction execution serve the Lean goals’’.

According to Salin “*Everything ‘more visual’ than current construction management systems like Gant charts, excel sheets, etc. are very beneficial. Visualizing with different tools like 3D, BIM, VR etc. gives a better understanding to whole project team. Better understanding = better Lean way of working*”. Obviously Salin linked the idea of better understanding to achieve better construction process which is in-line with serving the lean main goals; value and waste. He assumed that the management process will be more efficient if it is visual. In other words, something which you can see with

your eyes will be much easier to manage, therefore, positive outcomes will be achieved. In order to support that, as presented in the interaction matrix; visualization will benefit each goal of lean starting from increasing the value of work, minimizing waste, optimizing workflow, implementing Just in Time concept, reducing work cycle time, and making improvements happen.

On the other hand, Al-Saleh suggested that in order to reach the optimum use of Mixed Reality to serve the Lean Construction goals, the development of a shared platform is a must to visualize the whole construction process.

Al-Saleh idea's here is in-line with what the author highlighted under section three, the author suggested that BIM tools will serve as the platform to support the visualization process by developing a construction model for the project, and it is not limited to the physical elements only (3D BIM), this will go to another level by developing up to 8D BIM model. The 8D BIM model will be visually supported by Mixed Reality tools which will allow a full visualization of project's related data and again everything visual is better for the management process.

Interestingly, Bataineh highlighted that using a 5D BIM model for the planning process is already a huge step towards better lean management process in terms of quality, time and cost. Also, he stated "*if 5D BIM has proven to be an efficient management tool that supports project management pillars, imagine how efficient it would be to virtually visualize it. This will be like going through an imaginary journey through the construction execution phase, risks will be predefined, design issues will be highlighted, possible clashes among work trades can be defined, rooms of improvements can be suggested, cash flow can be analysed, all that and others as well. Most importantly, a visual identification of the project cash flow during the monitor and control phase where a margin can be determined to trigger an alarm when the project is running low on cash, running over budget, forecasted to run over budget and even it could possibly highlight the elements that has the potential to cause that*". Clearly Bataineh is talking from the perspective that how Mixed Reality will support Lean Construction in the planning, monitor and control phase in terms of time and cost control. This is in-line with the author's findings in relation with how visualization, simulation and prediction can minimize waste. As explained earlier both extra cost and time are considered main waste elements during construction, and the major goal of lean is to minimize and eliminate such waste if possible. Back to the matrix the author determined cost

overruns, waiting time, time disruptions, cycle time, and overhead costs as elements that outputs of Mixed Reality tools can determine and improve in relation with minimizing waste objective.

Furthermore, Mabrouk said that "*During the execution phase is very challenging for the construction managers to be aware of all details in the construction site when using the traditional methods, however, with decent visualizing tool it would be possible to cover all construction details which will reflect positively on the lean construction*". He believed that by using Mixed Reality tools to serve Lean construction goals, details are more visualized and can be simulated for increasing the awareness of construction employees.

After explaining possible potentials of Mixed Reality tools to enhance Lean goals through execution phase, the author wants to shed the light on how efficient this integration process at the moment and what possible expectations can be obtained in the near future.

Salin is more real as he stated that "*Not really efficient with current technology. We have to wait a couple of years tech to mature*". Salin described the current situation of Mixed Reality and its limited applications in the execution phase. As explained earlier and discussed through the case studies, most of the applications of Mixed Reality these days are limited to design, training and modelling, this is aided by the fact that the available technology these days are not enough to support further use of Mixed Reality as well as the enormous costs associated with the use of such technology.

While on the other hand, Al-Saleh clearly focused on the future potential of Mixed Reality tools to support lean goals within the execution phase, *"(Potential) It can be valuable because the practitioners will review the process before execution*" quoted by Al-Saleh. Clearly, both have agreed that the future is bright for this implementation conditioned by the availability of well-developed technology and platform, as well as the right skills and training for end-users.

Bataineh directed his interest towards the benefits of this technology vs. the extra cost and efforts associated with implementing it. Bataineh said that "*Mixed Reality on paper can bring almost unlimited positive impact to the construction industry but we have to take a step back and determine what would be the proper project scale to implement this technology*". Here Bataineh is more concerned about achieving costs

and time savings, his point of view is important, and the author has included a semi-related question to discuss this matter in detail. The specific question would be to what extent would implementing Mixed Reality tools be beneficial rather than just implying extra costs. This question can actually be an interesting field of research.

Mabrouk expressed his point for future and stated that "*I believe that MR has great potentials in the construction industry and especially mega projects with complex construction methods. MR can be applied in simulating the construction process, planning the construction site, and conducting virtual safety training*". He believed that Mixed Reality is in-line with mega and complex construction projects and can bring more benefits compared to small scale projects which seem is more realistic.

Now, let us move on to see the influence of using BIM to implement Mixed Reality tools within the execution phase for better lean management process. When asking Salin about it he quoted that "*BIM is fuel for VR, AR and MR*". Salin's point here is totally valid and true, based on this research and all the literature review carried-on in earlier sections; BIM is the main platform to implement Mixed Reality tools in all construction phases starting from the sketch up of the idea till the operation phase. The implementation of Mixed Reality tools starts by developing a BIM model to support the process, and the efficiency of using the BIM model depends on different factors but most importantly is the level of details provided. The more levels of BIM achieved then the better use of Mixed Reality tools can be reflected. Of course, another important factor is the availability of skilled employees and workers to reflect the project's data into a proper BIM model and their qualifications to practically use Mixed Reality tools to make the improvements.

Furthermore, Al-Saleh supported Salin's opinion by stating that "*BIM is the core of using Mixed Reality*", he supported his opinion based on one of the main outputs of Mixed Reality which is visualization. Al-Saleh sees that Mixed Reality's main output is visualization and in order to use this advantage first you must come up with the element that reflects the project development, the BIM model is the element that can be used to have a proper visualization of the project, efficient analysing and predicting of project development scenarios.

BIM is not only about visualization. Bataineh has an opinion that the use of Artificial Intelligence (AI) within BIM for the purpose of planning the construction works could

be a new level of implementing Mixed Reality with the construction execution phase. Bataineh stated that "*AI can provide automatic analytical view for different development scenarios while mixed reality can offer to simulate these, by doing that you will have different visual plans of project development aided by facts imported to the model. Once that is available it will be easy and more efficient to make critical decisions for managers and high-level stakeholders*". The point of Bataineh lies directly within the simulation row in the interaction matrix. Simulation offers many benefits to the construction development which in fact are in-line with the lean goals.

In addition, Mabrouk stated that ''*BIM is the main source for creating virtual environment. When creating a BIM model and experience it in real scale within a virtual environment it gives the feeling of being inside the real life. Therefore, BIM and MR are integrating augmenting each other*''. From Mabrouk point of view, BIM plays a crucial role for Mixed Reality that can help to have simulation and predating of the environment.

After talking about the potential that Mixed Reality tools have to support the application of lean goals within the execution phase and the important element of using BIM to support the whole interaction process, the author wants to shed the light on the benefits that Mixed Reality tools can bring to each characteristics of lean management; increasing value, minimizing waste, optimizing work flow, reducing work cycle time, just in time concept, and making improvement happen. The question which the author introduced to the experts included presenting their opinion in how the main three outputs of Mixed Reality can enhance certain practices which lead towards a lean management culture such as; construction trainings, efficient construction operations, construction safety, logistics, waste management, value management, time savings, and cost savings.

When asked specifically about the importance of Mixed Reality for construction trainings to make improvements happen all over the construction processes and site in-line specifically with the concepts of Kaizen and 5S the following answers were noted;

- Salin stated, "*Very efficient. Sky is the limits. We cannot yet even imagine these possibilities yet. MR will revolutionize all training methods in future….*".

- Al-Saleh stated, "*It shows how to perform the work in order to avoid double works*".
- Bataineh stated, "*A visual training is much more effective to deliver the massage especially when you have workers from different cultures and backgrounds beside that it is much more exciting, interesting and practical in comparison to the traditional training ways*".
- Mabrouk stated, "*Applying MR technology such as VR and AR can support in the training the construction team even before the construction begin. For instance, workers can experience the construction site in a virtual environment and become familiar with all construction components which will reduce the time and effort needed to do the same job in the real environment*".

Therefore, it is obvious that there is a potential of using Mixed Reality to support Lean Construction goals within training employees in the construction projects.

When asked specifically about the importance of Mixed Reality for construction operations to make improvements happen all over the construction processes and site in-line specifically with the concepts of value, waste, workflow, cycle time, and Just in Time the following answers were noted;

- Salin stated, "*Very efficient. Sky is the limits. We cannot yet even imagine these possibilities. MR will revolutionize construction operation methods in future….*".
- Al-Saleh stated, "*It can be a method to save cost time and effort before proceeding with works*".
- Bataineh stated, "*simulation is an efficient key to set up construction operations, analyse different scenarios, determine possible savings and advantages. All of that will be achieved in the pre-execution phase and goes continuously through the execution phase*".
- Mabrouk stated his point as an example, "*After creating a virtual model for the facility, facility managers can use the model to set the facility management plan and familiarize the operation team with the facility function. In addition, FMs could create the maintenance plan by the help of virtual model*".

When asked specifically about the importance of Mixed Reality for construction safety to make improvements happen all over the construction processes and site in-

line specifically with the concepts of waste management, Kaizen and 5S the following answers were noted;

- Salin stated, "*This will come next after training…*".
- Al-Saleh stated, "*It shows all potential risk that may accompanied the works during implementation*".
- Bataineh stated, "*Safety is a huge concern during the execution phase, safety management goal is to ensure that the construction environment has no hazards for workers and by the end of the project everyone goes home safe. So, simulation can help in predicting possible safety hazards, therefore, eliminate and reduce the possibility of occurrence in advance*".
- Mabrouk stated, "*Safety in construction is one of the critical tasks because construction industry is one of the most hazards workplaces. Usually training the construction works can be done either in-site which causes delays in the construction site or off-site and in this case the workers is not aware with all construction site hazards. When applying MR technology, workers will be able to experience the potential job hazards area and practice how to deal with it in a virtual environment*".

When asked specifically about the importance of Mixed Reality for construction logistics to make improvements happen all over the construction processes and site inline specifically with the concepts of minimizing waste, work flow, cycle time, Kaizen and 5S the following answers were noted;

- Salin stated, "*Not so relevant in near future*".
- Al-Saleh stated, "*It enables the construction companies to get an overview about all required Machineries, tools and equipment in advance*".
- Bataineh stated, "*visualization and simulation help in simplifying and evaluating the efficiency of the site logistics. It opens the door towards effectively imply the concept of Just in Time for every single process in construction*".
- Mabrouk stated, "*Planning the construction site and construction logistic is very important because it includes multiple tasks such as accesses and exits, material location, and equipment location and movement paths in the site. MR could help by creating a virtual model where all equipment and resources are located.*

In the virtual model, a simulation for the construction process can be added to predict the clashes in the construction site and avoid them".

As a summary, the author asked the experts how Lean Mixed Reality can be efficient to construction execution in terms of cost savings, time savings, waste reduction, and value optimization. The experts agreed that all of these can be achieved once implementation only if carried on efficiently according to a Lean Mixed Reality plan.

- Salin stated, "*These benefits will come automatically after previous steps*", "*You always have to invest new tech and new development first. Money will come back later*", and "*You always have to invest also time to new tech and new development*".
- Al-Saleh stated, "*Definitely since it shows all estimated works before execution so the contractors will avoid mistakes and double works and therefore, they will save time and cost*", "*The initial investment in such method may be quite expensive but it is worthy on long run since it helps to minimize double works and enhance quality of production*", and "*Enhancing quality of works means reduce required time to rework which means reduces used time of repairing*".
- Bataineh stated, "*Lean Mixed Reality is an interesting approach but as any other approach a proper plan should be prepared, and a relevant study should be carried on determining the cost/time/efforts of implementation vs. the cost/time/efforts/benefits achieved*".
- Mabrouk stated "*Each construction project is unique, therefore, should be analysed separately*", and "*Fortunately, over the last two decades, the cost of MR has decreased significantly as a result of the technology advancement, and the tools became more easier to use. This enhance the potential implementation of its tools without concerns of running over budget or time*".

Furthermore, the plan should be prepared prior to the construction execution. The Lean Mixed Reality plan should indicate level of use, targeted lean goals, required tools of MR, budget for implementation, timeline of implementation, required skills and knowledge to carry out the process, and finally the monitor and control process to ensure that the implementation process is efficient and in-line with the defined goals, budget and timeline. While Salin and Al-Saleh totally agreed that investing in a new technology even if it is time consuming and costly will always have a positive outcome

to construction execution, Bataineh insists that a study should be carried on determining which level of Lean Mixed Reality implementation will achieve the optimum values in term of time, cost and quality during construction execution. In other words, the implementation of Lean Mixed Reality can add additional cost, time and efforts which could be not worthy in comparison to the results and outcomes achieved. This is based on the fact that projects are different in budget, timelines and goals; therefore, sometime such approach will not be suitable in cases of low budget projects, short term projects, or projects with restrictions.

Finally, the author wants to analyse the acceptance/effect of Lean Mixed Reality for each group of people involved in the construction execution. This concern is based on the fact that, one of the major challenges is the commitment of top management to both the use of MR and the results achieved by Lean Construction. In addition to the possible usage of such approach by these groups.

Al-Saleh highlighted that "*Manager and engineers are more likely to use the Mixed Reality, but everyone eventually must engage in optimization process*". So, from his point of view which the author agrees with, Lean Mixed Reality is a brand-new approach, therefore, most likely it will be adapted by highly educated and skilled people. Once the concept proves to be smooth and efficient and is aided by the proper technology then all construction groups will be involved.

On the other hand, Salin stated that "*MR tools will probably make some roles to disappear. My guess is that engineers and workers will start to communicate more directly*". Salin's highlighted that regardless of the acceptance of top management, if Lean Mixed Reality is implemented properly and becomes a new trend then the whole organization chart structure will change; many roles will disappear, and the supervision process will change.

From a different perspective Bataineh highlighted the challenge in adapting Lean Mixed Reality for each group as following;

- Managers: "*Commitment of top management and their support for implementing Lean Mixed Reality*".
- Engineers: "*The only possible challenge would be the skills to use MR tools. Other than that, engineers will enjoy implanting such approach as it is beneficial and exciting*".

- Supervisors and direct workers: "*Knowledge and skills are the main concern for these group of people, as well as their motivation to spend more efforts applying this approach without any financial benefits for them*".

Mabrouk's answer was related to the possible use of Lean Mixed Reality for each group of people;

- Managers: "*Construction managers could adapt MR in many construction tasks such as simulating the construction process. By this technique, they can define the required equipment and construction sequence*".
- Engineers: "*Engineers could use MR in planning the construction site and understand the site daily activities related to the resources and equipment. By adding the simulation features, they could optimize their site planning and predict clashes*".
- Supervisors: "*Using MR, it is possible to train supervisors for practicing the daily construction activities before even the construction begins*".
- Direct workers: "*Workers also can simulate the equipment operation in virtual environment and leave feedback to site engineers*".

As Summary, the outcomes gained through this questionnaire highlighted many interesting points and helped in defining different factors that Lean Mixed Reality implementation will need to achieve the optimum results. By asking the experts about the potential outcomes of using Mixed Reality to support lean goals; the author reaches the conclusion that both concepts are in-line with each other and in fact Mixed Reality is a great tool to simplify and support the process of Lean Construction implementation. On the other hand, the available technology still applies some limits to the theory as it is still costly to fulfil Lean Construction requirements with all needed Mixed Reality tools. Moving forward, the author confirmed his thoughts that Lean Mixed Reality can be the future of Lean management in the execution phase conditioned by the availability of a well comprehensive plan as well as the qualified skilled people to implement, the right budget and timeline.

One more important thing that was clearly identified here is the importance of using BIM as the main platform to link between the elements of Mixed Reality tools and the implementation of Lean Construction. It proved that BIM simplifies the process and makes it possible to be implemented in real life case.

In relation to evaluating the efficiency that Lean Mixed Reality can bring to the execution phase in different areas such as; trainings, logistics, planning and site management the experts had contradicting opinions. This means that there are still missing parts to fulfil the whole concept, things like cost of implementation, efforts required, availability of skilled people to create a Lean Mixed Reality among the construction groups have to be given more efforts and researches.

Last but not least, in terms of cost, time, value and waste; the author reached the conclusion that a study should be carried out to define different categories for Lean Mixed Reality Implementation in execution phase from the following points of view;

- Project Budget
- Project Timeframe
- Project Type

Finally, the author would like to appreciate the efforts that the experts put in participating in the following questionnaire which helped a lot in structuring the findings of this study.

4.4. The challenges of Lean Mixed Reality and improvement suggestions

The author is previous sections shed the light on what are the challenges of using mixed reality tools in construction execution phase, what are the challenges for the implementation of lean in execution phase, and what could be the possible benefits/outcomes from integrating Mixed Reality tools with Lean Construction principles/practices in the execution phase (Lean Mixed Reality in Construction). In this part, the author finds it worthy to highlight possible challenges that Lean Mixed Reality could face and introduce related improvement's suggestions.

In terms of challenges, the author finds the followings are the most important challenges to be considered and studied before carrying out any implementation of Lean Mixed Reality;

- Required budget for implementing Lean Mixed Reality
- Timeline for implementing Lean Mixed Reality

- Knowledge & skills for both Mixed reality tools and Lean Construction practices
- Awareness & understanding of Lean Mixed Reality importance
- Commitment of top management and their expectations for the short/long term results.

Furthermore, the author introduces a process to evaluate the implementation of Lean Mixed Reality prior to construction commencement as presented in the below figure.

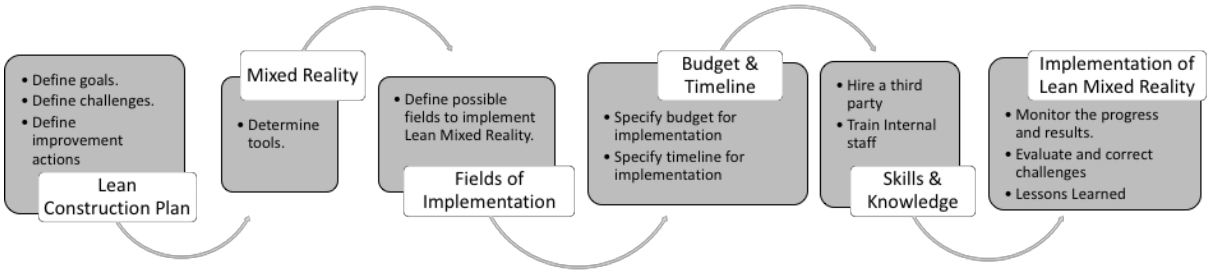

Figure 43 Lean Mixed Reality Implementation process. Source: Author.

Finally, the author created a matrix that presents the challenges generated from integrating Mixed Reality with Lean Construction and suggested improvements that can be carried on to overcoming such challenges and in-line with the Lean Mixed Reality Implementation process as presented in the table below.

Table 3 The challenges of Lean Mixed Reality and improvement suggestions. Source: Author.

Mixed Reality/ Lean Construction Challenges and Improvement suggestion Matrix		Lean Construction					
		Lack of awareness and understanding of the lean construction principles	Lack of top management commitment and support	Variable cultural backgrounds	Additional Cost, time and efforts	Improper implementation of lean construction techniques	Current Limited Practices
Mixed Reality	Additional Cost	**Challenge:** Extra cost to work without any benefical outcomes **Improvement Suggestion:** - Early study for the expected benefits of implementation. - Inductions, Workshops and trainings to determine expected lean goals to be achieved.	**Challenge:** Top management expectations; extra cost at the early stages of implementation as the results of lean come on the long run **Improvement Suggestion:** Determine a seprate budget in the company (not only the project) for the implementation.	**Challenge:** Extra costs due to diffenrent learning curves for the workers **Improvement Suggestion:** Inductions, Workshops and trainings to improve the learning rates, skills and knowledge.	**Challenge:** The integration process could be costly, therefore, not really efficient to use it for small scale projects **Improvement Suggestion:** Categorize the implementation process in different cost levels and select a suitable level of cost that will be optimum for the project use.	**Challenge:** Extra cost to work without any benefical outcomes, as well as additional cost to rectify the errors in processes and works **Improvement Suggestion:** Inductions, Workshops and trainings to ensure correct lean practices.	**Challenge:** Extra costs to the project while the outcomes are limited and invaluable **Improvement Suggestion:** Determine expected lean practices then select a proper level of cost for the implementation of mixed reality.
	Additonal Time	**Challenge:** Additional to work without any benefical outcomes **Improvement Suggestion:** - Early study for the expected benefits of implementation. - Inductions, Workshops and trainings to determine expected lean goals to be achieved.	**Challenge:** Top management expectations; additional time for implementation and the results of lean come on the long run **Improvement Suggestion:** Determine a seprate schedule of implementation progress in the company (not only the project) for the implementation.	**Challenge:** Time waste due to diffenrent learning curves for the workers **Improvement Suggestion:** Inductions, Workshops and trainings to improve the learning rates, skills and knowledge.	**Challenge:** The integration process could be time consuming, therefore, not really efficient to use it for short term projects **Improvement Suggestion:** Categorize the implementation process in different timeline levels and select a suitable level that will be optimum for the project use.	**Challenge:** Additional time to work without any benefical outcomes, as well as additional time to rectify the errors in processes and works **Improvement Suggestion:** Inductions, Workshops and trainings to ensure correct lean practices.	**Challenge:** Additional time to the project while the outcomes are limited and invaluable **Improvement Suggestion:** Determine expected lean practices then select a proper timeline level for the implementation of mixed reality.
	Limited Skills & Knowledge	**Challenge:** Negative Outcomes **Improvement Suggestion:** - Develop a plan, monitor and control for the implentation process - Inductions, Workshops and trainings to determine expected lean goals to be achieved.	**Challenge:** Top management refusal of implementation **Improvement Suggestion:** Hire a third party to carry out the implementation process.	**Challenge:** Negative outcomes **Improvement Suggestion:** - Hire a third party to carry out the implementation process. - Inductions, Workshops and trainings to improve the learning rates, skills and knowledge.	**Challenge:** Not possible to implenet using internal company resources **Improvement Suggestion:** Specify a suitable time and cost budget then hire a third party to carry out the implementation process.	**Challenge:** Not possible to implenet using internal company resources **Improvement Suggestion:** Hire a third party to carry out the implementation process.	**Challenge:** Inefficient outcomes **Improvement Suggestion:** Hire a third party to carry out a research on the benefical lean practices for the project then proceed with the implementation process.

5. Conclusion

The Lean Construction is a critical method for many companies throughout the world. It is clear to note that insufficient management practices can reduce the value of the project and increase the possible waste. By applying the Lean construction theory in construction execution limitations can be faced due to missing practical platform. Therefore, Mixed Reality application can identify as a sufficient technology which can offer visualization, simulation, and predicting options that will assist and simplify the process of achieving Lean goals. The availability of BIM these days in the construction field offers a platform to connect the Mixed Reality tools with Lean Construction practices to perceive a Lean way of management using Mixed Reality tools which can be called Lean Mixed Reality Management. Lean Mixed Reality Management as any other management approach has challenges that stands before its successful implementation; therefore, it has to be defined, analysed, and solutions have to be determined to overcome possible limitations.

This research covered the doubts related to the below-highlighted questions according to the literature review, different case studies, and interviewed experts by specific questions;

Firstly, the author defined possible challenges in construction execution phase by “What are the challenges in construction execution phase?” in section 2.4., which are noted as site conditions, client changes, design errors, unforeseen ground conditions, uncertainty in contract documents, external events, miscoordination, delays, severe weather condition, financial issues, and lack of communication.

Then, to clarify the second question, “How mixed reality can be integrated with lean construction in the execution phase?”, the author studied five different case studies in section 3.3. to determine the level of use for Mixed Reality tools up-to-date in the execution phase and in addition to the Matrix developed by the author that reflects the possible fields and out-comes from the implementation of Lean Mixed Reality within the execution phase. This question also covered by section 4.3. which is the interviewing with professionals. It shows the opinions of experts about how Mixed Reality can be integrated with Lean Construction in the execution phase.

The author evaluated third question, “What is the value added to the lean construction by integrating mixed reality?” according to the researches and case studies,

in the Lean Mixed Reality Matrix in section 4.2. which this Matrix shows interaction between Mixed Reality and Lean Construction (Lean Mixed Reality) and possible benefits/outcomes that will be achieved once supportive tools are in place. This question also covered by section 4.3. which is the interviewing with professionals. It shows the opinions of experts about the value added to Lean Construction by integrating Mixed Reality.

It is noticeable to note that the fourth question “How can mixed reality/lean construction perceive better execution process?” is covered in section 4.1. according the researches and case studies that shows the field of improvements by using Mixed Reality/Lean Construction in the execution phase. These fields include operation, logistics, safety, scheduling, communication, quality, time and cost, training, visualization, simulation, and predicting. This question also covered by section 4.3. which is the interviewing with professionals. It shows the opinions of experts about how Mixed Reality/ Lean Construction perceive better execution process.

Finally, according to researches and case studies, the author highlighted the fifth question “What are the challenges and limitation of integrating lean and mixed reality?” in section 4.4. to explain the possible challenges that Lean Mixed Reality could face and introduce related improvement’s suggestions by a Matrix.

6. Recommendations for future researches

This study highlighted a view of implementing Mixed Reality technology and Lean Construction concept within execution phase. It also covered challenges according to researches and different case studies within the construction field which supported the author in determining the theoretical basis of implementing Mixed Reality and Lean Construction concept within the execution phase. The Lean Mixed Reality theoretical method can be practiced by applying a Mixed Reality tool in a construction execution phase.

The author recommends that;

- The Lean Mixed Reality theoretical method can be operated by applying a Mixed Reality tool in a different phase of a construction project like hand over phase.
- A study can be carried on determining which level of Lean Mixed Reality implementation will achieve the optimum values in term of time, cost, and quality during construction execution.
- Studying the possible challenges of implementing Lean Mixed Reality in construction execution phase.
- Regarding achieving costs and time savings, it is valuable to study that what extent would implement Mixed Reality tools be beneficial rather than just implying extra costs.
- Studying the possible uses of QR code reader as an Augmented Reality tool in the execution phase.

Declaration of Authorship

I hereby declare that the attached master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

15th January 2020 _____

Date

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Signature of the student

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