

**T.C**  
**İSTANBUL KÜLTÜR UNIVERSITY**  
**INSTITUTE OF GRADUATE STUDIES**

**QUALITY MANAGEMENT THROUGH INDUSTRY 4.0 IN  
CONSTRUCTION COMPANIES**

**Masters of Science Thesis**

**Jahed Kambiz SHAMIM**

**2000006863**

**Department: Industrial Engineering**

**Program: Engineering Management**

**Supervisor: Assist. Prof. Duygun Fatih DEMİREL**

**JULY 2023**

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**Supervisor and Chairperson:**

**Assist. Prof. Duygun Fatih  
DEMİREL**

**Members of Examining Committee:**

**Assist. Prof. İlayda ÜLKÜ  
Assist. Prof. Eylül Damla  
GONÜL-SEZER**

**JULY 2023**

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Jahed Kambiz Shamim

## TABLE OF CONTENTS

<b>ACKNOWLEDGEMENT</b> .....	<b>i</b>
<b>LIST OF TABLES</b> .....	<b>iv</b>
<b>LIST OF FIGURES</b> .....	<b>v</b>
<b>LIST OF SYMBOLS</b> .....	<b>vi</b>
<b>ÖZET</b> .....	<b>vii</b>
<b>ABSTRACT</b> .....	<b>viii</b>
<b>INTRODUCTION</b> .....	<b>1</b>
<b>1.1 Quality management</b> .....	<b>4</b>
<b>1.2 industry 4.0</b> .....	<b>5</b>
<b>1.3 Industry 4.0 and construction companies</b> .....	<b>6</b>
<b>2. LITERATURE REVIEW</b> .....	<b>7</b>
<b>2.1 Multi-Criteria Decision-Making</b> .....	<b>11</b>
<b>3. METHODOLOGY</b> .....	<b>13</b>
<b>3.1 Identifying the problem</b> .....	<b>13</b>
<b>3.2 Determining the criteria</b> .....	<b>13</b>
3.2.1 Cost.....	14
3.2.2 Technological capability - innovation & technology.....	14
3.2.3 Speed.....	14
3.2.4 Time.....	15
3.2.5 Quality.....	15
<b>3.3 Determining the alternatives</b> .....	<b>15</b>
3.3.1 Cyber physical systems.....	15
3.3.2 Big data & Cloud computing.....	16
3.3.3 Smart sensors & robotics.....	16
<b>3.4 Obtaining the data</b> .....	<b>16</b>
3.4.1 Weighting the criteria through AHP method.....	16
3.4.2 Comparing the alternatives through TOPSIS method.....	20
3.3.3 Aggregating AHP and TOPSIS results.....	21
3.4.4 Analyzing the results.....	22

**4. IMPLEMENTATION AND RESULTS .....23**

**4.1 Weighting of the Criteria through AHP and TOPSIS method .....24**

**4.2 Comparing the alternatives through TOPSIS method.....27**

**4.3 Aggregating AHP and TOPSIS results.....32**

**4.4 Analyzing the results .....34**

        AHP criteria weights:.....35

        TOPSIS Ranking: .....36

**5. Discussions.....37**

**6. Conclusion .....38**

**8. REFERENCES.....40**

**APPENDIX.....43**

## LIST OF TABLES

Table 3.1: Numbered rating of the AHP method.....	18
Table 1.2: Random consistency index R.I.....	19
Table 3 adequate information such as the place of work, nationality, experience, gender and general information on the experts who provided numerical data for calculations of this report. ....	23
Table 4 Pairwise comparison matrix for Expert 1 .....	24
Table 5 Pairwise comparison matrix for Expert 2 .....	25
Table 6 Pairwise comparison matrix for Expert 3 .....	25
Table 7 Random table and consistency ratio for expert 1.....	26
Table 8 Random ratio for expert 2.....	26
Table 9 numerical TOPSIS numerical rating.....	27
Table 10 TOPSIS results of expert 2 .....	28
Table 11 TOPSIS results of expert 3 .....	29
Table 12 Normalized decision matrix for expert 1 .....	30
Table 13 Normalized decision matrix for expert 2 .....	31
Table 14 Normalized decision matrix for expert 3 .....	32
Table 15 Aggregated AHP results of all experts .....	33
Table 16 Combined TOPSIS result of all experts.....	34

## LIST OF FIGURES

Figure 1 Concept of quality management.....	4
Figure 2.2 Multi-Criteria Decision-Making Methods.....	12



## LIST OF SYMBOLS

<b>A</b>	system matrix controller
<b><math>\omega</math></b>	Eigen vector
<b>G</b>	Plant input mat
<b>LM</b>	Lean management
<b>CI</b>	The consistency index
<b>CR</b>	Consistency ratio



<b>Üniversite</b>	<b>: İstanbul Kültür Üniversitesi</b>
<b>Enstitü</b>	<b>: Lisansüstü Eğitim Enstitüsü</b>
<b>Anabilim Dalı</b>	<b>: Endüstri Mühendisliği</b>
<b>Programı</b>	<b>: Mühendislik Yönetimi</b>
<b>Tez Danışmanı</b>	<b>: Dr. Öğr. Üyesi Duygun Fatih DEMİREL</b>
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## ÖZET

### İnşaat Şirketlerinde Endüstri 4.0 ile Kalite Yönetimi

**Jahed Kambiz Shamim**

Günümüz inşaat firmalarının kalite yönetimi için endüstri 4.0 araçlarına yönelmesi ve sanayileşmenin gerekliliği, inşaat firmalarının yaşadığı zorluklar ve zaman, para kaybı nedeniyle, tüm inşaat firmalarının kalite yönetimi ile endüstri 4.0'ın önemi ile karşı karşıya kalması daha buyurgan hale gelmiştir. her zamankinden ,Çalışmanın temel amacı, orta doğudaki inşaat firmalarında uygulanacak en iyi Endüstri 4.0 uygulamasını seçmektir. Bu amaçla, alternatif seçim sürecinde dikkate alınabilecek kriterlerin önemi ve her bir alternatifin her bir kritere göre göreceli önemi hakkında üç uzman görüşü alınmıştır. Analitik Hiyerarşi Süreci (AHP) ve TOPSIS tabanlı hibrit bir metodoloji uygulanarak en iyi alternatif seçilir.

Günümüzde çevre, modern ve konforlu yapılar (binalar, kaldırımlar, köprüler, barajlar) gerektiriyor, bu nedenle şirketler kalite yönetimini endüstri 4.0 aracıyla uyarlamak zorunda. Endüstri 4.0 araçlarına hangi Ortadoğu ülkelerindeki inşaat şirketleri daha uygundur? Endüstri 4.0 inşaat firmalarına kolaylıklar sağlıyor mu? Bu çalışmaya göre siber-fiziksel sistem en uygun alternatif olarak bulunmuş,

Anahtar Kelimeler: İnşaat 4.0, MCDM, Endüstri 4.0, AHP, TOPSIS.

Bilim Kodu: 90602

<b>University</b>	<b>: İstanbul Kültür University</b>
<b>Institute</b>	<b>: Institute of Graduate Studies</b>
<b>Department</b>	<b>: Industrial Engineering</b>
<b>Program</b>	<b>: Engineering Management</b>
<b>Supervisor</b>	<b>: Assist. Prof. Duygun Fatih DEMİREL</b>
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## **ABSTRACT**

### **Quality Management through Industry 4.0 in Construction Companies**

**Jahed Kambiz Shamim**

Turn to industry4.0 tools and industrialization for quality management is require for today's construction companies, due to difficulties and waste of time, money in construction companies, that the entire construction companies face up the importance of industry 4.0 through quality management has become more peremptory than ever.

The main aim of the study is to select the best alternative Industry 4.0 application to be implemented in construction companies in Middle East. For this purpose, three experts are surveyed to obtain their point of view about the volubility of the criteria that could be considered in the alternative selection process, and the relative importance of each alternative in accordance with each criterion. A hybrid methodology based on Analytic Hierarchy Process (AHP) and TOPSIS is implemented, and the best alternative is selected.

Nowadays environment require modern and comfort constructions (buildings, pavements, bridges, dams), therefore companies have to adapt quality management through industry 4.0 tool. Construction companies in which countries of middle east are more applicable for industry 4.0 tools? Does industry 4.0 provide facilities in construction companies? According to this study cyber-physical system were found to be most suitable alternative, Big data & cloud computing was ranked second in middle east countries.

**Keywords:** Construction 4.0, MCDM, Industry 4.0, AHP, TOPSIS.

**Science Code:** 90602

## 1. INTRODUCTION

This paper based to applicability of industry 4.0 tools in construction companies for better quality management in middle east countries to provide a general benefits of Quality Management through industry 4.0 , The increasing population of humans around the world has continued to pressure the residential sector in terms of construction the buildings , because as time goes by the population is increasing rapidly, thus quality management and construction material quality is critical in residence and the emerging population of the world. The old conventional methods of construction where priority was on old methods; in the long term has led to a non-viable solution especially for a sustainable environment and society in general. Therefore, the conventional methods cannot provide a feasible result; hence new methods and processes need to be employed to provide a different solution, In construction companies in order to make a construction company and materials value it has to build which will promote the construction material in companies and work in companies, assure company that it's the right choice and avoid waste of time and money. Quality management through industry 4.0 is one of the most important aspects of a better construction company and a product of companies because it can be related to many factors such as delivery, usability and acceptable price, The main goal of the quality management through Industrial4.0 revolution in construction companies is that it has the management to potential to increase the earnings and to raise the standard of construction and buildings to living. , therefore, through advanced technologies, categories of materials and services are created that can facilitate and speed up companies and individuals of a society and facilitate their personal and professional lives.. Quality management through industry 4.0 impacts construction company quality professionals and manufacturers in several ways: material data quality, information sharing, speed of improvement, cost of quality, cost of construction material, and skills.

Multiple criteria decision making (MCDM) is a procedure that links alternative performances across opposing, different, numerous quantitative and/or qualitative criteria's and provides an outcome requiring a consensus. The goal of MCDM help the decision makers in choosing the most suitable alternatives or one alternative that can accomplish their requirement in a specific application area. Since the 1960s, Numerous MCDM

methods have been established, developed, and successfully implemented in various application domains. Several MCDM methods are available, such as fuzzy decision making, analytic network process (ANP), priority ordering technique based on similarity to ideal solutions (TOPSIS), data envelopment analysis (DEA), and analysis hierarchy process (AHP). . MCDM has been one of the fastest growing problem areas in many disciplines. In the last decade, researchers have used many of these methods in the field of industrial engineering in making decisions. All methods are relatively capable of making decisions in unpredictable situations and each has its own advantages.

However, the industrial revolution Industry 4.0 comes into play with recent studies showing a fair amount of industries around the globe adopting this new technology for the purpose of enhanced productivity. The fourth industrial revolution (Industry 4.0) implies a steep trend towards digitalization, the implementation of data exchange and various technologies for productions purposes such as Cyber-physical systems (CPS), Internet of Things (IOT), Big Data, Artificial Intelligence (AI), Smart Factories, Smart Manufacturing, Cloud Computing and Remote Sensors. This new drift towards embracing the forth industrial revolution in the manufacturing industries may be the solution for agri-business sector needs, especially in dismantling the major issues such as hunger, unproductivity, waste of natural resources, inefficiency, food wastage in supply chain management and sustainability issues.

This research aims to establish more knowledge and evaluate activities in industry 4.0 applications in construction companies in some countries of Middle East, using a criteria decision making methods and steps to obtain the better alternatives that provide to solve major problems. In the context of this study, Industry 4.0 tools and technology were combined with the parameters and to develop a best construction company framework in some Middle East countries which could be used in the quality management of residential building projects. More ever, In order to obtain the aim of the following research objectives must be fulfilled:

- The research makes comparisons between some Middle East countries that which construction companies in which countries are more applicable of industry 4.0 tools for quality management?
- This research shows alternatives to improve sustainability and efficiency in construction companies through industry 4.0 in some countries in Middle East.
- The research helps decision makers in identifying the most suitable alternatives depending on each problem encountered in applications of industry 4.0 in Middle East.

The following questions are answered in this research:

- Which quality management and industry 4.0 application is most suitable for the construction companies in Middle East?
- Which MCDM method would be easily adopted in industry 4.0 applications in the construction companies in Middle East?
- How to safe workers life and insure safety of workers in construction site through industry 4.0 applications?
- How to avoid waste of time and money in construction companies?
- What is the percentage (%) of industry 4.0 methods applications in terms of quality management in construction companies in Middle East?

This research is centered on the industry 4.0 applications through quality management in construction using MCDM methods to find better alternatives that can boost the country's economy as well as quality and better standard of living for its people, therefore in line with aim, the subsequent objectives of the research must be fulfilled and the smart research questions must be answered, For instance, industry4.0 has to the introduction of the new technologies in the design process and facility work. the latest 4D application in smart systems has recently emerged, enabling greater access to applications where smart building applications have been developed.

## 1. Quality Management

Quality management system is a system consisting of quality planning and quality improvement activities, establishing a set of quality policies and objectives that serve as guidelines within an organization. Quality organization-wide management actions to ensure the organization consistently meets or exceeds customer requirements. High-quality management eliminates waste and increases productivity at minimal cost. Therefore, this research study demonstrates against this background how the lean concept can be applied to create a regression model that can help build a quality model for a construction practice to prevent poor quality management on construction sites. Poor quality management on site always has negative consequences for the overall success of the project. Therefore, quality management should largely be clearly defined from the perspective of all stakeholders and determine the overall success of a project... Quality management follows some principles to insure management of a company as quality management follows leadership, customer focus, and continual improvement, and process approach, systematic approach to management of a company or organization.

In construction companies it's possible to define map of process, define and develop quality process by quality management principles and rules that in this study we will know about this process. Concepts of quality management are as shown in here,



**Figure 1** Concept of quality management

## 1.2 Industry 4.0

Industry 4.0 is a strategic initiative finally introduced by the German government that Industry 4.0, every companies and organizations. An initiative to make connected digital convergence between industry, business and other processes. The main goal of the Fourth Industrial Revolution is that it has change the world and to raise the standard in life cycle. The emergence of Construction with industry 4.0 has played an important role in the development of the construction companies by improving Quality performance.

One of the parameters that help a lot to manage construction quality in the era of industry is Industry 4.0, Internet of Things and lean thinking concepts. Lean is characterized by a set of clear objectives in project delivery, which includes simultaneous design of products and processes. In construction companies Industry 4.0 is going to change the way we innovate, the way we design constructions or construct, the way we think and the way we relate construction materials with other. In some cases, it's very complicated to make decisions for solving some problems in construction system or design of structures in that case. One of the critical components of Industry 4.0 is artificial intelligence (AI), which enables machines to think, learn, and solve problems in decision-making around the life cycle. Also internet of things (IOT), internet of people (IOP), cloud computing, cyber-physical systems (CPS), smart manufacture and other that cause a construction company or other organizations progress and develop. In fact we are living in industry 4<sup>th</sup> revolution right now, management of construction companies are going through the Fourth Industrial Revolution, aka Industry 4.0. We are experiencing it every day and every time, and its full magnitude is yet hidden.

### 1.3 Industry 4.0 & Construction Companies

These days, instead of building everything on site using traditional methods, industry contractors are moving towards Construction 4.0 with digitization and modern, smart technology to connect all aspects of a building to perform tasks more efficiently and effectively & Do more effectively. For example, with off-site construction, parts of prefabricated buildings are already created in warehouses and then delivered to the construction site, which saves time and money. Cost becomes much faster. Industry 4.0 is able to lead to more difficult challenges in construction fields, in order to further develop progress in works and maintain the possibility of challenges these companies need to implement new technologies.

The problem implementations of quality management through industry 4.0 concepts among construction companies confirm the results of research carried out in most countries which show the large companies are much better prepared to make changes in construction sector, In construction field works and pavements we use some machineries and machine made through industry 4.0 when we want to make mixture and other construction materials to avoid waste of time and progress in works.

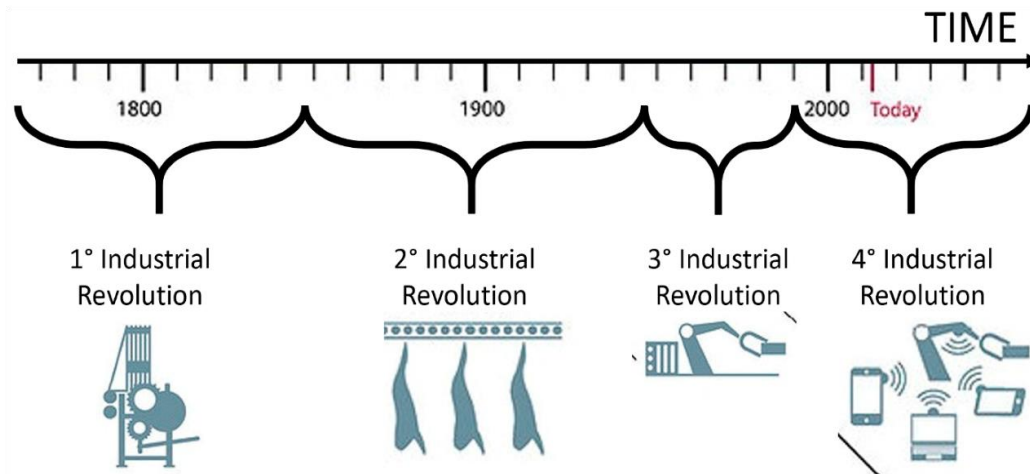
By use of cyber physical system and digitalization in companies' robots use for construction works instant humans also some software's for doing automatic design of constructions planes. such as , 3D printing is an example of Construction 4.0 in action with custom parts increasingly being digitally designed and printed for use in a specific building and digital quality management techniques through Industry 4.0 in the construction sector. Like Building Information Modeling (BIM), laser scanning can provide AI computing and intelligence that will change the way new structures are planned and designed. Virtual Reality Viewers are now used to view and test digital twins of a building before construction begins. , data can be collected, analyzed and stored at the front of the building. The construction process to speed up and result in a higher rum of working.

## 2. LITERATURE REVIEW

This study relates to making decision about different criteria or objectives along to quality management through industry 4.0 in construction companies or organizations in middle east countries , the decision making methode is Multi Criteria Decision Making (MCDM), is about making decisions when multiple criteria need to be considered together in order to rank or choose between alternatives. the methode analyse and evaluate multiple creteria through industry 4.0 to make decisions about using alternatives in construction companies.

The first industrial revolution (industry 1.0) around the period of 1750s which involved the use of steam engines and mechanization ultimately boosting production in the agricultural sector therefore reducing the amount of manual labor required in the manufacture of agricultural products, it started mainly in England then extended to Europe and USA (Slusarczyk, 2018). The second industrial revolution (Industry 2.0) started in Europe and the USA which was around the period 1870s where the use of assembly lines in electricity was invented, a major development in chemical synthesis, agricultural processes were performed with big machines for collection of crops, which resulted in greater productivity and efficiency with agricultural production equipment. However, this major improvement came with some negative issues, for instance contaminations of chemical fields, less sustainable environment and degeneration of natural resources. The third industrial revolution (Industry 3.0) which was around the period of 1970s till present date involved the usage of information technology, nuclear energy, automation in manufacturing and also development in electronics such as transistors. construction processes became much more efficient and machineries procedures were performed logically better (Akses, 2021). The fourth industrial revolution (Industry 4.0) which started around the period of 2010 till present date, it was first started in Germany (Mosconi, 2015 as cited in Roblek et al., 2016). This period involves the increasing trend towards digitalization, the implementation of data exchange and various technology for productions objectives. For instance, Artificial Intelligence (AI), Cyber-physical systems (CPS), Smart Factories, Internet of Things (IOT), Big Data, Smart Manufacturing, Cloud Computing and Remote Sensors. During this period, people started using flying drones, self-driving automobiles, having lectures without being physically present, programmable robots

(Akses,2021). Figure 1 shows the industrial revolutions according to the period it began and ended relative to the time.



**Figure 2.1** The Industrial Revolutions. Source : (Zambon et al.,2019)

The main aim of industry 4.0 is to develop an upper caliber of automation processes and a functional productivity and effectiveness in the human society. The leading characteristics are human-machine interaction (HMI), automation and robotization, digitization, production optimization, communication, data exchange and artificial intelligence. Where all these characteristics are solidly related with modern algorithms and internet technology (Roblek et al.,2016 as cited in Slusarczyk, 2018). The industry 4.0 main uses are commonly replaceable among each other and can be categorized into three (Zezulka et al.,2016):

- Digitization and combination of simple communication between humans, between machines and human .
- Digitization of products and service which leads to disruptive innovations.
- Advanced market structures.

Due to the nowadays construction of buildings has increased, and society needs new and update with advance technology buildings , roads , dams, and bridges .And ofcourse construction with speed and with out wasting time . To avoid waste of time and to build or construct buldings and road with update and new technology to make human life easier we need to use management through indsutry 4.0 in construction companies , Industrie 4.0 refers to the intelligent networking of machines and processes for the company with the help of information and communication technology (Plattform Industrie 4.0, STO building

group, USA). With Industry 4.0, distributed data storage will become one of the main challenges in terms of security (Umsetzungsstrategie Industry 4.0).

Quality management opens the doors of a more efficient world with industrial solutions that bring movement and wealth to the globalizing world and play an active role in the development and growth of investments and countries (Gap İnşaat, Turkey, 2021). The commercial potential of the fourth industrial revolution lies not only in the optimization of operational processes, but also in its services for a wide range of applications. That is why the Internet of Things is complemented by the term "Internet of Services". Smart products offer their capabilities as smart services (Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution, Germany, 2011). The fourth era of the industrial revolution was first introduced by a team of scientists who developed a high-tech strategy for the German government. Klaus Schwab, Executive Chairman of the World Economic Forum (WEF), introduced the term to a wider audience in an article published in 2015. By Foreign Affairs (Schwab Klaus, 12 December 2015).

The fourth industrial revolution is said to depend on 3D printing technology. Some of the benefits of 3D printing for industry are that 3D printing can print many geometric structures while also simplifying the product design process. It is also relatively environmentally friendly. In low volume production, it can also reduce production times and overall production costs (Yong; Stecke, Kathryn E.; Li, Dongni, 17 January 2018). Quality management through Industry 4.0 practices can increase flexibility, reduce inventory costs, and help a company adopt a mass customization business strategy. In addition, 3D printing can be very useful for printing and locally installing spare parts, thereby reducing supplier dependency and shortening lead times (Partha Pratim, January 1, 2017). An innovative construction management technique (Robert Prieto January 2021) through or through Industry 4.0 technologies that enables the creation of Smart construction companies can include the use of cloud data quality-dependent construction robots to predict performance trends and develop optimized responses, and project management processes involving big data analytics and real-time data. Construction robots are advancing rapidly and will make the most of fixed modules and construction sites in a short and fast way (M.A. Hussan, A. Nadeem, 2019). Industry 4.0 is an interesting construction project. To create a good output environment in the construction industry

requires the use of Industry 4.0 tools. Industry 4.0 enables the application of new dimensions in the design, construction and management of civil works (Behrouzi, F. 2019).

It has different dimensions in design such as 2D, 3D, 4D, D and the smart technology of that era helps customers and construction to solve construction challenges (Behrouzi, F.; Wong, K.Y. 2019).

Traditionally reliable, highly productive, and technologically inefficient, this new technology has greatly impacted the industry (Autom. Constr. 2015). In addition to concepts such as Industry 4.0, Quality 4.0, Maintenance 4.0, Security 4.0, Cyber Security 4.0, Operator 4.0 and Logistics 4.0, by opening the way for influence and communication with a simple, it will create a great impact in different fields. supply chain. for management. We want to examine the quality of management in the concept of sustainability using Industry 4.0 tools and technological innovations. According to ISO 9001, Industry 4.0 vertical, horizontal and end-to-end integration have a major impact on the direction of Industry 4.0 (Dr. Miladin Stefanovic, 2022).

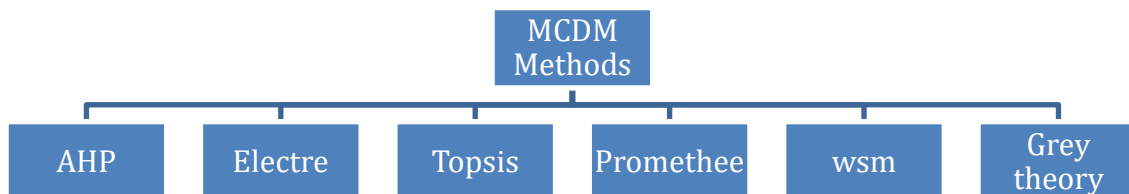
Industry 4.0 and quality system Intehmessi diange old system in irinsaat companies in their alternatives. You should identify and detail the factors that led to your decision. Common examples of decision criteria include costs, schedules, public opinion, proven needs, and quality ratings.

Recently, a new 4D application has appeared in Smart Systems, which gives more access to smart building applications (Eiffage Construction Company: French, 2021). The industrial revolution has made a significant contribution to modern society through quality management, industry 4.0 has increased productivity in the manufacturing sector, the GDP of the world's countries has increased by 6%, and the GDP of the construction sector has increased. 8 percent. Global construction investment reached \$11 trillion in 2019 and is estimated to reach \$14 trillion in 2025 (Howell, G.A.2014).

## 2.1 Multi-Criteria Decision-Making

MCDM means the process of determining the valuable solution according to established criteria and problems that are creating everyday (B. Sarkar, 2011). The application of criteria decision-making system (MCDM) is the use of computational methods that it includes different criteria and order of priority in the evaluation and selection of the best option among the many options according to the desired result. (Mubarak Tayo Mostafa, Journal of Multi-Criteria Decision Making, 2021). Multi-criteria decision making (MCDM) methods have been widely used in recent years. Due to the development of new methods and the improvement of existing methods, its importance has generally increased greatly in various application areas (Velasquez and Hester, 2013). MCDM methods are generally performed to find the most beneficial solution when faced with multiple alternatives with multiple negative and inconsistent decision criteria. This technique is a popular tool for exploring complex real-world problems due to its fundamental ability to evaluate different options based on multiple decision criteria to select the most appropriate alternative (Emovon & Oghenenyero, 2020). MCDM is often considered a confounding outcome mechanism involving quantitative and qualitative factors. In the last decade, various MCDM methods and techniques have been proposed to select the best possible alternative (Mardani et al., 2015). A literature review was carried out in relation to decision analysis and a search was implemented for popular MCDM approaches using google scholar and various databases. The following eleven MCDM methods were discovered throughout the review: Analytic Hierarchy Process, Fuzzy Set Theory, Multi-Attribute Utility Theory, Data Envelopment Analysis, Technique for Order of Preference by Similarity to Ideal Solutions, Simple Multi-Attribute Rate Technique, ELECTRE, PROMETHEE, Simple Additive Weighting, Case-based Reasoning and Goal Programming (Velasquez & Hester, 2013). Application of criteria decision-making theory is the use of calculate or evaluate the methods that incorporate several criteria and alternatives of preference in evaluating and selecting the best option among many alternatives based on the desired final outcome (Selection of Engineering Materials in Product Design, 2013). Construction is a field of study where making the right decisions can mean the difference between owners and loser (Emetere, M.E. 2021). Furthermore, most of the activities belonging to this sector involve taking into account a large number of

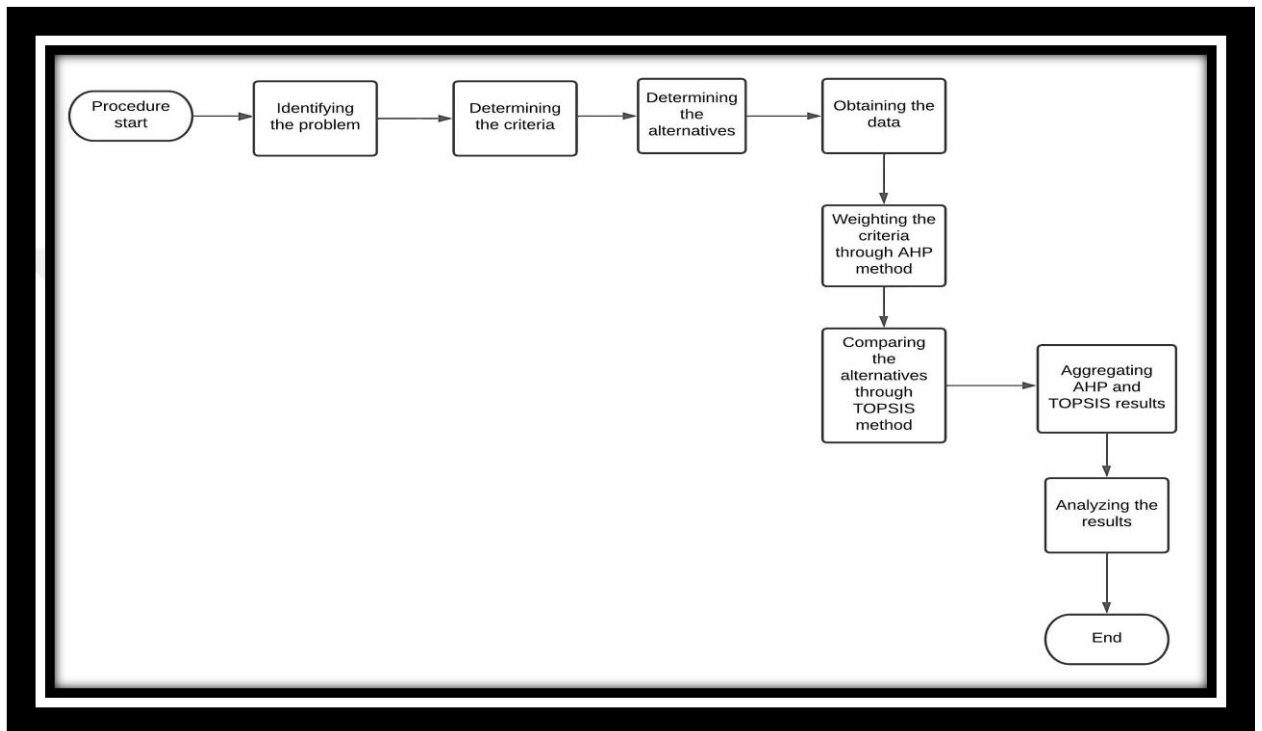
MCDM involves determining the optimal priority among multiple criteria, combat and interaction (Chen et al., 1992). In MCDM, many measures are often highly correlated (Ramik and Prezina, 2010; Angelella et al., 2004), and combining several interdependent measures can lead to misleading results, while arbitrary exclusion of some measures requires Eliminate more criteria. or less useful sources of data (Diakulaki et al., 1995). With the continuous expansion of decision-making methods and their types, it is important to understand their comparative value. Each method uses numerical techniques to help decision makers choose from a discrete set of alternative decisions. It is derived based on the impact of options on specific criteria and thus on the overall utility of the decision maker(s). A problem that always occurs when trying to compare decision making methods and choose the best one (Triantaphyllou, E. Multi Criteria Decision Making Methods, 2000). MCDM mainly follows six steps, which include (1) problem formulation, (2) needed (3) goal setting, (4) identification of various alternatives, and (6) identification and decision making systems (abaei, Erkoyuncu, & Roy, 2015). A few MCDM techniques used to solve the decision problem are: Analytical Hierarchy Process (AHP), Weighted Sum Model (WSM), Weighted Product Model (WPM), Order Priority Technique Based on Similarity to Ideal Solution (TOPSIS), VIKOR, ELECTRE and multi analysis (MAUA).



**Figure 2.2** Multi-Criteria Decision-Making Methods

### 3. METHODOLOGY

In this section, the methodology to be applied is described in detail. The steps of the methodology are provided in the flowchart in below figure.



#### 3.1 Identifying the Problem

The study indicates that which construction companies in Middle East are most applicable of industry 4.0 tools for quality management, that construction companies in which countries are adapted to industry 4.0 tools and quality management According to different criteria's and alternatives.

#### 3.2 Determining the Criteria

Five criteria and numerous sub criteria were selected in this report, which were determined to be the most relevant in the literature review to the objectives of this thesis. The criteria and sub criteria that I choose are as follow,

1. Cost – purchase cost & operation cost
2. Technological capability - innovation & technology.
3. Speed
4. Time
5. Quality.

### **3.2.1 Cost**

Cost is one of the important criteria in the literature review when considering many decision-making problems especially in industry 4.0 implementations. Cost can be measured numerically through real data from several articles and thesis related to the objectives of this report. Cost was one of the key criteria in supplier selection factors identified in industry 4.0 (Miah, Ahsan & Msimangira, 2013). Additionally, two sub criteria emerged namely purchase cost and operational cost.

### **3.2.2 Technological Capability - Innovation & Technology**

Represents the ability of a company or organization using a technology beyond the present company's technological ability. The more advanced the technological capability the higher inclination for technology transfer, research and development. This criterion can be measured through expert opinions-based data. Technological capability was a major criterion in the interactive trade decision making research which used an application case of novel hybrid MCDM (Wang, 2012). There are two sub-criteria under this criterion namely; innovation & technology.

### **3.2.3 Speed**

The rate at which the position of any object changes Speed is measured as the ratio of distance to time traveled. In construction, the process of moving a project towards completion faster than originally anticipated. The idea is to finish the job before the contract date and finish the program before the deadline. (Mastrocinque et al., 2020).

### **3.2.4 Time**

Time can be defined as a continuous movement of events that occur sequentially from the past to the present. Time is used to measure, measure or compare the duration of events or the intervals between them and the series of events. Time is not measurable we just measure time consistence's.

### **3.2.5 Quality**

The standard of something may measure by similar; the degree of excellence of something else. Quality means effectiveness or usefulness of products or services to the consumers. It can be measure through expert opinions-based data. It was one of the key criteria in supplier selection factors identified in industries (Miah, Ahsan & Msimangira, 2013).

## **3.3 Determining the Alternatives**

Three alternatives were considered in this thesis. Which were considered to be suitable in meeting the objectives of this thesis after several extensive literature reviews, they are listed below as follows;

1. Cyber physical systems
2. Big data & Cloud computing
3. Smart sensors & robotics

### **3.3.1 Cyber Physical Systems**

A CPS can be described as combination of computer usage for research with physical processes. It uses smart sensors and actuators to connect computational structures and the real physical world. (Fresco & Ferrari, 2018). CPS may be considered a new dimension of systems under automatic independent nature. It is different from the old conventional robot automation; whereby industrial robots carry out a repetitive task under certain conditions and boundaries.

### **3.3.2 Big data & Cloud Computing**

Big data is often known as a combination of analytics and technology that can retrieve and process data in a Cloud services generally include storage, special hardware resources, processors, network and various services. Cloud is provided to users through three Service models are; software as a service (SaaS), platform as a service (PaaS) and infrastructure as a service (IaaS). Cloud computing allows resources to be shared with a cheaper cost, Faster and more effective way to help decision making.

### **3.3.3 Smart Sensors & Robotics**

Smart sensors can be explained as the advanced development of the wireless sensor. Smart sensors usually involve advanced techniques such as artificial intelligence. Smart sensors are key in construction because productivity of material is highly enhanced and sustainable in industry improved, which ultimately helps empower farmers globally (Ullo & Sinha, 2021).

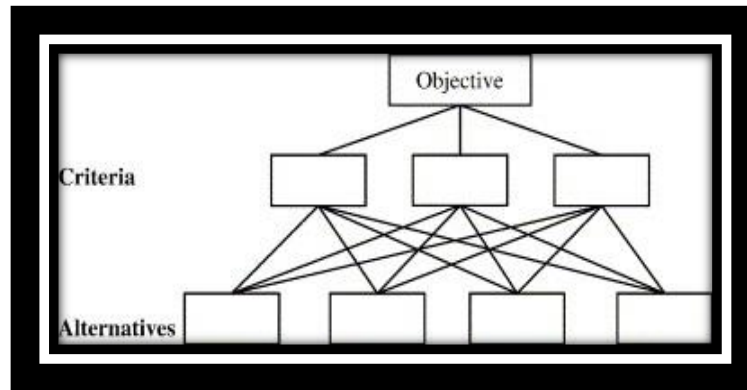
## **3.4 Obtaining the Data**

In this report, data was obtained majorly through the use of real numerical data and expert opinion-based data.

### **3.4.1 Weighting the Criteria through AHP Method**

The AHP method was used to determine the weights of the criteria for this report. This is an adequate technique for calculating the importance of the criteria especially when decision making is important.

The implementation process of AHP method uses four steps (Songur, 2018). Firstly, the decision issues are explained and a ranking structure is created; the effective criteria related to the issues are selected and the ranking structure which consist of different levels are established. For every issue, a ranking structure including criterion, possible sub-criteria stages & alternatives are established.



Secondly, comparisons of pair-wise matrix are developed among the criteria; the pair-wise similarity is carried out by querying experts or decision makers, with questions such as which criterion is more relevant or valuable to the main aim of the decision and compare them according to rating scale as shown in Table 1. AHP,  $P = ||P_{ij}||$  Calculates the significant weights of each criterion using  $(i, j = 1, 2, \dots, m)$ . experts then compare the estimation criteria  $R_i$  and  $R_j$  ( $i, j = 1, 2, \dots, m$ ) where  $m$  is the total number of criteria being compared. In an optimal scenario, the values of the matrix will show the relationships between the unknown criteria weights:

$$P = \begin{bmatrix} P_{11} & P_{12} \cdots & p_{1m} \\ P_{21} & P_{22} \cdots & p_{2m} \\ \vdots & & \vdots \\ P_{m1} & P_{m2} \cdots & p_{mm} \end{bmatrix} = \begin{bmatrix} \frac{\omega_1}{\omega_1} & \frac{\omega_1}{\omega_2} & \cdots & \frac{\omega_1}{\omega_m} \\ \frac{\omega_2}{\omega_1} & \frac{\omega_2}{\omega_2} & \cdots & \frac{\omega_2}{\omega_m} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\omega_m}{\omega_1} & \frac{\omega_m}{\omega_2} & \cdots & \frac{\omega_m}{\omega_m} \end{bmatrix} \quad (3.1)$$

The comparison is created easy to implement. It shows which criterion is more significant and the priority level. This method permits qualitative evaluation from experts to be changed to quantitative ones. The matrix  $P$  is an inverse symmetrical matrix, that is  $P_{ij}=1/P_{ji}$ . Furthermore, the part of the matrix above the main diagonal or below it can be filled up. The number of elements being compared is  $m(m-1)/2$ , so the total number of elements of the comparison matrix is equal to  $m^2$ .

The estimation of the criteria ranges from  $P_{ij} = 1$  when  $R_i$  and  $R_j$  are equally important, to  $P_{ij} = 9$  when, for research purposes, the  $R_i$  criterion is much more important than  $R_j$ . (Saaty 1980, 2005) In a real case, the inverse symmetry of matrix  $P$  is

obvious, the elements of any duo matrix rows or columns will correspond. For instance, the connection between the first and second column elements are described below:

$$\frac{P_{i1}}{P_{i2}} = \frac{\omega_i}{\omega_1} \div \frac{\omega_i}{\omega_2} = \frac{\omega_2}{\omega_1} \quad (i = 1, \dots, m). \quad (3.2)$$

**Table 3.1:** Numbered rating of the AHP method

Scale	Meaning
1	Equal importance
3	Average importance
5	Strong importance
7	Verified importance
9	Utmost importance
2, 4, 6, 8	Intermediate values

Thirdly, estimation of the criteria weights; building of normalized matrices happens here. The normalized matrix is derived through the division of each horizontal amount by the specific column aggregate. After the normalized matrix, the average of every series is derived and the derived values are the key weights for every criterion.

The situation needed for a matrix to agree can also be conveyed calculation terms. In a model case, with the use of equality (1), matrix P is multiplied by the column of the weights. i.e the transposed row  $\omega = (\omega_1, \omega_2, \dots, \omega_m)^T$  :

$$P\omega = \begin{bmatrix} P_{11} & P_{12} \dots & p_{1m} \\ P_{21} & P_{22} \dots & p_{2m} \\ \vdots & & \vdots \\ P_{m1} & P_{m2} \dots & p_{mm} \end{bmatrix} \begin{bmatrix} \omega_1 \\ \omega_2 \\ \vdots \\ \omega_m \end{bmatrix} = \quad (3.3)$$

$$P\omega = \lambda_{max} \cdot \omega \quad (3.4)$$

Where P = m dimensional comparison matrix i.e number of criteria compared,  $\lambda_{max}$  = largest eigenvalue of P and

$\omega$  = eigenvector corresponding to  $\lambda_{max}$ .

$$\omega_i = \sum_{j=1}^m P_{ij}^* / m \quad (3.5)$$

Finally, the consistency ratio (CR) of the comparison matrices is reviewed; the consistency is measured because the precision of the procedure is to be tested. If the comparison matrix is inconsistent, for instance the CR is greater than 10%, and then the values of weights cannot be used. The CR coefficient is estimated after the Consistency Index (CI). The consistency index (CI) is defined to estimate the inconsistency in the pairwise comparison matrix A.

$$CI = (\lambda_{max} - m) / (m - 1) \quad (3.6)$$

Next the CR is derived by dividing the CI value by the many consistency index (RI).

$$RI = 1.98 (m - 2) / m \quad (3.7)$$

The RI value is related to the dimension of the matrix listed in Table 2.

**Table1.1:** Random consistency index R.I

<b>n</b>	1	2	3	4	5	6	7	8	9	10
<b>RI</b>	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49

$$(CR) = CI / RI \quad (3.8)$$

The consistency test is achieved when the CR is calculated. If the CR is less than 10%, it means the data is consistent. If CR is greater or equal to 10%, the data is inconsistent; the original values in the pairwise comparison matrix should be reevaluated and revised.

### 3.4.2 Comparing the Alternatives through TOPSIS Method

Alternatives were analyzed using MCDM technique called TOPSIS. The TOPSIS method is established by the fact that the selected option or the most suitable option should have the closest distance to the optimal solution and also the farthest distance from the geometric point of view, using the Euclidean distance to estimate the relative proximity of an alternative to The ideal solution. . (Indahingwati et al., 2018). The technique priority order according to the similarity of ideal solutions (TOPSIS) can be explained by the steps described below: (Özcan, Ünlüsoy, & Eren, 2017).

Step 1: Constructing the decision matrix.

The generated matrix contains m alternatives and n criteria with the combination of each criterion and alternative given as  $x_{ij}$  and thus has the matrix  $[[[x]_{ij}]]_{m \times n}$ .

Step 2: Create a normalized decision matrix. Normalization is built to attain scales that are comparable. The vector normalization is explained below.

$$R_{ij} = a_{ij} / \sqrt{\sum_{k=1}^m a_{kj}^2} \quad i = 1, 2, \dots, m \text{ and } j = 1, 2, \dots, n \quad (3.10)$$

Step 3: Estimate the weighted decision matrix.

When the normalized decision matrix is formed, afterwards the weight of the normalized decision matrix V is calculated;

$$V_{ij} = w_j \times r_{ij} \quad \forall i, j, w_j \text{ is the weight of criterion } j. \quad (3.11)$$

Step 4: Identify the optimum and the negative optimum solution.

$$V^+ = (\max_i v_{ij} / j \in J), (\min_i v_{ij} / j \in J) \quad (3.12)$$

$$V^- = (\min_i v_{ij} / j \in J), (\max_i v_{ij} / j \in J) \quad (3.13)$$

The optimum solution consists of the one closest to the best alternative whereas the negative optimum solution consists of the worst performance values.

Step 5: Estimate the distance between each alternative from the optimum best and least optimum solution.

$$S_i^+ = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^+)^2} \quad i = 1, 2, 3, \dots, m. \quad (3.14)$$

$$S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2} \quad i=1,2,3,\dots, m. \quad (3.15)$$

Step 6: the rank of the alternatives is determined by comparing  $C^+$  values.

$$C_i^+ = S_i^- / (S_i^- + S_i^+) \quad i=1,2,3,\dots, m. \quad (3.16)$$

Where  $0 \leq C_i^+ \leq 1$ .

### 3.3.3 Aggregating AHP and TOPSIS results

AHP is used to obtain the value of the criteria weights and the numerical weightage. TOPSIS was used to select and rank the alternatives for the most suitable one in Middle East countries while using the criteria weights from AHP, this is how the two multiple criteria decision-making methods were combined for making decisions in this thesis. The weights of the three experts are equal to each other

$$(W_{\text{one}} = W_{\text{two}} = W_{\text{three}} = 1/3) \quad (3.17)$$

The weights of criteria for each expert are separately found using AHP.

Then the weight of criteria of each expert is combined into a single criteria weight vector.

$$W_{cij} = \text{weight of criterion } i \text{ for expert } j \quad (3.18)$$

For each  $i$  apply

$$W_{ci} = 1/3 \sum_j W_{cij} \quad (3.19)$$

For each experts' alternative comparisons, the common weights of criteria that were found in equation 1.3. Then apply TOPSIS for each expert separately.

We assume the weight of alternative  $K$  is  $W_{ak}$ .

$$W_{ak} = 1/3 \sum_j W_{akj} \quad (3.20)$$

Where  $W_{akj}$  = weight of alternative  $K$  for expert  $j$  which is found by TOPSIS.

### **3.4.4 Analyzing The Results**

The alternative with the highest performance score is going to be ranked first, which means this is the most preferred choice based on criteria used in this thesis and in also in real life applications, followed by the next highest which would be the second preferred alternative and finally the least preferred alternative would be ranked third.



## 4. IMPLEMENTATION AND RESULTS

In this part, the methodology is being implemented using numerical data from three experts. The experts were contacted virtually through numerous zoom meetings and they filled excel forms, rating and ranking the criteria and alternatives which were implemented in this project. The implementation aided in the selection of the most suitable alternatives in the application of quality management through industry 4.0 in construction companies of Middle East. The application of these steps involves three alternatives (cyber-physical system, big data & cloud computing and smart sensors & robotics) against criteria (cost, technological capability, speed, time and quality).

**Table 4.1** Adequate information such as the place of work, nationality, experience, gender and general information on the experts who provided numerical data for calculations of this report.

	Expert 1	Expert 2	Expert 3
Title	Deputy Director	Project manager	Senior solution sales executive digital supply chain
Gender	Male	Male	Female
Age	Adult	Adult	37
Field of expertise	Civil Engineering	Structure Design	Sales of supply chain and technology services
Place of work	United Arab Emirates Dubai	Hamd constructions	SAP, Turkey.
Years of Experience	30	18	14

#### 4.1 Weighting of the Criteria through AHP and TOPSIS Method

Table 4.2 shows the numerical value of pairwise comparison matrix derived from the opinion of first expert. At first glance cost appears to be the most important criteria in comparisons to the other criteria followed by speed; however time appears to be the least important criteria.

**Table 2.2** Pair Wise comparison matrix for Expert 1

CRITERIA	Cost	Technological capability	Speed	Time	Quality
Cost	1	2	4	6	5
Technological capability	0.5	1	0.22	2	1
speed	0.25	3	1	5	3
time	0.16666667	0.5	0.2	1	0.5
Quality	0.2	1	0.33333333	4	1
Sum	2.11666667	7.5	5.75333333	18	10.5

Table 4.3 shows the numerical value of pairwise comparison matrix derived from the opinion of second expert. At first it can be pointed that cost has a verified importance in comparison with technological capability, followed closely by quality with a strong importance and then time consumption with a below average importance however cost in comparison to resource consumption is less important.

**Table 4.3** Pairwise comparison matrix for Expert 2

Criteria	Cost	Technological capability	speed	time	Quality
Cost	1.00	6.00	0.33	4.00	5.00
Technological capability	0.17	1.00	0.14	0.33	0.50
speed	3.00	7.00	1.00	5.00	5.00
time	0.25	3.00	0.20	1.00	0.50
Quality	0.20	2.00	0.20	2.00	1.00
Sum	4.62	19.00	1.88	12.33	12.00

Table 4.4 shows the numerical value of pairwise comparison matrix derived from the opinion of third expert. It can be observed from the table Speed had the lowest numerical value in every pairwise comparison except from its duo with Speed, which means it, had less importance in comparison to the other criteria for the third expert.

**Table 4.4** Pair Wise comparison matrix for Expert 3

CRITERIA	Cost	Technological capability	Speed	Time	Quality
Cost	1	3	3	4	1
Technological capability	0.33333333	1	3	2	1
Sustainability	0.33333333	3	1	0.5	0.5
Resource consumption	0.25	0.5	2	1	0.25
Quality	1	1	2	4	1
Sum	2.91666667	8.5	11	11.5	3.75

Table 4.5 shows the calculated numerical results of the random index,  $\lambda_{\max}$ , consistency index and consistency ratio. The consistency ratio was less than 0.10 which means the matrix calculations were feasible for expert 1.

**Table 4.5** Random index and consistency ratio for expert 1

Random index	1.188
$\lambda_{\max}$	5.602484161
Consistency index	0.15062104
Consistency ratio	0.126785387

Table 4.6 shows the calculated numerical results of the random index,  $\lambda_{\max}$ , consistency index and consistency ratio. The consistency ratio was less than 0.10 which means the matrix calculations were feasible for expert 2.

**Table 4.6** Random index and consistency ratio for expert 2

Random index	1.188
$\lambda_{\max}$	5.40831936
Consistency index	0.10207984
Consistency ratio	0.0859

Table 4.7 below shows the calculated numerical results of the random index,  $\lambda_{\max}$ , consistency index and consistency ratio. The consistency ratio was less than 0.10 which means the matrix calculations were feasible for expert 3. The consistency ratio of the third expert had the smallest consistent ratio among all three experts which means the calculations and matrices was the best amongst all experts. The consistency index is also the smallest among the three criteria.

**Table 4.7** Random index and consistency ratio for expert 3

Random index	1.188
$\lambda_{\max}$	6.1937831
Consistency index	0.298445775
Consistency ratio	0.251216982

#### 4.2 Comparing the alternatives through TOPSIS method

The rating for the TOPSIS method used in this project was 0 (worst) and 10 (best).

Table 4.8 shows the numerical TOPSIS ratings from the first expert. The expert ranked cyber-physical systems the highest in terms of time, big data & cloud computing were ranked the highest in quality and smart sensors & robotics were ranked highest in technological capability.

**Table 4.8** Numerical TOPSIS numerical rating

	Cost	Technological capability	speed	Time	Quality
Cyber-physical systems	7	9	3	10	7
Big data & Cloud computing	4	7	8	3	10
Smart sensors & Robotics	3	10	5	9	7

Table 4.9 shows the numerical TOPSIS ratings provided by the second expert. The second expert rated big data & Cloud computing in terms of cost the highest which means that the expert believed it to be the most preferred option in cost terms. Smart sensors and robotics were the least preferred in terms of time which means the expert believed it would consume majority of resources in Middle East. Cyber-physical systems has the lowest score in terms of technological capability among the other alternatives which means the ability to implement this alternative in construction companies in middle east is low compared to the other alternatives.

**Table 4.9** TOPSIS results of expert 2

	Cost	Technological capability	speed	time	Quality
Cyber- physical systems	8	8	7	6	6
Big data & Cloud Computing	9	9	8	7	6
Smart sensors & robotics	6	8	6	5	8

Table 4.10 below shows the TOPSIS ratings from expert 3, it can be observed that the ranking for big data & cloud computing are the highest ranking for technology capability which means this would be the easy to apply with the current innovations and technology standard in middle east against the other alternatives. it also ranked cyber-physical systems highest in speed & quality construction companies in comparison to the other alternatives and smart sensors & robotics were the highest ranked in terms of the quality criteria and speed which means the implementation of this alternative would provide the highest standard compared to the other alternatives.

**Table 3** TOPSIS results of expert 3

		<b>Technological capability</b>	<b>Speed</b>	<b>Time</b>	<b>Quality</b>
	<b>Cost</b>				
<b>Cyber physical systems</b>	5	6	7	5	7
<b>Big data &amp; Cloud computing</b>	8	10	8	8	7
<b>Smart sensors &amp; robotics</b>	5	9	10	8	10

Table 4.11 below shows the normalized decision matrix, optimum solution, negative optimum solution, the estimated distance between each alternative from the optimum best, the estimated distance between each alternative from the optimum worst, performance rating and the ranking for the first expert. At first glance cyber physical system has a very low estimated distance value between each alternative from the optimum best and a very high estimated distance between each alternative from the worst optimum solution, Cloud computing has a high estimated distance value between each alternative from the optimum best and a low estimated distance between each alternative from the worst optimum solution, therefore it results in an average performance score and it is ranked the second preferred alternative. Smart sensors and robotics has a very high estimated distance value between each alternative from the optimum best and a very low estimated distance between each alternative from the worst optimum solution, which results in a low performance score and it ranked third which is the least preferred alternative.

**Table 4** Normalized decision matrix for expert 1

	Cost	Technological capability	speed	time	Quality	+	-	+ S	P =performance score	nk	Ra
Cyber-physical systems	0.36	0.07	0.07	0.04	0.06	.12	.21	.34	0.6		1
Big data & Cloud computing	0.20	0.05	0.2	0.01	0.08	.16	.09	.25	0.3		2
Smart sensors & Robotics	0.15	0.08	0.12	0.03	0.06	.22	.03	.25	0.1		3
+ V	0.36	0.08	0.2	0.04	0.08						
- V	0.15	0.05	0.1	0.01	0.06						

Table 4.12 below shows the normalized decision matrix, optimum solution, negative optimum solution, the estimated distance between each alternative from the optimum best, the estimated distance between each alternative from the optimum worst, performance rating and the final ranking for the second expert. At first glance, it can be seen cyber physical system has a lower estimated distance value between each alternative from the optimum best than the estimated distance between each alternative from the worst optimum solution, hence it has an average performance score and it is ranked the second most preferred alternative with a score close to the second alternative. Cloud computing has a low estimated distance value between each alternative from the optimum best and a high estimated distance between each alternative from the worst optimum solution, therefore it results in the highest performance score among the other alternatives and it is ranked the first preferred alternative. Smart sensors and robotics have a high estimated distance value between each alternative from the optimum best and a low estimated distance between each alternative from the worst optimum solution, which results in a low performance score and it ranked third which is the least preferred alternative.

**Table 4.12** Normalized decision matrix for expert 2

	Cost	Technological capability	speed	time	quality	S+	S-	Performan c	Rank
Cyber-physical system	.218	0.070	0.161	0.046	0.77	.045	.055	0.545	2
Cloud computing	.245	0.079	0.184	0.053	0.77	.053	.086	0.620	1
Smart sensors & robotics	.164	0.070	0.138	0.038	1.03	.084	.035	0.297	3
V+	.245	0.079	0.138	0.053	1.03				
V-	.164	0.071	0.161	0.046	0.077				

Table 4.13 below shows the normalized decision matrix, optimum solution, negative optimum solution, the estimated distance between each alternative from the optimum best, the estimated distance between each alternative from the optimum worst, performance rating and the ranking for the first expert. At first glance cyber physical system has a very low estimated distance value between each alternative from the optimum best and a very high estimated distance between each alternative from the worst optimum solution, Cloud computing has a high estimated distance value between each alternative from the optimum best and a low estimated distance between each alternative from the worst optimum solution, therefore it results in an average performance score and it is ranked the second preferred alternative. Smart sensors and robotics has a very high estimated distance value between each alternative from the optimum best and a very low estimated distance between each alternative from the worst optimum solution, which results in a low performance score and it ranked third which is the least preferred alternative.

**Table 4.13** Normalized decision matrix for expert 3

	Cost	Technological capability	Sustainability	Resource consumption	Quality	S+	S-	S + S	P =performance score	Rank
Cyber-physical systems	0.14	0.07	0.07	0.03	0.12	0.03	0.08	0.12	0.67	1
Big data & Cloud computing	0.23	0.12	0.08	0.06	0.12	0.09	0.10	0.19	0.53	2
Smart sensors & Robotics	0.14	0.1	0.10	0.06	0.17	0.06	0.01	0.07	0.17	3
V+	0.14	0.1155007	0.08	0.03	0.12					
V-	0.14	0.12	0.1	0.06	0.17					

### 4.3 Aggregating AHP and TOPSIS results

Table 4.14 shows the final results and obtain for all the three experts' criteria for AHP method and the aggregate of all expert results. The aggregate was derived by finding the average of all three expert results. At first view, it can be observed that after the final average of all expert opinion cost is the most important criteria, then speed comes second with no huge difference, followed by technological capability, followed by quality and then finally Time which is the least important criteria amongst the five criteria. It can also be observed that for the first and third expert cost was the highest scored criteria, however for the second expert sustainability was the highest scored criteria. Technological capability is weighted lowly for all three experts in comparison to other criteria.

**Table 4.14** Aggregated AHP results of all experts

	Expert 1	Expert 2	Expert 3	$W_{ci}=1/3$ $\sum_j W_{cij}$
Cost	0.45	0.29	0.32	0.353
Technological capability	0.12	0.05	0.19	0.12
speed	0.25	0.47	0.15	0.29
Time	0.06	0.09	0.10	0.083
Quality	0.12	0.1	0.25	0.156

Table 4.15 shows the combined TOPSIS results of all three experts and the final ranks of all alternatives. At an initial glance it can be observed that the first expert ranked cyber-physical systems number 1 followed by big data & cloud computing which was ranked second however it was relatively small in comparison to cyber-physical system and smart sensors & robotics was ranked third with a very small score. The second expert ranked big data & cloud computing first followed closely by cyber-physical systems which was ranked second and smart sensors was ranked third with a small score. The third expert ranked big data & cloud computing first with a high score, followed by cyber-physical systems which was ranked second with a low score and smart sensors and robotics was ranked third with a very similar score to cyber-physical system. Overall, the average of all experts shows that cyber physical system computing was the most preferred alternative in this research, big data & cloud was ranked second with a close score to the first ranked and smart sensor & robotics was ranked third which is the least preferred alternative.

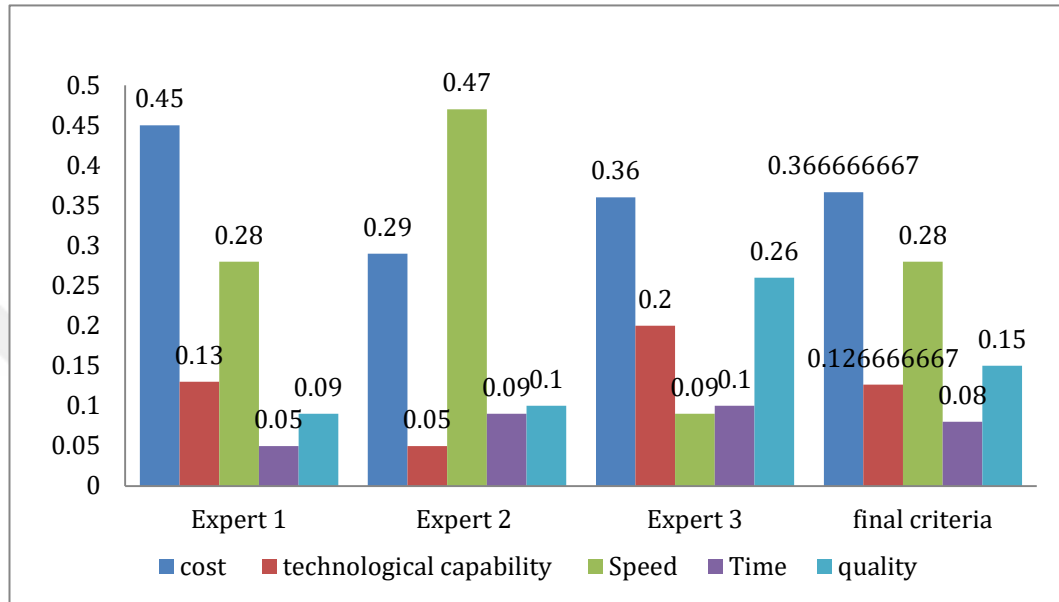
**Table 4.15** Combined TOPSIS result of all experts

	Expert 1	Expert 2	Expert 3	$W_{ak} =$ $1/3 \sum_j W_{akj}$	r ank
Cyber-physical systems	0.626	0.545	0.677	0.616	1
Big data & Cloud computing	0.373	0.619	0.532	0.508	2
Smart sensors & Robotics	0.134	0.296	0.171	0.200	3

Table 4.15 shows the combined TOPSIS results of all three experts and the final ranks of all alternatives. At an initial glance it can be observed that the first expert ranked cyber-physical systems number 1 followed by big data & cloud computing which was ranked second however it was relatively small in comparison to cyber-physical system and smart sensors & robotics was ranked third with a very small score.

#### 4.4 Analyzing the results

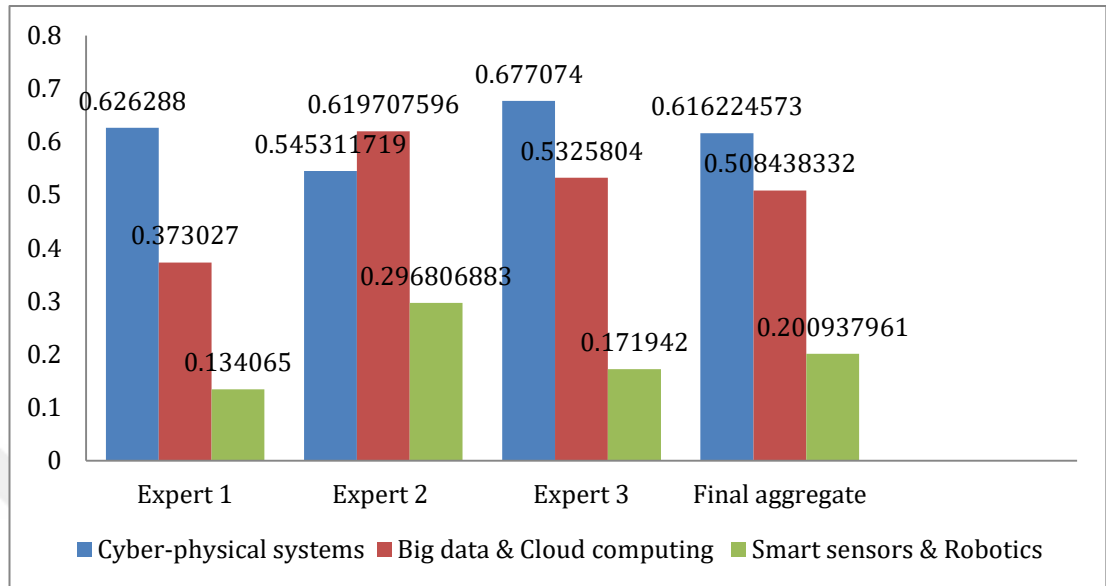
##### AHP criteria weights:



**Figure4.1** AHP Criteria weights

Figure 4.1 shows the aggregated criteria of all experts on a chart and it makes it easy understand each expert opinion on the different criteria. It indicates that cost is the most important criteria whereas speed is also very important and the least important criteria is Time.

### TOPSIS Ranking:



**Figure4.2** TOPSIS Ranking

Figure 4.2 shows the ranking of the three experts and the final aggregate ranking. it can be observed from the chart that cyber-physical systems computing are the most preferred alternative, followed by the big data & cloud which comes close in performance score to cyber-physical system but it is second in ranking and finally the least preferred alternative is smart sensors & robotics.

## 5. Discussions

The present research contributes an extensive and organized way of implementing of quality management through industry 4.0 applications successfully in Middle East construction companies. The first objective of this study was to develop more knowledge, evaluate and make comparisons within the different activities of industry 4.0 applications in the construction companies of Middle East countries. In order to realize the first objective, the study investigated the current literature to identify five important criteria affecting the successful implementation of industry 4.0 in construction field and evaluate them by experts. The study recommended five criteria which were critical for the successful implementation of construction 4.0 in Middle East, namely, cost, technological capability, speed, time and quality.

The second objective of the study was to aid decision makers in identifying the most suitable alternative depending on each problem encountered in construction 4.0 in Middle East. Hence an integrated AHP and TOPSIS approach was used to prioritize the criteria with numerical weights and TOPSIS was used to rank the alternatives preferred for industry 4.0 applications in Middle East countries. Cyber-physical systems were ranked first and found to be the most suitable alternative. Big data & cloud were ranked second in alternatives and the performance score was really close to the first ranked. They can create a modern and precise infrastructure in construction sector. The least preferred alternative was smart sensors and robotics which is because it would be the most expensive alternative, consumes the most resources for implementation in Middle East and may even lead to less human labor.

Two of the experts are males from Afghanistan & Pakistan who are experienced in the construction and the third expert is a female from Turkey and she is an expert in supply chain management. The results are fairly accurate in reality because Middle East countries are an under developed and cost is a major factor in success and implementation of any new technology in Middle East.

## 6. Conclusion

The research is mainly focused on the concept of quality management through industry 4.0 applications in construction companies in Middle East countries or applicability of industry4.0 for quality management of construction companies in Middle East through multi criteria decision making method. High quality management through industry 4.0 eliminates waste and increases productivity at the minimum cost, Industry 4.0 is able to lead to more significant challenges in construction fields, to avoid waste of time and to build or construct buildings and road with update and new technology to make human life easier. In this thesis, MCDM methods such as AHP and TOPSIS method were combined to select the most suitable quality management industry 4.0 applications of construction companies in Middle East, In our methodology a group of experts were selected and queried to provide values for decision matrix of pairwise comparison and also for ranking of alternatives in TOPSIS. This research was carried out because new efficient methods are required to construct, designed, time wastage and safety problems in the construction field, it may provide a new sustainable means of productivity, alternative modern methods, reduce time wastage and construction sector in the middle east countries and it is the first-time industry 4.0 applications using MCDM approaches are being applied in construction sector of middle east countries. **cyber-physical system were found to be most suitable alternative, Big data & cloud computing was ranked second and the least preferred alternative was smart sensors and robotics for industry 4.0 applications in middle east countries.** For the companies that want to improve their construction material product and constructing building skills, avoid wasting time and money, it's necessary to adapt in quality management through industry 4.0 tools to become a modern and update technology Construction Company in world.

More ever, **by using modern machine and robots in construction companies working site not only avoid waste of time and money, also companies safe their workers life from danger and insure safety of human life and workers in site.** Quality management for industry 4.0 in construction companies progress and improve construction building modeling , construction material, safe time , money , energy even human life and change the environment to an industrial and modern environment In all over the world . In the era of industry 4.0 for quality management it is possible to offer

Personal, intelligent and connected building products This includes digital design and manufacturing as well as digital transformation in the industry.

Quality issues are of great importance in construction companies that have adapted to Industry 4.0 and the production of building materials. The material and advertisement of construction products today has quality management parameters embedded in many of their concurrent applications. Industry 4.0 practices and quality are not something we can impose on a company from the outside. The company must be willing to adopt, internalize and fully adhere to quality management through industrialization. Complementing the philosophy of quality management, adapting to Industry 4.0 practices together brings significant improvements to the company while making less cost and creating more value. Turner and STO construction companies in the middle East are a good example of how quality management through Industry 4.0 can transform a construction company into a midsize, industrial global company.

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## **APPENDIX**

APPENDIX A: The English Version of the industry 4.0 in constructions about (industry 4.0 applications in construction companies for Middle East countries)

I would like to thank you for your effort filling the questionnaire which is about quality management through industry 4.0 in construction companies in Middle East countries.

Researcher Name:

Jahed Kambiz Shamim

