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**Name : Sabire Melek**
**Surname : Kılıçkan Öztürk**
**E-Mail : melek.kilickan@metu.edu.tr**
**Date : 11.08.2022**
**Signature : ______________________**

# AN INVESTIGATION INTO THE IMPLEMENTATION OF CONSTRUCTION AUTOMATION AND ROBOTICS TECHNOLOGIES FOR CONSTRUCTION WASTE MANAGEMENT

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

SABİRE MELEK KILIÇKAN ÖZTÜRK

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
BUILDING SCIENCE IN ARCHITECTURE

AUGUST 2022

Approval of the thesis:

**AN INVESTIGATION INTO THE IMPLEMENTATION OF CONSTRUCTION AUTOMATION AND ROBOTICS TECHNOLOGIES FOR CONSTRUCTION WASTE MANAGEMENT**

submitted by **SABİRE MELEK KILIÇKAN ÖZTÜRK** in partial fulfillment of the requirements for the degree of **Master of Science** i**n Building Science in Architecture, Middle East Technical University** by,

Prof. Dr. Halil Kalıpçılar
Dean, Graduate School of **Natural and Applied Sciences** ________________

Prof. Dr. F. Cânâ Bilsel
Head of the Department, **Architecture** ________________

Prof. Dr. Soofia Tahira Elias Ozkan
Supervisor, **Architecture, METU** ________________

**Examining Committee Members:**

Asst. Prof. Bekir Özer Ay
Architecture, METU ________________

Prof. Dr. Soofia Tahira Elias Ozkan
Architecture, METU ________________

Asst. Prof. Aslı Akçamete Güngör
Civil Engineering METU ________________

Assoc. Prof. Abdurrahman Yağmur Topraklı
Architecture, Gazi University ________________

Prof. Ali İhsan Ünay
Architecture, Gazi University ________________

Date: 11.08.2022

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Name Last name : Sabire Melek Kılıçkan Öztürk

Signature :

**ABSTRACT**

**AN INVESTIGATION INTO THE IMPLEMENTATION OF CONSTRUCTION AUTOMATION AND ROBOTICS TECHNOLOGIES FOR CONSTRUCTION WASTE MANAGEMENT**

Kılıçkan Öztürk, Sabire Melek
Master of Science, Building Science in Architecture
Supervisor: Prof. Dr. Soofia Tahira Elias Ozkan

August 2022, 132 pages

The construction industry is responsible for tons of construction waste. It is crucial to take the necessary precautions to avoid the impacts of construction waste on the environment. With the help of developments in automation technology and building information modeling systems, robotics in the construction industry is getting more common every day. It is argued that construction robots can be effective in the management of construction waste.

This study aims first to understand the reasons for construction waste, identify construction waste management strategies, and then understand the application of automation and robotics in the construction industry. And lastly, to evaluate the applicability of construction automation and robotics in Turkey and their use for construction waste management.

A literature survey was conducted to understand the related concepts. With the help of literature, an outline was designed for on-site workers to be used for group discussions. In addition, a questionnaire was prepared and delivered to designers and contractors in Ankara and Istanbul. The data thus collected were analyzed to provide a set of relationships and definitions.

Based on the findings, it is concluded that there is a knowledge gap in the sector in Turkey on construction waste, automation, and robotics. If this gap of knowledge and lack of is addressed, it is predicted that construction automation and robotics technologies would be beneficial in reducing construction waste.

Keywords: Construction Waste, Construction Automation, Construction Robotics, Construction Waste Management, Waste Management Robotics

# ÖZ

## TÜRKİYEDE İNŞAAT ATIK YÖNETİMİ İÇİN İNŞAAT OTOMASYON VE ROBOTİK TEKNOLOJİLERİNİN KULLANILABİLİRLİĞİ ÜZERİNE BİR ARAŞTIRMA

Kılıçkan Öztürk, Sabire Melek
Yüksek Lisans, Yapı Bilimleri, Mimarlık
Tez Yöneticisi: Prof. Dr. Soofia Tahira Elias Ozkan

Ağustos 2022, 132 sayfa

Çok sayıda doğal kaynağı tüketen inşaat sektörü, tonlarca inşaat, yıkım ve hafriyat atığından sorumludur. İnşaat atıklarının çevre üzerindeki etkilerinden kaçınmak için gerekli önlemlerin alınması büyük önem taşımaktadır. Otomasyon teknolojisi ve yapı bilgi modelleme sistemlerindeki gelişmelerin de yardımıyla, inşaat sektöründe robotik her geçen gün daha da yaygınlaşmakta ve bu yükselen trendle birlikte inşaat robotlarının inşaat atıklarının yönetiminde etkili olabileceği tartışılmaktadır.

Bu araştırmanın amacı öncelikle inşaat atıklarının mevcut durumunu ve nedenlerini anlamak ve inşaat atık yönetimi stratejilerini belirlemektir. Ayrıca, inşaat sektöründeki otomasyon ve robot teknolojilerini ve bu teknolojilerin uygulanmasında etkili olan faktörleri anlamayı amaçlamaktadır. Son olarak, Türkiye'de inşaat otomasyonu ve robot teknolojilerinin uygulanabilirliğini ve inşaat atıklarının yönetiminde kullanımını değerlendirmektir.

İlgili kavramları anlamak için öncelikle bir literatür araştırması yapılmış ve elde edilen verilerin yardımıyla bir anket hazırlanıp, Ankara ve İstanbul'daki tasarım ve

saha ofisi çalışanlarına iletilmiştir. Şantiyelerde aktif çalışan işçiler ile ise hazırlanmış kalıp sorular yardımıyla yüzyüze grup tartışmaları gerçekleştirilmiştir. Bulgular, bir dizi ilişki ve tanım sağlamak için analiz edilmiştir.

Sektörde inşaat atıkları ile otomasyon ve robotik konusunda bir bilgi boşluğu olduğu ve bu boşluğun ancak kolektif bir bilinç ve tüm sektörü dikkate alan genelden özele bir düzenleme ile giderilebileceği sonucuna varılmıştır. İnşaat otomasyonu ve robotik teknolojilerinin, bu dallarda bilinç ve bilgi birikiminin geliştirilmesi ve sektörde yaygınlaştırılmasıyla inşaat atıklarının azaltılmasında yararlı olacağı öngörülmektedir.

Anahtar Kelimeler: İnşaat Atıkları, İnşaat Otomasyon ve Robotikleri, Atık Yönetim Stratejileri, Atık Yönetim Robotları

To my family.

## ACKNOWLEDGMENTS

I would like to thank the many people who provided me with the necessary effort, guidance, and motivation to complete this research. The completion of the study would not have been possible without their encouragement and support.

First, I would like to express my deep and sincere gratitude to my research supervisor, Prof. Dr. Soofia Tahira Elias Ozkan, who has shown great dedication, patience, and guidance at all stages of the study from the beginning to end. She has given me great support to work on a subject I am passionate about and embrace. It was a great honor and privilege to study under her guidance.

I am also thankful to all jury members for their sincere feedback and contributions.

I would like to express my gratitude to all the research participants for their invaluable contributions to this thesis, who were generous with their time and knowledge.

I would like to thank all my friends who stood by me during this process. Without their constructive opinions, criticisms, and help, I would not have reached the final stage of my study.

Finally, my deepest thanks and gratitude are to my beloved family. I am grateful to my mother, who was there for me whenever I needed her; to my sisters, who have been my biggest supporters throughout my life; and to my husband, who encouraged me during my ups and downs, for their constant kindness, endless love, and motivation.

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| | |
|---|---|
| 3DP | Three-Dimensional Printing |
| AI | Artificial Intelligence |
| AR | Augmented Reality |
| BIM | Building Information Modelling |
| CAM | Computer Aided Manufacturing |
| CAR | Construction Automation and Robotics |
| CIM | Computer Integrated Manufacturing |
| CWM | Construction Waste Management |
| EU | European Union |
| GIS | Geographic Information System |
| GPS | Global Positioning System |
| IoT | Internet of Things |
| LIDAR | Light Detection and Ranging |
| RFID | Radio frequency identification |
| RTLD | Real Time Location System |
| UAS | Unmanned Aerial Systems |
| VR | Virtual Reality |

# CHAPTER 1

# INTRODUCTION

In this study, construction waste, waste management strategies and construction automation and robotics are discussed from the perspective of building construction. The motivation of the research is explained in this chapter as an argument and a research problem, followed by the research objectives, and disposition of the thesis.

## 1.1 Research Problem

The waste generated by the construction industry in all countries poses an environmental problem, accelerates the consumption of limited primary materials, and exacerbates the climate crisis, as well as having sectoral economic costs.

Like many countries with developed construction industries, construction waste poses a significant threat in Turkey. Urgent measures need to be taken as construction waste seriously affects the economy and the environment.

Automation and robotics are widely used in every sector and follow a continuous development process with developing technology. Various types of robots, which have recently been used in construction, have spread rapidly. In the construction industry, maximum efficiency is aimed at the building process with these technologies. Automation and robotics can also be a solution for waste management in the construction industry.

In the light of the information gathered through a review of pertinent literature, the following issues can be underlined globally:

- There is a lack of awareness of construction waste as an environmental problem, and waste is seen as an inevitable by-product.
- The sector lacks adequate regulations and know-how to manage construction waste and apply construction waste management (CWM) strategies.
- Construction automation and robotics (CAR) technologies are not recognized and utilized in the sector.
- There is not enough knowledge and qualified workforce to implement CAR for waste management.
- On the other hand, CAR is considered effective for waste management.

However, there is no reliable information on the amount of waste generated by the construction sector in Turkey, and the extent to which these tools are applied in the Turkish construction industry is unknown. It is therefore important to first understand the main causes of waste generation, then establish what is the degree to which automation and robotic technologies are being used locally to reduce construction waste, and then to explore ways in which they can be applied more widely in order to eliminate this waste completely.

## 1.2 Research Objectives

This study aims to examine if construction automation and robotics can be adopted as practical solutions for construction waste management in Turkey. The main objectives of the research are,

- To understand the sources of the waste caused by the building construction industry,
- To establish an understanding of the construction waste management strategies,
- To understand the possible use of construction automation and robotics,

- To evaluate the factors that limit and emphasize the use of construction automation and robotics,
- To examine the perspective of designers, contractors, and workers in Turkey about construction waste,
- To examine the perspective of designers, contractors, and workers in Turkey regarding construction automation and robotics,
- To discuss the applicability of robotics to minimize construction waste in Turkey,
- To predict the future trends for implementing construction automation and robotics in Turkey.

## 1.3 Research Questions

In line with objectives mentioned above, the research addressed the following questions.

- What is the perspective of the construction sector in Turkey on the generation of construction waste?
- Are construction waste management strategies being implemented in Turkey?
- What is the effectiveness of waste management strategies in Turkey?
- Are construction automation and robotics being used in the construction industry in Turkey?
- Can construction automation and robotics gain a share in Turkey's construction industry in the near future?
- Can construction automation and robotics be applied to minimize construction waste in Turkey?

## 1.4 Procedure

The study was carried out in 5 phases (Figure 1.1). The problem and questions were identified in the first phase, and background information was collected in the second phase. With the information gathered, in phase 3 a detailed questionnaire was prepared that was directed at designers and contractors, while a guideline was prepared for group discussions to be conducted with workers on construction sites. In phase 4, the questionnaire was sent online to 250 people and 35 complete responses were received, while group discussions were held face-to-face at 4 different sites. In the final stage, the collected data was tabulated and analyzed to answer the research questions and to evaluate the assumptions made in light of the literature.

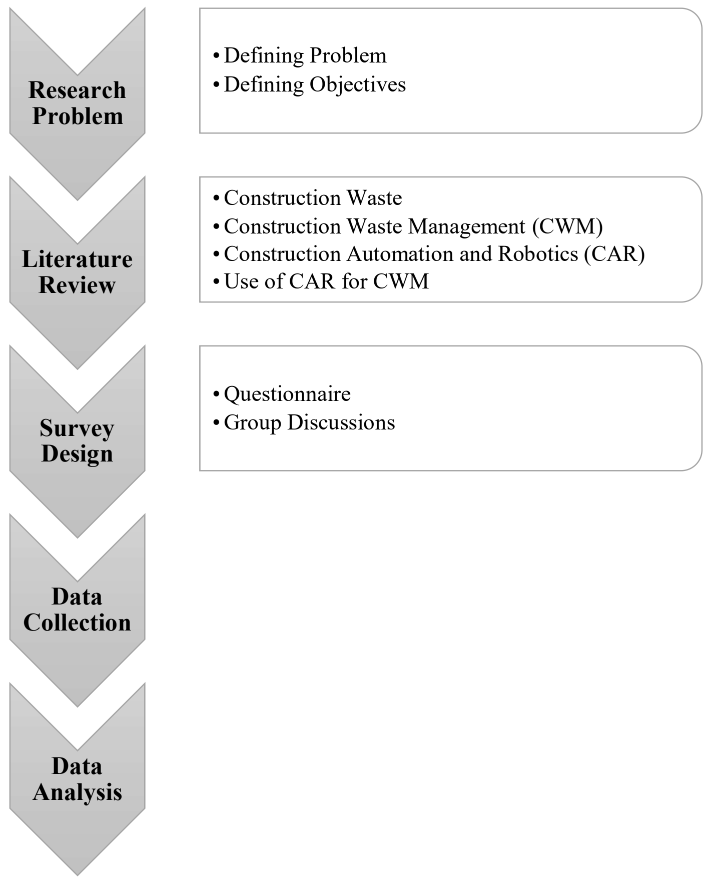


Figure 1.1 Research process

## 1.5 Disposition

This thesis consists of five chapters. In this first chapter, the research problem, objectives, questions, and process are presented briefly.

Chapter 2 includes detailed information from a literature review on related concepts. Firstly, general information on construction waste, classification, reasons, and effects of construction waste are explained. Later, the waste management strategies and barriers in construction waste management were clarified. Then, the information regarding construction automation and robotics is summarized in range, benefits, barriers, and future directions. Lastly, construction automation and robotics for construction waste management are studied and outlined.

Chapter 3 explains the materials and method of the study.

Chapter 4 includes the result and discussion. First, the results of face-to-face interviews with on-site workers are discussed and evaluated. Later the result of the questionnaire survey is discussed and evaluated. All data is illustrated with the help of several charts. Then the results are combined, analyzed, and summarized.

Lastly, chapter 5 contains the highlighted and summarized results of the research as well as the future trends and recommendations for further studies.

# CHAPTER 2

# LITERATURE REVIEW

To prepare a foundation for the research, this section has been designed with the help of several studies in the literature to understand the status of building construction waste, highlight the construction waste management (CWM) strategies, and discuss the use, benefits, and challenges faced in the industry of construction automation and robotics (CAR).

## 2.1 Construction Waste

Waste generation is one of the fundamental environmental problems due to excessive urban population, climate change, and depletion of natural materials. Today the amount of waste produced by the production, operation, and transportation processes in the construction industry is higher than ever before (Fırat & Akbaş, 2015). The amount of waste produced escalates annually (Matthews, 2000); hence, a clear understanding of the reasons for this increase is crucial.

### 2.1.1 Definition and Classification of Construction Waste

According to Osmani and Villoria-Saez (2019), there is no definition of waste in the literature that is generally accepted. However, many define waste as any substance or object disposed of or desired to be disposed of. (Çekirge & Çubukçuoğlu, 2017; Islam et al., 2019; Lu et al., 2011) Construction waste is defined by Osmani and Villoria-Saez (2019) as the materials that cannot be used following production purposes in construction. Those can be the materials that are damaged, defective, or surplus. In addition to that, by-products of the construction process are also defined by authors as construction waste. A large number of natural resources is depleted by the construction industry as input, and waste is produced as an output (Osmani & Villoria-Sáez, 2019). The waste generated by the construction industry has the highest proportion of all (Çekirge & Çubukçuoğlu, 2017). There are different classifications of construction waste in the literature, but it is mainly categorized in two ways.

From the first point of view, construction and demolition wastes are divided into four main groups depending on the waste type resources. Arslan Cosgun, and Salgın (2012) made a classification based on the “Regulation of the Control of Excavation Soil and Construction and Demolition Waste” by the Ministry of the Environment and Forestry Turkey. The Ministry of Science, Industry, and Technology (2016) explains the same four groups in the National Recycling Strategy Document and Action Plan. According to the report, excavation soil is defined as the soil formed due to the land's preparation activities before construction. Roadwork wastes are generated due to the renovation and repair of roads, railroads, and highways. Demolition wastes are caused by demolition, renovation, and repair of the infra- and super-structures or natural disasters. Lastly, the complex wastes are produced by the construction process of infra and superstructures. (Figure 2.1)

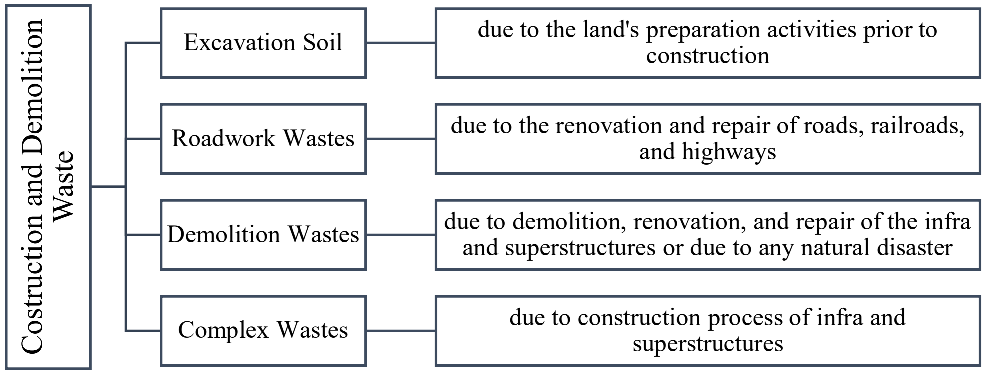


Figure 2.1 Classification of construction and demolition waste according to resources (Arslan et al., 2012; T.C. Çevre ve Şehircilik Bakanlığı, 2016)

There is also another classification based on the phase in which the waste is produced. Osmani (2011) defines the waste generated by the decisions taken before construction as design waste. The ones generated while construction is underway are the clean wastes because they are easy to segregate for reuse or recycle. Osmani, Glass and Price (2008) refer to the research by Innes (2004), who argues that one of three wastes is a result of failures at the design phase, while complex wastes are generated during the demolition and renovation phases. These wastes are considered complex because they are a mixture of various materials and are hard to segregate. Arslan et al. (2012) note that the amount of complex waste is approximately three times more than clean waste in the construction industry.

### 2.1.2 Reasons for Construction Waste

There are multiple approaches to understanding the generation of waste. Research was done by Formoso, Soibelman, De Cesare and Isatto (2002) evaluated the main reason for the waste by investigating seventy-four construction sites. Researchers summarize key factors for eighteen different building materials: such as steel, reinforcement, concrete, ceramic blocks, pipes, and wires. The study revealed that poor site management of flow operations is the main reason for the waste generation for each category of building materials.

Tam, Tam, Chan and Ng (2005) summarize the waste resources into four main groups; which are “poor site management and practices,” “lack of environmental awareness,” “delivery mistakes,” and “poor workmanship.”.

Osmani et al. (2008) classify the reasons for construction waste in eleven categories with the help of related literature research. The paper includes types of construction stages with the relevant explanations for those stages. The detailed classification by writers provides a basis for the following analysis in the literature.

At the design stage, waste generation depends on several factors such as lack of communication and information, detail deficiencies, and product preferences, according to Arslan et al. (2012). Those factors may also affect the amount of waste generated during the construction stage. A study done by Polat, Damci, Turkoglu, & Gurgun (2017) shows that the "design and contract documents related factors" have the highest importance for waste management in construction.

Surplus materials, failures in transportation, storage, construction, and improper equipment are the main origins of the waste generated during the construction stage. The study done by Polat et al. (2017) indicates that qualified and trained workers are also critical for minimum wastage.

Research done by Islam et al. (2019) summarizes the waste resources into six groups according to the construction task which generates the waste, similar to the previous categorization by Osmani (2011). Another research (Narcis, Ray, & Hosein, 2019) also identifies the waste flow with a summarized version of the table prepared by Osmani et al. (2008), focusing on the design and operational tasks.

There are several factors that directly or indirectly affect the generation of construction waste. Table 2.1 indicates all the related factors mentioned in the literature.

Table 2.1 Reasons for construction waste as reported in 8 publications.

| | Reasons for Construction Waste | Reference |
|---|---|---|
| **Contractual** | Errors in contract documents | 3, 4, 6, 7, 8, |
| | Incomplete contractual documentation | 3, 4, 8, |
| **Design** | Frequent design changes and change orders | 2, 3, 4, 6, 7, 8, |
| | Design and construction detail errors | 1, 3, 4, 5, 6, 7, 8, |
| | Design and detailing the complexity | 1, 3, 4, 6, 7 |
| | Selection of low-quality materials | 6, 7 |
| | Inadequate, insufficient specification | 1, 2, 3, 4, 5, |
| | Incomplete construction documentation | 3, 4, 5, 8, |
| | Ignoring buildability | 2, |
| | Resistance to adopting alternative materials | 2, |
| | Poor communication and coordination at the design stage | 3, 4, 5, |
| **Procurement** | Incomplete procurement documentation | 3, 4, 5, |
| | Lack of allocated responsibility for decision making | 3, 4, |
| | Lack of early stakeholders' involvement | 3, 4, |
| | Poor communication/coordination at the procurement stage | 3, 4, |
| **Ordering** | Over ordering due to minimum package sizes | 1, 2, 3, 4, 6, 7, 8, |
| | Mistakes in quantity take-offs | 3, 4, 6, |
| | Purchasing materials do not comply with specifications | 1, 3, 4, 6, |
| | Unnecessary material handling on site | 1, 6, |
| **Transportation** | Damage during transportation to site/on-site | 1, 3, 4, 5, 6, 7, 8, |
| | Methods of unloading | 1, 3, 4, |
| | Insufficient protection during unloading | 3, 4, |
| | Difficulties for delivery vehicles accessing construction sites | 6, 7, |
| | Materials supplied in loose form | 3, 4, 6, 7, 8, |
| | Suppliers’ and shipping errors | 3, 4, |

Table 2.1 (cont'd)

| | | |
|---|---|---|
| **Storage** | Improper storing methods | 1, 2, 5, 6, 7, 8 |
| | Inappropriate site storage area leading to damage and deterioration | 2, 3, 4, 5, 6, |
| | | |
| | Relocation Materials (Materials stored far away from the point of application) | 3, 4, 5, |
| **Site Management** | Lack of process standardization | 1, |
| | Lack of supervision | 1, 3, 4, 6, 8, |
| | Lack of waste management plans | 2, 3, 4, 6, |
| | Lack of on-site material control | 3, 4, 6, 8, |
| | Lack of environmental awareness | 6, |
| | Delays in passing information on types and sizes of materials to be used | 1, 3, 4, 6, |
| | Disorder of site layout | 2, |
| **Site Operation** | Unused/leftover materials and products on site | 1, 4, 5, 6, 7, |
| | Scarcity of equipment | 1, 4, 6, 7, 8, |
| | Inappropriate construction methods | 6, |
| | Damage caused by subsequent trades | 6, |
| | Use of incorrect materials resulting in their disposal | 1, 3, 4, 5, 6, 8, |
| | Poor workmanship | 1, 2, 3, 4, 6, 7, 8, |
| | Damage caused by workers due to lack of experience | 1, 3, 4, 6, 7, |
| | Too much overtime for workers | 4, 6, |
| | Poor lighting of the site | 2, 6, |
| | Poor ethics | 3, 4, |
| | Deviations in the dimensions of structural elements | 1, |
| **Residual** | Waste from cutting uneconomical shapes | 1, 2, 3, 4, 5, 6, 8, |
| | Packaging | 2, 3, 4, 5, 7, 8, |
| | Over preparation of materials | 3, 4, 8, |
| | Off-cuts from the original length | 1, 3, 4, 5, |
| **External** | Weather conditions | 3, 4, 5, 6, 7, 8, |
| | Unpredictable local conditions | 6, |
| | Theft | 3, 4, 6, 7, 8, |
| | Vandalism | 3, 4, 6, 7, |
| | Damages caused by third parties | 6, |

1:(Formoso et al., 2002), 2:(Tam et al., 2005), 3:(Osmani et al., 2008), 4:(Osmani, 2011), 5:(Arslan et al., 2012), 6:(Polat et al., 2017), 7:(Islam et al., 2019), 8:(Narcis et al., 2019),

### 2.1.3 Effects of Construction Waste

Construction waste has several vital economic, environmental, and social impacts. The amount of waste directly affects the project's cost due to flow operations such as sorting, eliminating, transportation, and disposing of the wasted material. The cost of the waste in construction is expected to be 30% of the cost of materials (Fadiya, Georgakis, & Chinyio, 2014). In addition to that, those flow operations for waste disposal cause an increase in the project time, resulting in project cost overrun. An increase in the project cost decreases the profits of the firms, leading to business failure.

There are several environmental effects of construction waste. Due to the complex nature of the construction works, the waste contains several hazardous materials, which pollute the environment if not handled properly. A recent study indicates that construction activities are responsible for 60% of raw material consumption and 35% of total waste production (Bribián, Capilla, & Usón, 2011). In addition, the construction industry consumes 40% of the total energy. According to Eurostat (2018), approximately 45.7% of the waste is landfilled, which means excessive land occupation and biodiversity destruction (Tafesse, Girma, & Dessalegn, 2022).

Environmental impacts of the construction waste form public risks in health and safety since the absence of proper waste handling could lead to health problems.

Tafesse et al. (2022) conducted research with contractors, consultants, and clients in the Ethiopian construction industry to understand the critical impacts of construction waste. The results show that the most important three effects of construction waste are "Projects cost overrun," "Pollution of environment," and "Failure of firms as a result of profit reduction."

The important effects of construction waste found in the literature are represented in Table 2.2.

Table 2.2 Effects of construction waste reported in 2 publications

| | Effects of Construction Waste | Reference |
|---|---|---|
| **Economic** | Projects cost overrun | 2, |
| | Increase in project cost due to landfill fees | 2, |
| | Increase in project cost due to transportation cost of waste | 2, |
| | Failure of firms because of profit reduction | 2, |
| **Environmental** | Pollution of soil, water, and air | 2, |
| | Pollution due to dust generation | 2, |
| | An excessive amount of raw material consumption | 1, 2, |
| | An excessive amount of resource depletion | 1, 2, |
| | An excessive amount of land occupancy | 1, 2, |
| | Construction sector's low sustainability | 2, |
| | Biodiversity destruction | 2, |
| | Greenhouse gas emissions and global warming | 1, 2, |
| **Social** | Public health risks due to contamination | 1, 2, |
| | Public safety risks | 2, |

1:**(Marzouk & Azab, 2014)**, 2:(Tafesse et al., 2022),

### 2.1.4 The Status of the Construction Waste

The construction industry has the largest share of total waste produced by European Union (EU) countries with 35.9%. After the construction, mining and quarrying activities have the most considerable waste production, with 26.6% (Figure 2.2)(Eurostaat, 2018). According to the data given by Eurostat (2018), each EU citizen generates 1.8 tons of waste, which makes total waste of 813 million tonnes for 28 EU countries and several non-member countries.

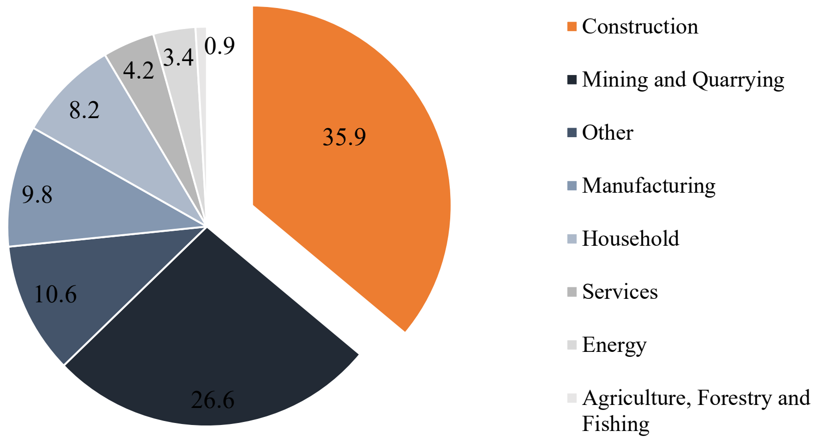


Figure 2.2 Waste Generation by Economic Activities and Households (Eurostaat, 2018)

According to the Eurostat data belonging to 2018, approximately 38.4% of the produced waste is landfilled. However, a current study by Islam et al. (2019) indicates that the European countries recycle over 60% of the construction waste while the UK has over 85% recycling rate (Figure 2.3).

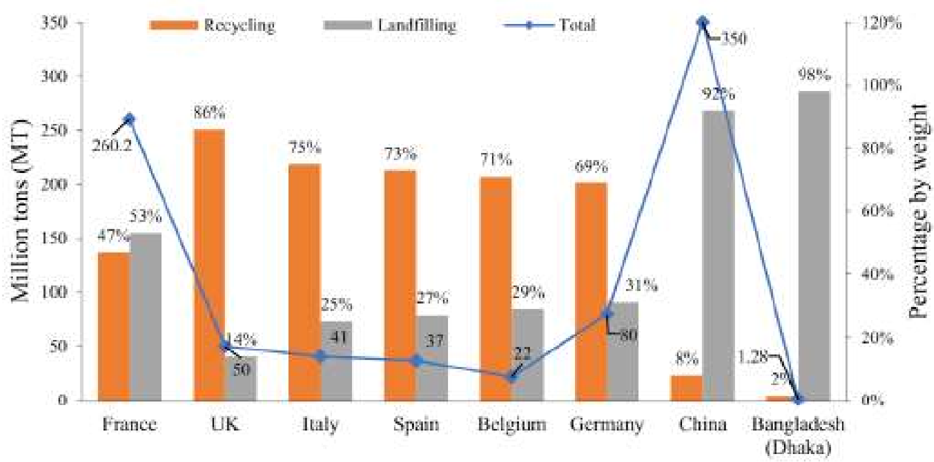


Figure 2.3 . Construction waste generation and recycling status of different countries (Islam et al., 2019)

The composition of the construction waste produced by different countries varies according to the purpose and construction system, as well as the cultural differences and environmental conditions. However, today concrete is the most widely used building material in all cultures and environmental conditions. The amount of concrete by volume fallows the water as the second most used material (Fırat & Akbaş, 2015). For the construction, concrete is followed by brick, ceramic, and timber with respect to countries.

Unfortunately, Turkey has no reliable data on construction waste because construction and demolition wastes are not included in total waste data. (T.C. Çevre ve Şehircilik Bakanlığı, 2016). In addition to that, due to the urban transformation project, the amount of construction and demolition increased uncontrollably, and the resulting wastes are not documented and appropriately managed.

## 2.2 Construction Waste Management

The increasing amount of waste and its economic, environmental, and social impacts show that it is important to take measures to manage construction waste urgently. The productivity of the construction industry will escalate with the implementation of waste management, as well as the sustainability of the sector (Jaillon, Poon, & Chiang, 2009).

### 2.2.1 Construction Waste Management Strategies

To manage construction waste, the current literature suggests several management strategies. These can be examined under two main headings: governmental strategies and business strategies. A summary of defined procedures is represented in Table 2.3. The categorization of the table is adapted from one of the most referred papers in the literature (Osmani & Villoria-Sáez, 2019).

Table 2.3 Construction waste management strategies identified in 15 publications

| | | CWM Strategies | Reference |
|---|---|---|---|
| GOVERNMENTAL STRATEGIES | GENERAL | Government legislations | 2, 5, 7, 10, 11, 13, |
| | | Economic instrument and no tax policies | 7, 10, |
| | | Implementation of green building codes and specifications | 2, 15, |
| | | Introduction of penalties for poor waste management practices | 12, 13, 15, |
| | | Increased landfill charges | 15, |
| | | Incorporation of a material waste minimization plan policy in construction contracts | 2, 6, 15, |
| | | Offer waste management intensives | 15, |
| | | Promote decent quality recycled products | 6, 10, |
| | | Conduct comparative waste management studies | 1, 5, 11, |
| | | Implementation of additional tender for waste initiatives | 2, 13, |
| BUSINESS STRATEGIES | GENERAL | BIM aided CWM | 8, 9, 11, |
| | | Standardized construction materials and design. | 6, 12, 13, |
| | | Providing training and increasing consciousness on construction waste among the workers | 6, 10, 13, 15, |
| | | Employing a specific professional to inspect and manage construction waste related issues | 14, 15, |
| | | Strong coordination between all parties | 2, 14, 15, |
| | | Providing scheduled training on material waste minimization strategies for construction workers | 7, 13, 14, 15, |
| | PRECONSTRUCTION STAGE | Supporting off-site construction and prefabrication | 2, 4, 5, 8, 12, 13, 15, |
| | | Taking measures to minimize rework, repair, and replace | 13, 15, |
| | | Procurement waste minimization strategies | 4, 6, 8, 12, |
| | | Designing out waste | 5, 9, 12, 14, |
| | | Use of waste prediction tools | 8, 12, |
| | | Site waste management planning and supervision | 2, 8, |
| | | Design for flexibility and deconstruction | 7, 8, |
| | | Identification of client's requirements correctly | 4, 7, |
| | | Waste minimization manuals and guides | 4, 6, 12, |
| | | Minimum design changes | 14, |
| | | Setting recycling targets for each phase | 14, |

Table 2.3 (cont'd)

| | | | |
|---|---|---|---|
| BUSINESS STRATEGIES | CONSTRUCTION | Reusing and recycling the material leftover on sites | 15, |
| | | Implementing strong on-site management practice | 4, 15, |
| | | Implementing incentive reward programs | 1, |
| | | Enhancing proper material storage, effective and frequent site supervision | 7, 14, 15, |
| | | Improvements in on-site waste management practices | 5, 14, |
| | | Utilizing durable and repairable construction materials | 7, 14, |
| | END-OF-LIFE | Material recycling and reuse | 2, 5, 8, 11, 12, 14, |
| | | Construction waste quantification and source evaluation | 4, 6, 12, 14, |
| | | On-site construction waste sorting | 5, 8, 12, 14, |
| | | Waste management mapping | 5, 12, |
| | | On-site waste auditing and assessment tools | 5, 12, |

1:(Chen et al., 2002) , 2: **(Shen & Tam, 2002)** 3:(Tam et al., 2005), 4:(Tam et al., 2007), 5:(Osmani et al., 2008) , 6:(Osmani, 2011) , 7:(Arslan et al., 2012), 8:(Ajayi et al., 2015), 9:(Bilal et al., 2016) , 10:(Lu et al., 2017), 11:(Islam et al., 2019) , 12:**(Osmani & Villoria-Sáez, 2019)** , 13:(Narcis et al., 2019) , 14:(Hasmori et al., 2020), 15:(Tafesse et al., 2022)

*A. <u>Governmental Strategies</u>*

Mcdonald and Smithers (1998) demonstrate the effectiveness of the governmental site waste management plan through a case study which resulted in 15% reduced construction waste. Shen and Tam (2002) support this result with the help of a survey conducted in Hong Kong. Research done by Osmani et al. (2009) clearly shows the most important incentives for waste minimization are governmental measures such as legislation, waste management policies, and financial rewards and taxes for firms. Another research shows that the implementation of the construction waste charging scheme in Hong Kong resulted in the successful reduction of construction waste for three years (Yu, Poon, Wong, Yip, & Jaillon, 2013). Yu, Wong, Wu, & Poon (2021) also support the importance of legislation and taxes while adding the need for a mature recycling market.

*B. <u>Business Strategies</u>*

Chen, Li, & Wong (2002) propose that the most effective waste management could be done by encouraging construction workers since poor workmanship is one of the critical factors in waste generation. The researchers noted that construction waste would decrease when workers are properly motivated.

Tam, Tam, Zeng, & Ng (2007) conducted a research to understand the waste reduction efficiency of prefabrication by comparing it with conventional construction. The research results show that prefabrication can effectively minimize construction waste since it supports the standardization of building materials and components. More research supports the effectiveness of prefabrication for waste reduction. (Tam et al., 2005).

Ajayi et al. (2015) support that the initiatives for construction waste minimization need to be a collection of several directions for the project's whole life, from the design stage to the end of life. They noted that the management tools that comply with building information modeling (BIM) would be practical to adopt an integrated project delivery.

According to Hasmori et al. (2020), the most important strategy is improving workers' awareness of construction waste. In addition, they indicate proper handling, successful waste segregation, building material standardization, and off-site construction are other essential factors in managing construction waste.

### 2.2.2 Barriers in Construction Waste Management

Despite the fact that researches are showing the importance of management strategies for minimizing construction waste and emphasizing the key tasks, the construction industry is reluctant to implement those strategies. There are several reasons why companies do not include CWM in their project cycle. Based on literature, those barriers are summarised under four groups and twenty items. (Table 2.4)

Table 2.4 Barriers in construction waste management identified in 6 publications

| | Barriers in CWM | Reference |
|---|---|---|
| **Governmental** | Lack of government support and enforcement | 1, 4, 5, 6, |
| | Lack of waste minimization norms | 3, |
| | Lack of waste minimization guidance | 2, 3, 5, |
| | Lack of training in environmental management | 1, |
| | Poorly defined responsibilities | 3, |
| **Economic** | Extra costs to implement CWM | 1, 2, 3, |
| | Need of extra labor/man-hours | 2, |
| | Extending the work plan schedule | 2, 3, |
| | Lack of information on cost effectiveness of waste management | 3, 6, |
| | High recycling cost | 4, 5, |
| | Immature recycling market | 2, 4, |
| **Technical** | Insufficient skilled labors | 1, 4, |
| | Lack of experienced site waste management staff | 1, 2, 3, |
| | Composite site condition | 2, 4, |
| | Need of extra paperwork | 1, 3, |
| | Lack of available technologies | 1, 2, 6, |
| **Behavioral** | Lack of client support | 1, 4, |
| | Lack of managerial commitment | 1, 3, 5, |
| | Reluctance to change habitual practices | 1, 3, |
| | Waste seems inevitable | 3, |

1: **(Shen & Tam, 2002)**, 2: (Ajayi et al., 2015), 3: **(Osmani & Villoria-Sáez, 2019)**, 4: (Yu et al., 2021), 5: (Kolaventi et al., 2021), 6: (Kabirifar et al., 2021)

### A. *Governmental Barriers*

The study by Kabirifar, Mojtahedi, & Wang (2021) shows that national regulations, standards and reports are insufficient to promote succesfull waste management. There are many more studies supporting the inadequacy of norms, guidelines and education on waste minimization. (Ajayi et al., 2015; Kolaventi, Momand, Tezeswi, & Kumar, 2021; Osmani & Villoria-Sáez, 2019; Shen & Tam, 2002)

### B. *Economic Barriers*

Several pieces research show that the main reason why companies do not implement the CWM strategies is the increased project cost due to additional managerial and application costs. (Osmani & Villoria-Sáez, 2019; Shen & Tam, 2002; Tam et al., 2005). Planing and implementation of the management plan increase the project time as well as requires expertise which leads to cost overrun. (Ajayi et al., 2015; Osmani & Villoria-Sáez, 2019). Although CWM strategies can reduce costs in the long term, high initial costs create a negative perception of waste management. (Shen & Tam, 2002)

### C. *Technical Barriers*

There is a technical gap in the sector due to lack of education and experience. In addition, the absence of support for the necessary technology and tools causes the necessary technological infrastructure to fail to develop. (Kabirifar, Mojtahedi, & Wang, 2020; Kolaventi et al., 2021; Shen & Tam, 2002)

The immature recycling industry is unable to offer a good quality product range that meets all needs. Furthermore, the lack of availability of local recycling companies makes it difficult to access products and affects the transportation cost of products. (Ajayi et al., 2015; Yu et al., 2021)

### D. *Behavioral Barriers*

There is a lot of misleading information on waste management. Due to the lack of information about the economic and environmental benefits of waste management, clients and managers are reluctant to implement it. (Kolaventi et al., 2021; Osmani & Villoria-Sáez, 2019; Shen & Tam, 2002;. Yu et al., 2021) According to Osmani and Villoria-Saez (2019), waste is seen as an inevitable consequence of construction work, with no alternatives to stereotypical construction methods, and the amount of waste generated is ignored.

### 2.2.3 Regulations for Waste Management

Because of the environmental and economic problems in many countries, various regulations are developed to regulate and eliminate the negative impact of construction waste (Polat et al., 2017). Although those regulations are successful in raising awareness and reducing some amount of waste, they fail to achieve global success(Fırat & Akbaş, 2015).

According to the 'Council directive 2008/98/EC' (2008), each European Union country should follow a priority order while managing waste. Directives note that the waste should be prevented. If the waste is inevitable, it should be prepared for reuse, recycling, or recovery. If none of the operations are applicable, the waste materials should be disposed of. All of the operations must be provided by the Member States without any harm to the environment and nature. In addition, the hazardous waste substance should be controlled, labeled, and recorded. Unless the directives are ensured, Member States will be subjected to dissuasive and effective penalties. Those directives aim to reach a 50% rate for recycling of all wastes and %70 for recycling and reuse of construction wastes until 2020 with the help of waste management plans, and by 2024 the commission will set new reuse and recycle targets for the construction waste.

In the United States, there are regulations named as 'Resource Conservation and Recovery Act' (1976) on solid and hazardous wastes. The generation, deposition, transportation, and treatment of solid and hazardous wastes are controlled and managed by those regulations.

In Canada, there is 'Canadian Environmental Protection Act' (1999) to protect the environment and nature. Similar to the United States, the management of hazardous waste generation, transportation, deposition, and treatment activities are regulated by this Act. It is the responsibility of provinces to implement and control the application of regulations.

Table 2.5 Main legislation in Turkey on construction waste management (Bayram et al., 2012; T.C. Çevre ve Şehircilik Bakanlığı, 2016)

| **Regulation** | **Year** |
|---|---|
| Environmental Law /2872 | 1983 |
| Regulation on Management of Solid Waste | 1991 |
| Municipality Law /5393 | 2005 |
| Regulation on Control of Excavation, Construction, and Demolishing Wastes | 2004 |
| Regulation on General Principles of Waste Management | 2008 |
| Environmental Impact Assessment Regulation | 2008 |
| Regulation on Permits and Licenses Required by the Environmental Law | 2009 |
| Regulation on Landfilling of Wastes | 2010 |
| Waste Collection Center Directive | 2014 |
| Regulation Waste Management | 2015 |

In Turkey, practices to regulate construction wastes have recently begun and accelerated with an increase in construction activities (Fırat & Akbaş, 2015). Regulations and laws related to building construction waste management are listed in Table 2.5. In 2004, "Regulation on Control of Excavation Soil, Construction and Demolition Wastes" was published as an intention for control of construction wastes. It is crucial to minimize the waste at the source, recycle and reuse it, and provide a clear separation of wastes by selective demolition (T.C. Çevre ve Şehircilik Bakanlığı, 2016).

According to the context of the European Union's waste report, it is aimed to recycle 70% of construction waste by 2020 (Bilim Sanayi ve Teknoloji Bakanlığı, 2014). However, according to the National Waste Management and Action Plan (2016), ven any accurate data entry and documentation is not performed yet. Under these conditions, it seems that the 70% recycling rate is impossible within the next year.

## 2.3 Construction Automation and Robotics

Construction Automation and Robotics (CAR) is the development of electronic and mechanical systems called robots by using information technologies to perform construction tasks and operations automatically, to enable, assist the task or reduce the need for manpower. (Pereira, Pires, & Calmeiro, 2002; Vähä, Heikkilä, Kilpeläinen, Järviluoma, & Gambao, 2013)

According to the Encyclopaedia Britannica (2022), robotics is defined as "the design, construction, and use of machines, called robots, to perform tasks done traditionally by people." Robots are mostly used for repetitive tasks that need intensive manual labor.

Automation and robotics is an interdisciplinary industry that involves mechanical and electrical engineering, as well as computer science. With the help of developing technology, many industries benefit from robotics. Pereira et al., (2002) write that the car industry is among the leading sectors that benefit from robots, followed by military and health care.

### 2.3.1 Automation and Robotics in Construction Industry

The construction industry is a sector that has existed and developed since the existence of man. Almost all old civilizations attached importance to technology in construction (Gimenez, Abderrahim, Padron, & Balaguer, 2002). Today, although the construction sector maintains its same importance by being the most critical economic sector, it could not keep its relationship with technology as strong as before.

Until recently, there has been no effort for automation in the construction industry. Due to the lack of construction workers in Japan in the 1970s for the first time, several Japanese companies directed their investments to automation in construction and construction robotics. During this period, Shimizu Corporation and Takenaka

Corporation were pioneers in the production of robots involved in various tasks. They tried to solve the construction worker deficit with robots that do repetitive and straightforward work in construction sites and off-site and provided the development of construction robotics in Japan (Higgins, 2019). Automation in construction, which gained momentum in Japan in this period, pioneered the start of academic studies, even if it was not adopted by the whole world (Pan, Linner, Pan, Cheng, & Bock, 2020a).

Today, the construction industry is still one of the least automated industries (Matthews, 2000; Melenbrink, Werfel, & Menges, 2020). Regardless of the type of construction work, almost all work is dependent on labor. With the help of academic studies that research and prove the capabilities and advantages of construction robotics, studies started to accelerate. In addition to that, developing technologies such as building information modeling and augmented technology are prepared for a suitable environment for robots in the construction industry. Although the contribution of robotics to the construction sector has increased with these developments, it still provides a limited service that has not reached its maximum efficiency (Pan et al., 2020a).

Globally, while adapting to new technologies, the construction industry shows a low performance. It has not been able to catch up with technological developments in robotics and lags behind other sectors (Gharbia, Chang-Richards, Lu, Zhong, 2020). The 6% GDP of the construction sector shows that the sector needs urgent help for efficiency and sustainability (Zhang, Luo, & Xu, 2022). Automation and robotics are seen by many authors as full of potential to change the negative state of the industry. (Pan, Linner, Pan, Cheng, & Bock, 2020b; Wong Chong, Zhang, Voyles, & Min, 2022; Zhang et al., 2022)

### 2.3.2 Range of Construction Automation and Robotics

There are various definitions and requirements for construction robotics in the literature defined by people from different branches of the construction industry. For example, the expectations and definition of construction robotics for a person involved in the design phase and a person involved in the construction phase are completely different. (Chen, García de Soto, & Adey, 2018)

One of the detailed classifications is done by Son, Kim, Kim, Han, & Kim, (2010). The authors divided construction robotics into six categories. These are control systems, automated systems, earth working equipment, heavy lifting equipment, sensor systems, and path planning system. The most cited grouping of construction robotics is classified by Bock (2015) as robot-oriented design, robotic industrialization, construction robots, site automation, and ambient robotics.

Another categorization is done by Strukova and Liska (2012) by dividing construction robotics into three main groups which are an enhancement to existing construction plants and equipment, task-specific robots, and intelligent or cognitive machines. Another research summarized and grouped the construction robotics according to their task in the lifetime of the project. Monitoring, planning, and estimating, construction manufacturing, designing, and quality control are the categories defined by the author. (Oke, Akinradewo, Aigbavboa, & Akinradewo, 2019).

Melenbrink et al., (2020) categorize the automation and robotic technologies according to level of autonomy of the system. 0 is defined as no automation, while 5 as full automation and each system is placed in a category according to its level of automation. The fully automated systems are the ones that can fulfill their task in all field conditions without the need for any human guidance.(Table 2.6)

Table 2.6 Categorization of construction robotics according to level of autonomy (Melenbrink et al., 2020)

| Level | Definition | Description |
|---|---|---|
| **0** | Non autonomous | System does not have any freedom to fulfill a task |
| **1** | Operator assistance | System controls only one directive, the rest is dependent on the operator |
| **2** | Partially autonomous | System controls multiple directives, however, it is still dependent on an operator |
| **3** | Conditionally autonomous | System controls all directives, however, needs reprogramming in change of conditions. |
| **4** | Highly autonomous | System can operate in a certain condition without need of assistance |
| **5** | Fully autonomous | System can operate in any conditions without need of assistance |

Gharbia et al. (2020) defines the robotic technology into twelve groups according to their on-site operations. Those are additive manufacturing, automated installation systems, automated robotic assembly system, autonomous robotic assembly, robotic bricklaying, in-situ robotic fabrication system, automated concrete spraying, autonomous spraying, distributed robotic construction, fused filament fabrication, printing technology and unevenness recognition.

Lastly, one of the most recent papers (Pan et al., 2020b) groups the construction automation and robotics according to the building life cycle and level of task integration. This two-dimensional perspective is taken as a basis for the categorization of automation and robotics, and with the help of other studies in the literature, Table 2.7 is prepared.

Table 2.7 Categorization of construction automation and robotics according to building life cycle and level of task integration (Bock, 2015; Chen et al., 2018; Gharbia et al., 2020; Oke et al., 2019; Pan et al., 2020b; Son et al., 2010; Strukova & Liska, 2012)

| | PLANNING & DESIGN | OFF-SITE CONSTRUCTION | ON-SITE CONSTRUCTION | SURVEYING & MONITORING | OPERATION & MAINTENANCE | DECONSTRUCTION & DEMOLITION |
|---|---|---|---|---|---|---|
| GENERAL PURPOSE | Design assistance tools | | | Inspection drones | | |
| | Estimation tools | Autonomous vehicles | | | | |
| | Visualization tools | Exoskeletons and wearables | | | | |
| | Procurement systems | Cable driven parallel robots | | | | |
| TASK ORIENTED | | Material handling robots | | | | |
| | | Prefabrication | Site preparation robots | Site mapping drones | Material sorting robots | |
| | | | Automatic pilers | Climbing robots | | Material recycling robots |
| | | | Heavy lifting equipment | | Facade cleaning robots | Demolition equipment |
| | | | Brick laying robots | | Pipe cleaning robots | |
| | | | Assembly robots | | | |
| | | | Plastering and painting robots | | | |
| | | | Tiling robots | | | |
| | | | Floor leveling robots | | | |
| | | | Path planning systems | | | |
| INTEGRATED | Simulation tools | Modular construction | | | | Deconstruction factory HAT down system |
| | AR/VR Systems | Off and on-site integrated factories | | | | |
| | | | Sky factories Big canopy system | | | |
| | | | Ground factories | | | |
| | | Additive manufacturing Contour crafting | | | | |

### 2.3.3 Benefits of Applying Construction Automation and Robotics

Traditional construction approaches have reached their limits in fulfilling the increasing needs of the construction industry (Bock, 2015). Studies indicate that because the construction industry is stuck with conventional methods and cannot exceed the limits, it cannot progress, and productivity in the construction sector has been decreasing for over a hundred years (Figure 2.4).

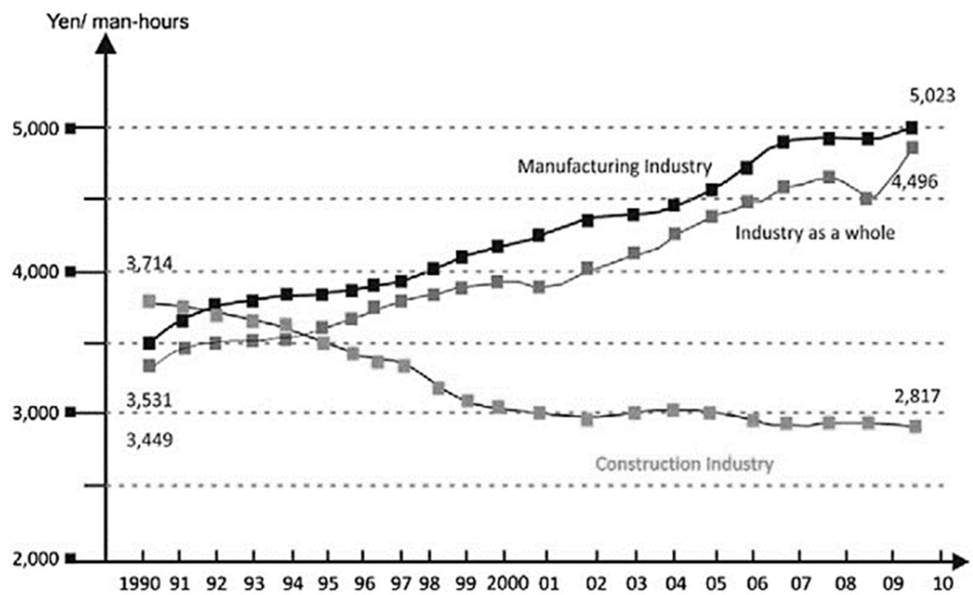


Figure 2.4 Comparison of labor productivity of construction industry and manufacturing industry between 1990 and 2010 (Bock, 2015)

The contribution of robotics to the construction industry is considered as one of the most feasible solutions to improve the performance of the sector. (Bock & Linner, 2013; Cai, Ma, Skibniewski, Bao, & Wang, 2020; Pan et al., 2018) Gharbia et al. (2020) systematically reviewed the 52 articles to understand the current status of robotics in the construction industry. As mentioned in 47 out of 52 articles, efficiency is the most cited benefit of construction robotics.

Since the construction process is generally based on human resources, capabilities affect productivity directly. For this reason, one of the first goals of construction robotics is to increase efficiency as a solution to these problems related to human behaviors (Fleming, Callaghan, & Craig, 2019). Human characteristics that reduce work productivity, such as forgetfulness and fatigue, do not apply to robots. The efficiency of the robots depends on the collaboration type of the machine with human. The more autonomous the system is, the more efficient it will be as the work that the robotic technology will perform will be less affected by human characteristics. (Wu, Lin, & Zhang, 2022).

Research done by Oke et al. (2019) clearly shows the benefits of robotics to the construction industry. Survey results indicate that architects, contractors, project managers, and quantity surveyors in South Africa think that the construction industry benefits significantly from construction robotics in many areas. The most ranked benefits of robots are "increases the accuracy of the components" and "promotes design specification," followed by "increases the quality of construction products" and "reduces the duration of the project's delivery." Those benefits are all related to productivity and final product quality.

Another survey was conducted in China in order to understand the opinion of the companies which have experience with construction robotics on the benefits of the construction industry. (Cai et al., 2020) The companies were questioned about their opinions on the advantages of the implementation of automation and robotics. Results indicate that more than half of the respondents point out that construction robots enhance the quality, efficiency, safety, and labor-saving, as well as to conduct high-difficulty or impossible construction tasks for human workers (Figure 2.5). According to results, construction robots also have the advantage of reducing construction waste and saving raw materials. However, environmental protection is not as important as increased efficiency and quality.

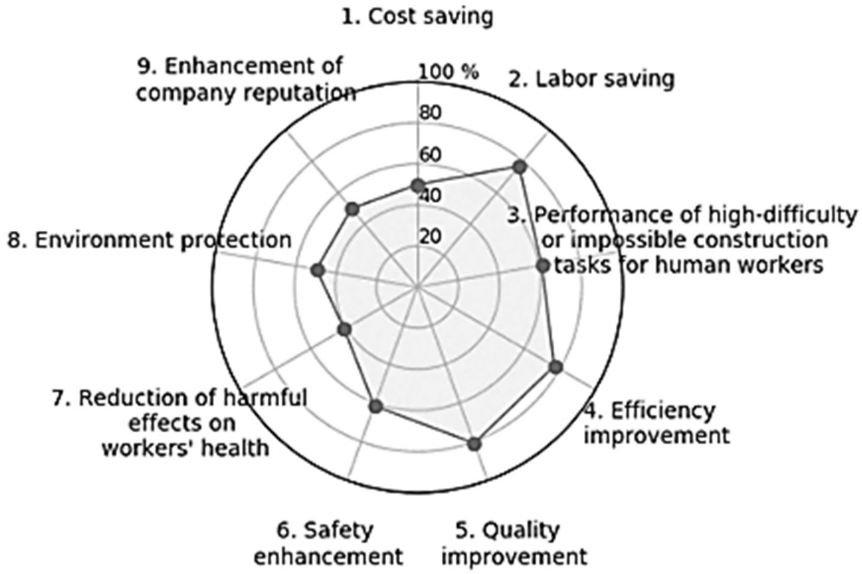


Figure 2.5 The opinion of the companies in China on the benefits of construction robotics (Cai et al., 2020)

Research on the productivity of the bricklaying robot (Wu et al., 2022) reveals the effects of several influential factors. One of the factors is that a robot whose proactivity is enhanced with sensors increases the efficiency of the construction. The other factor is the number of robots on the site. When the number has increased, the productivity of each robot also increases.

Another similar research is conducted by Wong Chong et al. (2022) to understand the effect of wood framing robots on productivity by comparing it with manual assembly. The results show that the proposed robotic construction is 39 times more efficient on average than the manual construction method (Figure 2.6). The results of three tests with different complexity also show that as the BIM model complexity increases, the efficiency of robotic technology and the accuracy of the resulting work increases.

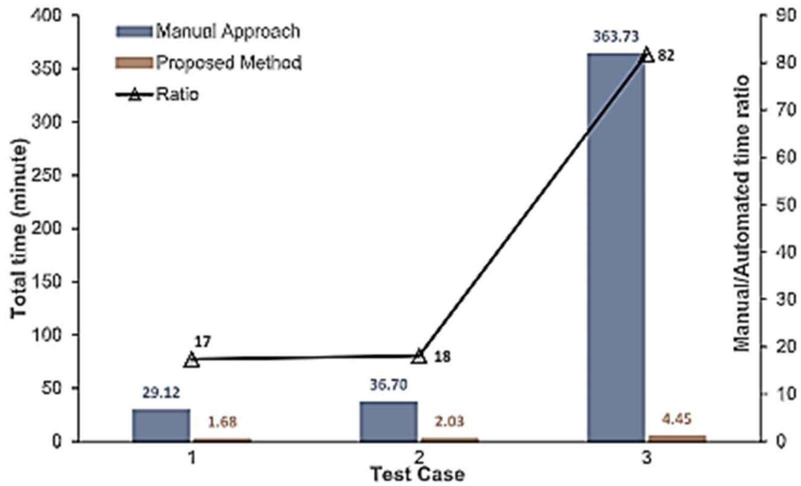


Figure 2.6 Time comparison of the manual approach and the proposed robotic methodology. (Wong Chong et al., 2022)

#### 2.3.4 Barriers for Applying Construction Automation and Robotics

Although it is accepted that it has many advantages, construction robots are still not included in the construction sector with their full efficiency. Many barriers limit the use of robots in the construction industry. Firms that encounter these obstacles do not take risks and prefer traditional working methods generally (Kamaruddin, Fadhil, & Mahrub, 2016).

Many studies are trying to understand the obstacles faced by robotics in the construction industry.

##### 2.3.4.1 Financial Issues

The most important problem faced by the construction companies is the initial cost of the construction robots. Companies need high capital to invest in robotics. In addition to that, robots need a high amount of maintenance and update costs. Only competitive companies with high capital can afford such an expense, while medium and small-sized companies do not have the possibility (Yahya et al., 2019).

Studies conducted in many different parts of the world show similar results. Many studies conclude that cost-related reasons are recognized as the most important factor for the slow development of robotics in the construction industry. (Cai et al., 2020; Strukova & Liska, 2012; Yahya et al., 2019).

A survey was done by Cai et al. (2020) aimed to perceive the perspective of both experienced and inexperienced companies in China on the challenges of robotics in the construction industry. While experienced companies are mostly concerned about the initial cost of the robots, inexperienced companies think that the immaturity of the technologies and lack of technicians is the most important obstacle for construction robots (Figure 2.7). Almost none of the companies think that the application of robotics in the construction industry is unnecessary, which means most construction companies are enthusiastic and willing to use construction robots when appropriate conditions are met.

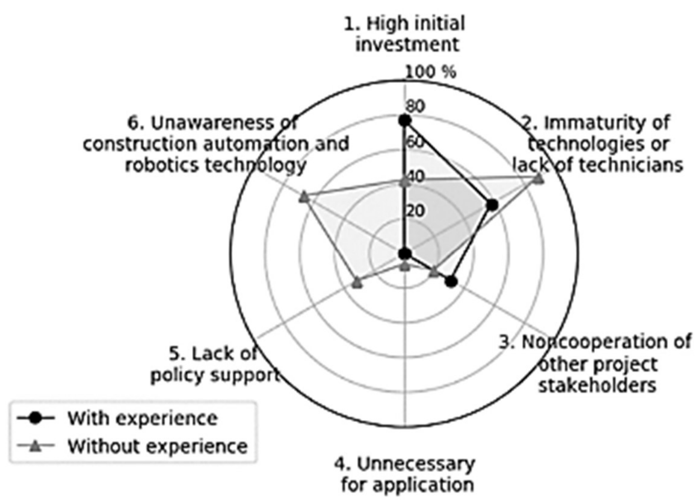


Figure 2.7 Opinion of companies in China on problems, concerns, and hindrances to robotics (Cai et al., 2020)

#### 2.3.4.2 Technical Issues

In addition to the capital needed to acquire robotics technology, companies should also have the technical infrastructure to use them. It is necessary to include the necessary software and hardware for a complete and effective transfer of knowledge and for the actual benefit of robotics (Brosque et al., 2020b). In addition, the necessary tasks must be carried out by trained personnel in order to use this software and hardware correctly. The entire project, from design to implementation, should be arranged and prepared in accordance with the robotic construction (Howe, 2000).

Construction sites require different types of information exchange, such as human-human, human-robot, and robot-robot interactions. To ensure successful coordination in the field, it is important to have clearly defined hierarchies of interrelationships. In addition, the technologies developed must be able to adapt to these forms of communication. (J. Zhang et al., 2022)

#### 2.3.4.3 Construction Environment

From start to finish, the construction process appears to be a repetition of one another, but when you drill down into the details, each task is unique with no exact repetition (Liang, Kamat, & Menassa, 2020). Due to its unpredictable, unstable, and complex nature, the construction site is a significant barrier to the effective use of construction robotics.

Robots that have proven their success in controlled areas such as factories must be able to quickly adapt to changes in location, direction, or mission without any need for reprogramming (Robotics Online Marketing Team, 2018). To enable this adaptation, robotic technologies must be capable of capturing complex and changing field conditions (Lee, Ham, Park, & Kim, 2022; Zhang et al., 2022) and kept simple. For this, the workflow should be derived from a set of basic tasks that are as simplified and standardized as possible. This requires a certain degree of standardization in both design and construction methods in response to the complex nature of the construction site (Linner et al., 2020; Warszawski & Navon, 1998).

Besides, the construction environment should be arranged according to the need for robots (Warszawski & Navon, 1998). Power and networking must be supplied for the effective operation of robots all over the site (Brosque et al., 2020b). It is also unlikely to guarantee a safe environment for workers in such complex field conditions (Wu et al., 2022).

#### 2.3.4.4 The complexity of the industry

Adapting to a new system is a complex process, and it requires commitment in every aspect. Due to its nature, construction is a fragmented and complicated process where many sectors work together (Skibniewski & Zavadskas, 2013). If robotics is expected to be involved in a construction process, the entire team, from the designers to the engineers, must meet this expectation. This requires not only the inclusion of robots in the construction area but the necessary technologies to be established in every sector related to the construction industry (Yahya et al., 2019). Since interdisciplinary collaborations are difficult to manage and ensure (Linner et al., 2020), the development and dissemination of systems cannot be ensured. For construction robots to gain a place in the sector, studies should be supported by all disciplines and common knowledge should be created.

Many factors need to be considered to monitor the effectiveness of any innovation coming into the sector. However, these criteria have a subjective approach in the sector, causing the analysis to lose validity in some areas. Studies that will reduce this uncertainty regarding the performance of robots can only be achieved through government support, standards, and training (Linner et al., 2020).

Currently, the most efficient construction methods are the result of centuries of know-how in the manpower-based construction industry. Some studies (Melenbrink et al., 2020; Warszawski & Navon, 1998) argue that it would be more effective to change this fragmented and complex structure of the construction industry, re-evaluate the process with automation and developing technology and build it as a whole from the beginning, rather than trying to fit robotic technologies into the existing system.

#### 2.3.4.5 Lack of Trained Labor

It is impossible to operate construction robots without laborers who can handle them. o benefit from the construction robotics, there must be a system that allows human and robot collaboration based on the tasks at different levels. (Brosque, Galbally, Khatib, & Fischer, 2020a; Linner et al., 2020)

Moreover, low skilled and untrained employees make up a substantial portion of the workforce in the construction industry. To be able to operate in the same environment with robots and maintain and handle this technology, additional training should be offered to this untrained labor. Although these training constitute an expense on their own, labor costs will also escalate according to the education level of the labor (Bock, 2004).

The robotic construction must be supported at the managerial level. It is important that management has sufficient knowledge so that they have the freedom and confidence to incorporate technological innovations. In addition, the design and construction processes should be organized according to automation and appropriate technologies should be preferred, and this process requires trained and experienced managers. (Warszawski & Navon, 1998)

### 2.3.5 Future Directions for Construction Automation and Robotics

Although some companies have made advanced construction technologies and robotics as a company policy and developed it, still a large part of the industry is not aware of construction robots. Even if they are willing to incorporate these technologies, economic and technical requirements do not allow them to do so. Particularly small companies are unable to find the necessary capital and labor force. (Yahya et al., 2019)

Due to the aforementioned barriers, today CAR technologies are preferred in off-site construction (Pan et al., 2020) . Prefabrication has become widespread, as production in a controlled factory environment can prove its efficiency in terms of cost, time, and labor with solid evidence. For the adaptation of on-site automation and robotics in the sector, its reliability needs to be proven with more studies and datasets. The studies available in the literature generally evaluate the simulation results of a single type of robots. (Brosque et al., 2020b; Cusack, 1994; Cusack, 1989; Kurien, Kim, Kopsida, & Brilakis, 2018; Lee, Pan, Linner, & Bock, 2015; Wang, Li, & Yang, 2020; Wong Chong et al., 2022; Wu et al., 2022; Yu, Lee, Han, Lee, Lee, 2007). However, actual construction site studies are not widely available and cannot evaluate all factors in accuracy due to the high cost of prototypes and the complexity of the construction environment. (Wu et al., 2022)

The common point of all studies in the literature is that CAR systems have great potential. They are expected to develop in the same way as 3D printers. While 3D printers were very expensive and complicated products in the beginning, today they are affordable and can be used for individual needs (Hager, Golonka, & Putanowicz, 2016).

Thanks to the widespread use of Internet of Things (IoT), open-source systems, and technologies such as BIM and additive manufacturing (Melenbrink et al., 2020), exponential growth of the robotics in the construction industry is predicted.

The development of CAR systems depends on how well the technologies are supported. The first and main action that needs to be taken to overcome these challenges and maximize the benefits of construction automation and robotics is to review and reorganize the construction process with the robot and human coordination in mind (Lee et al., 2022). In addition, construction technologies should be supported by legal regulations and information standardization (Chen et al., 2018). When the construction process is considered as a whole and regulations are made to cover all members and components, the construction sector, which has lagged behind other sectors in automation and efficiency, will take its place among the sectors with a rapid breakthrough.

## 2.4 Use of Construction Automation and Robotics for Construction Waste Management

Because of the increase in population, the cities and towns are getting bigger and bigger with a need for housing and infrastructure. So, the amount of the generated waste due to construction and demolition increases parallel to that demand. The growing construction industry brings environmental problems. Therefore, countries are carrying out studies for the evaluation of solid wastes produced by construction activities. Studies are carried out to understand the amount, type, and source of construction waste in order to find solutions to manage and recover it.

Research proves that the main reason for the construction waste generated is failure due to human resources (Li, Li, & Sang, 2022; Osmani, 2011; Osmani et al., 2008; Polat et al., 2017; Wu, Yu, Shen, & Liu, 2014). Since the construction process is generally based on human resources, capabilities affect the results directly. Robots usually function more effectively and precisely than humans. For this purpose, the use of robots is seen as an efficient way of minimizing the failures due to human behaviors and the waste caused by these failures (Pan, Linner, Pan, Cheng, & Bock, 2018).

Robotics may be used for waste management in many respects. For example, robots used for prefabrication may provide preparation and optimization for raw material use. On-site robots are used for single tasks and increase productivity. In addition, sensory robots are used to monitor on-site applications and to detect failures before that failure results in waste of material. They are also used for the sorting of waste materials and provide efficiency in the recycling of construction waste (Lee et al., 2015). In summary, by comparing human and robot use in construction, it is seen that robotic technologies decrease the use of raw materials, improve recycling, and reduce construction waste (Pan et al., 2018).

Besides, while several researchers are studying the impact of robotics on the building industry, few studies have concentrated on construction waste. Of the more than 120 sources reviewed for this study, only 28 mention the impact of CAR on CWM (Table 2.8) and only 10 focus on the waste reduction potential of related technologies (Akinade et al., 2016; Guerra, Leite, & Faust, 2020; Jaillon et al., 2009; Lu, Webster, Chen, Zhang, & Chen, 2017; Sepasgozar et al., 2021; Tam et al., 2005; Wang, Li, & Tam, 2015; Wang, Li, Zhang 2019; Wang et al., 2020; Zoghi & Kim, 2020). It is seen that most of these studies mention three main subjects which are “prefabrication”, “additive construction”, “modular construction” and “BIM compliance”.

Table 2.8 Research mentioning CAR for CWM

| | Incentive reward programs | Prefabrication | Waste prediction tools | BIM compliance | Additive construction | Single-task construction robot | Monitoring and tracking robot | Sorting and recycling robot | Planning and estimating robot | Modular construction |
|---|---|---|---|---|---|---|---|---|---|---|
| (Chen et al., 2002) | * | | | | | | | | | |
| (Tam et al., 2005) | | * | | | | | | | | |
| (Tam et al., 2007) | | * | | | | | | | | |
| (Kim, 2008) | | | | | | | | | | * |
| (Jaillon et al., 2009) | | * | | | | | | | | |
| (Shen et al., 2009) | | * | | | | | | | | |
| (Osmani, 2011) | | * | | | | | | | | |
| (Lim et al., 2012) | | | | | * | | | | | |
| (Porwal & Hewage, 2013) | | | | * | | | | | | |
| (Ajayi et al., 2015) | | | * | * | | | | | | |
| (Lee et al., 2015) | | | | | | * | | | | |
| (Wang et al., 2015) | | * | | | | | | | | |
| (Labonnote et al., 2016) | | | | | * | | | | | |
| (Hager et al., 2016) | | | | | * | | | | | |
| (Bilal et al., 2016) | | | * | * | | | | | | |
| (Lu et al., 2017) | | | | * | | | | | | |
| (Ghaffar et al., 2018) | | | | | * | | | | | |
| (Pan et al., 2018) | | * | | * | * | * | * | | | |
| (Wang et al., 2019) | | | | | | | | * | | |
| (Oke et al., 2019) | | | | | | * | * | * | * | |
| (Osmani & Villoria-Sáez, 2019) | | | * | * | | | | | | |
| (Kamali et al., 2019) | | | | | | | | | | * |
| (Guerra et al., 2020) | | | * | * | | | | | | |
| (Wang et al., 2020) | | | | | | | | * | | |
| (Zoghi & Kim, 2020) | | | | * | | | | | | |
| (Loizou et al., 2021) | | * | | | | | | | | * |
| (Yu et al., 2021) | | * | | | | | | | | * |
| (Sepasgozar et al., 2021) | | | | * | * | | | | * | |

Prefabrication is one of the most mentioned construction technologies for waste management. It is seen as one of the most effective methods as it can be applied partially or fully according to the nature of the project. Tam et al. (2007) compare wastage levels of 15 conventional and 15 partially prefabrication projects for several tasks. The results show that waste can be reduced up to 90% with prefabrication. Another research found that prefabrication can be effective for waste reduction by up to 70% (Jaillon et al., 2009). The authors also asked users about the benefits of prefabrication and found that waste management was the highest ranked benefit.

The other focused subject is additive manufacturing and 3D printing in construction. Since it is an additive construction method, it generates less waste when compared with conventional construction, which is a subtractive process (Labonnote, Rønnquist, Manum, & Rüther, 2016). In addition, the material technology of 3d printing supports the use of recycled materials (Ghaffar, Corker, & Fan, 2018).

Modular construction is another key technology that is considered for waste management in the construction industry. It is demonstrated by Kim D. (2008) that during construction of a modular building 60% less waste is generated when compared to a conventional building. Loizou, Barati, Shen, Li, & Guarino, (2021) consider this value as 83.2% and 81.3% for large and small structures respectfully.

BIM compliance of the systems is another important factor for waste management with CAR. BIM ensures integrity in the planning, design, and construction process. Thus, it promotes effective waste management planning by ensuring precise data estimation (Guerra et al., 2020). The BIM-based design prevents potential waste by revealing design and planning errors before they occur (Zoghi & Kim, 2020). Wong Chong et al. (2022) demonstrate that with the help of clash detection it is possible to reduce construction waste by up to 15.2%,

Despite its potential in CWM, CAR technologies are not sufficiently explored in this specific area. Research usually includes sector opinions or qualitative data. There is not enough study analyzing the quantitative impacts of CAR on waste management.

The role of robots, whose use is expected to increase rapidly in the construction sector, in waste management should be investigated, and awareness should be raised about the endless possibilities of the use of automation and robotics in the industry.

# CHAPTER 3

# RESEARCH DESIGN

Material and method of research are presented in this chapter. Section 3.1 describes all materials used in the study in detail, while the research method is explained in section 3.2.

## 3.1 Material of the Study

The aims of the study are to understand the current status of waste, waste management systems, automation, and robotic technologies and their use to manage waste in the construction industry in Turkey. Initially, a literature review was conducted to understand and define the related topics. With the help of information retrieved from the literature review, firstly, group discussions were conducted with laborers in the construction sites; later, a questionnaire was conducted with the architects and engineers who work in design and site offices.

### 3.1.1 Literature Review

Initially, for the background information, 132 sources published between 1984 and 2022 were reviewed, including 120 journal articles, five conference proceedings, four book chapters, four reports, and two web pages. Research Gate and Science Direct databases are used for the search and "construction waste", "construction waste management", "construction automation", "construction robotics", "automation and robotics in construction", "waste management robotics" keywords are used for the collection of the sources. Similar survey studies were examined and these studies were utilized in the preparation of the outline of the survey and focus group discussion. exemplary studies are given in Table 3.1. The information collected from the literature review was collated and tabulated under the headings specified in section 2. The compact information collected was summarized and used to formulate each survey question.

Table 3.1 Exemplary studies in the preparation of questionnaire and discussion outline

| Reference | Main Topic | Method |
|---|---|---|
| (Warszawski & Navon, 1998) | Benefits, barriers, and future trends for the use of construction automation and robotics | Questionnaire |
| (Osmani et al., 2008) | Construction waste management | Questionnaire |
| (Mahbub, 2008) | Barriers to construction automation and robotics | Questionnaire |
| (Jaillon et al., 2009) | Construction waste management with prefabrication | Questionnaire<br>Case study comparison |
| (Zhang et al., 2012) | Construction waste management | Interview discussion |
| (Strukova & Liska, 2012) | Benefits, barriers, and future trends for the use of construction automation and robotics | Questionnaire |
| (Fadiya et al., 2014) | Source of construction waste | Questionnaire |
| (Wang et al., 2014) | Construction waste management | Questionnaire |
| (Ajayi et al., 2015) | Construction waste management | Focus group discussion |
| (Polat et al., 2017) | Source of construction waste | Questionnaire |
| (Fleming et al., 2019) | Availability of constructon automation and robotics | Questionnaire |
| (Oke et al., 2019) | Benefits of construction automation and robotics | Questionnaire |
| (Yahya et al., 2019) | Barriers to construction automation and robotics | Questionnaire |
| (Manuel et al., 2019) | Barriers to construction automation and robotics | Focus group discussion |
| (Cai et al., 2020) | Barriers to construction automation and robotics | Questionnaire |

### 3.1.2 Group Discussion

Group discussions were held with workers on four construction sites in Ankara. For the sake of the study, care was taken to select sites of different construction sizes and at various stages of construction.

The first group includes five site preparation and mechanical installation workers. Some of them have more than 25 years of experience. The second group consists of eight workers with 3 to 35 years of experience in formwork, reinforcement, and concrete works. The third group is the formwork and a water insulation team which includes 11 participants with expertise ranging from 2 to 20 years. And finally, the fourth team consists of nine workers with 5 to 35 years of experience working on masonry, plaster, paint, and ceramic wall coverings.

As indicated in Appendix A, the discussion was conducted with eight questions. The first two questions were about the background information of the group members. 3rd question was about their opinion on the most common waste during the entire construction process. Questions 4, 5 and 6 were asked to understand if respondents have any training or information to deal with waste management. The last two questions (7-8) were asked to find out what methods they use for the minimization, separation, and storage of construction waste.

An outline was prepared for the group discussions. The raw results are collected and summarized with the help of Microsoft Excel software (Appendix B).

### 3.1.3 Questionnaire Survey

The questionnaire indicated in Appendix C consists of 5 sections and 29 questions. Each section is prepared to evaluate one of the objectives of this study which are mentioned in the objectives given in the Introduction chapter.

The first section consists of 3 questions that are asked to understand the respondents' job description, experience, and scale of the respondents' firm.

The second section evaluates the reasons for construction waste and consists of 8 questions. The 4th question was **"What is the importance of the following factors during the design of a building?"** and respondents were asked to measure on a scale of 1 to 5 importance of several factors.

In the 5th question, respondents were asked to evaluate the impact of seven construction stages on waste generation with a 5-degree Likert scale. Later, they were asked to assess the detailed tasks in those stages in the following six questions (6-11).

The third section focuses on CWM strategies and available applications in Turkey. The section consists of 8 questions. Questions 12, 13, 14, and 15 are about the current use of the management strategies, statutes of the waste management department, and use of waste prediction tools.

The following two questions (16-17) try to understand if the respondent has any education on CWM. Question 18 was **"Evaluate the impact of these strategies on reducing construction waste."** Respondents were asked to evaluate the importance of the several waste management strategies retrieved from the literature. And the last question of this section (Q19) was designed to obtain the participants' views on the applicability and effectiveness of these strategies.

The fourth section was composed of seven questions that evaluated the respondents' information and experience with CAR. Several examples of automation and robotics technologies were shown to participants before the questions to clear the definition of CAR (Figure 3.1).

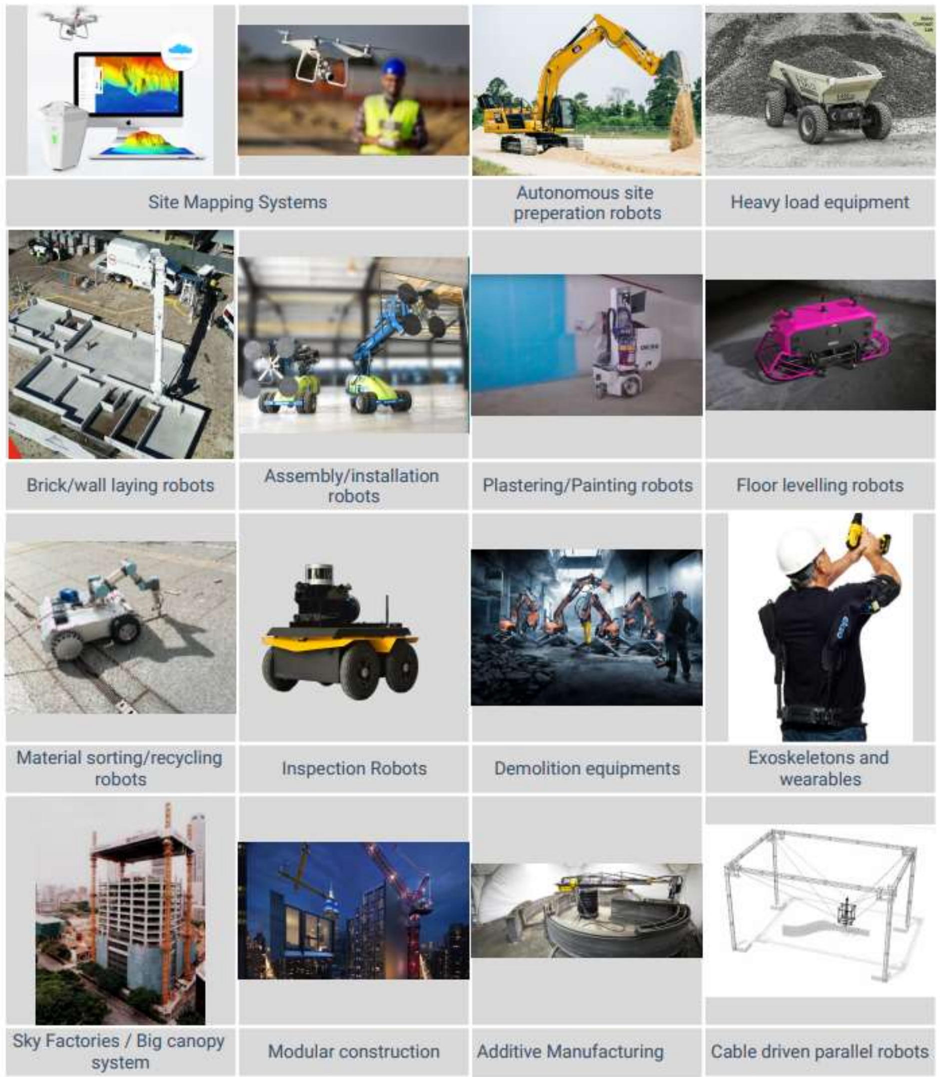


Figure 3.1 Photos showing examples of CAR that were shown to the participants in the survey to clarify the definitions

Questions 20, 21, 22, and 23 assess if the respondent ever uses one of these technologies or attends an education or event on CAR. Question 24 evaluates whether the respondent would like to take training on the topic. The following two questions (25-26) were asked to understand whether the company of the respondent has plans to incorporate these technologies into its projects in the near future.

The last section was designed to evaluate the applicability of CAR in Turkey. The first question of the section (Q27) examines the participant's knowledge of the information technologies required to use and develop CAR.

Question 28 was **"Evaluate the availability of construction automation and robotics technologies in Turkey for the specified work groups."** Respondents were asked to measure on a scale of 1 to 5 available stages.

The 29th question was designed to assess the respondent's opinion on the possible advantages of CAR. The evaluation of the answers to the statements related to waste generation in this question is one of the essential parts of the research.

The questionnaire was prepared and delivered via Google Forms. The raw data were analyzed with the help of Microsoft Excel (Appendix D).

### 3.2 Method of the Study

This section describes how the literature was reviewed, how the questionnaires were designed and distributed, as well as how the group discussion was conducted.

The research starts with identfying the research problem and defining the objectives, questions, and expected findings based on similar research analyzed. Then a literature review was conducted to get background information on related subjects. Information obtained from the literature was used to prepare a questionnaire and group discussions.

Data collected from this survey was analyzed, and the results are presented with future recommendations.

### 3.2.1 Design of the Surveys

In the first phase of this study, Research Gate and Science Direct databases were searched with related keywords, which are,

> *"construction waste", "construction waste management", "construction automation", "construction robotics", "automation and robotics in construction", "waste management robotics"*

Drawing on these studies, essential terms, explanations, and factors are summarized under headings to provide a basis for the preparation of discussion and questionnaire, in line with the narrative in chapter 1. Those headings are,

- Construction waste
    - Reasons for construction waste
    - Type of construction waste
    - CWM direction
    - Barriers and difficulties in CWM
- Construction automation and robotics
    - Type of CAR
    - Necessary information technologies
    - Possible advantages of automation
    - Influential factors of applying automation and robotics
    - Possible advantages of automation

After the comprehensive analysis of the literature, discussion questions and the questionnaire were prepared.

### 3.2.2 Method of Group Discussion

The group discussion was conducted face-to-face with active workers at the construction sites of 4 different projects. First, a short briefing was given about the purpose and scope of the study; then, the listed questions were posed to the group one by one, creating a discussion environment where ideas could be freely shared within the group. Participants' information and opinions were recorded anonymously.

The group discussion section does not include construction automation and robotics systems, but focuses only on the causes of construction waste generation and methods of storage and segregation. This is because construction automation and robotics systems are not yet practiced in Turkey, and workers do not have any experience in this field, so it does not distract the study.

### 3.2.3 Delivery of Questionnaires

The survey was conducted among the architects and engineers in May and June 2022. The questionnaire was delivered to design and construction site offices in Ankara and Istanbul, the two major cities of Turkey. In order to ensure that the results are representative of the whole sector, it was confirmed that the companies to which the questionnaire was sent were of different sizes and had a diversity of active businesses.

The questionnaires reached a total of 250 people. The questionnaire was sent to 8 architecture offices with 110 architects and 6 construction offices with 140 engineers. However, only 35 complete responses were obtained, 13 of them work in an architectural office while 22 are works for construction site offices.

The qualitative and quantitative analyses were made according to the data obtained through this questionnaire, and the results were evaluated to achieve the research objectives.

# CHAPTER 4

# RESULT AND DISCUSSION

This study aims to understand the current status of the waste, waste generating factors, and waste management strategies applied through construction projects in Turkey. In addition, the purpose of the study is to define the knowledge, usage, and approach to CAR in Turkey. The results of the questionnaires and discussions conducted to reach the intended results of the study are illustrated and explained in this section.

Data obtained in this study are presented under three headings, namely: group discussion analysis, questionnaire survey analysis, and summary of the results.

## 4.1 Group Discussion Analysis

The information collected through group discussions is presented in the following section. Related questions are collected and grouped in subheadings to provide a more readable narrative.

### 4.1.1 Demographic Information

Questions 1 and 2 were asked to gather information on the background of the participants. The data collected with those questions are summarised in Table 4.1.

A total of 33 workers participated in the discussion in 4 groups. Groups include different numbers of participants depending on the size of the work. In addition, since the projects are at various stages, the job description of the groups also differs.

Table 4.1 Information of participants of four focus groups

| | Participants | Job Description (Q1) | Experience (Q2) |
|---|---|---|---|
| **Group 1** | 5 | Site Preparation<br>Mechanical Installations | 5-35 years |
| **Group 2** | 8 | Formwork<br>Reinforcement<br>Concrete works | 3-25 years |
| **Group 3** | 11 | Formwork<br>Water insulation | 2-20 years |
| **Group 4** | 9 | Masonry<br>Plaster, Paint<br>Ceramic finishes | 5-35 years |

The first group discussion was conducted with a team where the construction phase had not yet started, and site preparation and infrastructure works were going on. As it was an individual housing project, the study was conducted with a smaller group of 5 participants.

The second group discussion took place at a construction site where the construction of the building structure was ongoing. The workers participating in the study were part of teams who were responsible for erecting the formwork, laying out the steel reinforcement and pouring the concrete.

The third group, including 11 people, consisted of workers in a public housing project. It was the largest group of the study that was composed of concrete and insulation workers since the foundation and basement works were still in progress on the construction site.

The last group study was conducted at a construction site where finishing works were in progress. This group consisted of 9 workers engaged in masonry and wall cladding works such as plastering, painting, and ceramic tiling.

According to their stage in the whole construction process, the groups are ordered according to the construction phase they are in, from the earliest to the latest.

Although the length of experience of the groups is not very different, each included experienced and inexperienced members. During the discussions, it was realized that the experienced participants were more attentive to the study and more willing to share their views, whereas the inexperienced participants did not have much attention and knowledge on the subject.

### 4.1.2 Construction Waste Generation

In question 3, respondents were asked which tasks in the construction process have the most significant impact on waste generation. For the sake of answers, the construction process is summarized in 10 tasks and a list shared with participants. The listed tasks are,

- Site Preparation
- Concrete Works
- Mechanical Equipment Installation
- Electrical Equipment Installation
- Prefabricated Element Installation
- Façade Works
- Wall/Partition Wall Construction
- Floor Installations
- Ceiling Installations
- Control and Supervision

As indicated by each group, the three tasks that cause the most waste generation are listed in Table 4.2.

Table 4.2 Top three tasks that cause waste generation as listed by each focus group of workers

| | **Waste Generating Tasks (Q3)** |
|---|---|
| **Group 1** | • Ceiling Installations<br>• Façade Works<br>• Site Preparation |
| **Group 2** | • Wall/Partition Wall Construction<br>• Ceiling Installations<br>• Façade Works |
| **Group 3** | • Wall/Partition Wall Construction<br>• Ceiling Installations<br>• Façade Works |
| **Group 4** | • Façade works<br>• Wall/Partition Wall Construction<br>• Floor installations |

Ceiling installation and facade works are specified by the second group as the most waste generating tasks. The 3rd task given in response to this question by this group, which includes participants involved in site preparation, was also site preparation. This is the only task belonging to the stage of the rough work mentioned by all participants.

Groups 2 and 3 mentioned the same three tasks in the same order, “Wall/Partition Wall Construction,” “Ceiling Installations,” and “Façade Works.” It should be noted that these two groups have similar job descriptions.

The 4th group, similar to the other groups, gave the answers “Façade Works” and “Wall/Partition Wall Construction.” In addition, they state the 3rd task that has a significant impact on waste generation is “Floor Installations.”

The results show that whatever the job description of the participants, they all mentioned tasks at the fine work stage. As can be seen in the table, all 4 of the four groups mentioned “Façade Works” among the first three tasks. Another most frequently mentioned task is "Wall/Partition Wall Construction." "Ceiling Installations" is also a common answer.

### 4.1.3 Construction Waste Management

In question 4, respondents were asked whether there is a waste management strategy applied in the works they are involved in. Within the scope of this question, they were also asked whether any information on construction waste was provided by their workplaces.

As noted in Table 4.3

Table 4.3, none of the participants were given any information about a strategy to implement in their works. In addition, no information on construction waste was provided by the workplace.

Table 4.3 Waste management strategies applied by focus groups and training of participants on waste management

| | Applied Strategies (Q4) | Training (Q5+Q6) | |
|---|---|---|---|
| **Group 1** | None | None | |
| **Group 2** | None | 1 Person | No content information |
| **Group 3** | None | None | |
| **Group 4** | None | None | |

Later, they were asked whether they had attended any training on construction waste during their professional life. Only 1 out of 33 respondents stated that they participated i a one-year training but did not provide any information on the content of this training. (Table 4.3)

Since no waste management system was mandatory at any of the construction sites, the participants were asked about the personal measures they took for waste minimization. The summarised answers are given in Table 4.4.

It was noted during the interviews that the workers involved in rough construction works did not have much to comment on, while the ones in charge of finishing works had more of an approach to the issue.

Table 4.4 Personal measures for construction waste minimization on site taken by the focus groups interviewed.

| | **Waste Minimisation Measures (Q7)** |
|---|---|
| **Group 1** | • Cut and use the materials without any waste<br>• Ethics of the labour |
| **Group 2** | • Care is taken in material selection and measurement. |
| **Group 3** | • Materials to be reused (e.g., molding wood) are handled carefully, and care is taken not to damage them.<br>• The material is treated carefully. |
| **Group 4** | • Just in time delivery methods have been adopted.<br>• Attention is paid to the shelf life of purchased materials.<br>• In fine work, the layout is made considering the dimensions of the material; materials are cut in such a way that minimum waste is generated.<br>• Colleagues are informed about environmental pollution and asked to take care.<br>• Weather conditions are also considered when preparing the materials. |

The first group stated that the most critical factor in preventing waste is to cut and use materials in such a way as to minimize residuals, as they consider that most construction waste is leftover pieces of cut materials. They also emphasized the importance of developing ethical thinking, noting that the attitude of the worker has a significant impact on the amount of waste.

Focus group 2 expressed the impact of material selection on waste and emphasized the need to supply materials within the requirements, not to prepare more mixture than necessary. They also noted that measurements should be double-checked, and maximum care should be taken before cutting or shaping material in order to prevent waste generation.

Focus group 3, like the other two groups, noted the importance of size and material selection and highlighted the need to be careful with materials that can be reused in the field. They stated that since they repeatedly use the formwork timbers, they take care during the construction and dismantling of the formworks and try not to damage the material.

While focus groups 1, 2, and 3 talked about general approaches, focus group 4 provided more detailed information. In addition to the measure mentioned by previous groups, they also noted the methods they used to minimize the waiting time of the material on site. The just-in-time delivery method prevents materials from waiting for a long time on the site and prevents losses that may occur in the meantime. In addition, since re-measurements are done just before the application, the required amount of material is supplied, and leftover material is prevented.

They also underlined the importance of workmanship. They mentioned issues such as the shelf life of the materials, mixing ratios, specialized applications, the ambient temperature and humidity (weather conditions) during the preparation of the mixtures, and expressed the impact of the decisions made by the worker on waste generation. Focus group 4 stated that by taking such details into account during the construction process, waste is reduced.

The results are in line with the findings of Osmani et al. (2008) as all groups repeatedly emphasized the importance of material size and dimensions in particular.

Table 4.5 summarises the answers of each group to question 8, which asked to understand the waste sorting and storage techniques that participants used.

All respondents indicated that there is no specific waste segregation and collection system in the works they are involved in. All groups sort materials by material type while paying attention to whether materials are recyclable or reusable.

The first focus group also stated that resaleable materials are separated from other materials.

Focus group 3 stated that they cover materials that are kept for a long time with a tarpoline, while they do not take any special precautions for others. They also noted that some materials were burned or buried, such as residual wood.

Group 4, in addition to similar notes, added that special attention is paid to materials that are harmful to nature, such as synthetic and solvent-containing materials. Besides, they emphasize that problems arising from material storage are encountered relatively frequently.

Table 4.5 Waste separation and storage techniques as indicated by the focus groups interviewed.

| | **Waste Separation and Storage (Q8)** |
|---|---|
| **Group 1** | • Sorting is done according to the type of material.<br>• Materials to be sold back are stored in a protected area. |
| **Group 2** | • No specific storage system.<br>• The waste is sorted as reusables, recyclables, and others.<br>• Containers are used for the storage of the waste. |
| **Group 3** | • The storage is done according to the usage duration of the materials. If material is kept for a long time, they cover it with a tarp.<br>• There is no particular storage area.<br>• While plastic waste is recycled, some of the leftover materials are sold. The rest is incinerated or buried. |
| **Group 4** | • There is no particular storage area.<br>• Care is taken to ensure that materials that may be harmful to the environment (e.g., synthetic, and solvent-containing materials) do not contaminate the soil or water.<br>• Incorrect application and improper stacking of material are quite common. |

Besides the answers to the questions, groups 3 and 4 mentioned several other problems related to construction waste generation. Those additional notes are summarised in Table 4.6.

Table 4.6 Additional information provided by 3rd and 4th focus groups during discussions

| | Additional Notes |
|---|---|
| **Group 3** | • The domestic waste of the workers staying at the site is also mixed with the construction waste.<br>• There is no organization for the management of waste at the sites. |
| **Group 4** | • There is a lack of supervision and control.<br>• The lack of qualified personnel leads to an increase in labor-related waste. If the worker is knowledgeable and qualified, it will increase the correct material selection and initiative authority. Thus, unnecessary waste can be prevented. |

The 3rd focus group stated that the domestic wastes of the workers staying at the site were also at a level to cause problems and that there was no organization and management of such waste on the site. The 4th focus group drew attention to the lack of supervision and control at the management level. They also mentioned the impact of the lack of a competent workforce on waste generation and repeatedly emphasized the importance of increasing the knowledge and qualification of construction site workers.

### 4.1.4 Summary of Group Discussion Analysis

The answers collected from the participants show alignment with the information gathered from the literature study. Many studies indicate that worker errors and decisions are the most important factor in waste minimization, and the interviews, especially with focus group 4, support this data (Formoso et al., 2002; Islam et al., 2019; Osmani, 2011; Osmani et al., 2008; Polat et al., 2017; Tam et al., 2005). The fact that all groups identified the line of work in which the 4th group is involved as the task with the highest impact on waste generation shows the consistency of these results.

As the findings indicate, there is no regulation on waste in any of the sites. Information on waste minimization, proper storage, and sorting is not provided, and the necessary attention is not paid to the issue. It is seen that none of the participants have received appropriate training or knowledge on construction waste. This lack of knowledge and awareness of field workers leads to low recognition of waste in the field. For this reason, when asked about their strategies to reduce waste, most respondents mentioned general items and found it challenging to make a personal comment.

Participants also mentioned the lack of management, stating that the necessary regulations and controls are not in place. These discourses are consistent with the studies of several researches ((Kabirifar et al., 2021; Kolaventi et al., 2021; L. Y. Shen & Tam, 2002; A. T. W. Yu et al., 2021) which ephasize that the most important measure for waste mangement is "Government legislations".

## 4.2 Questionnaire Survey Analysis

The information collected through the questionnaire survey is presented in the following pages. The answers to each questionnaire section were analyzed under separate subheadings, and the results were evaluated reciprocally in the summary section.

### 4.2.1 Demographic Information

The first chapter of the questionnaire is designed to collect demographic information of the participants. The questionnaire was sent to 250 people from design and construction site offices, and only 35 complete results were obtained. 22 of these 35 people are working for a design office, while 13 of them are actively working in construction site offices (Figure 4.1).

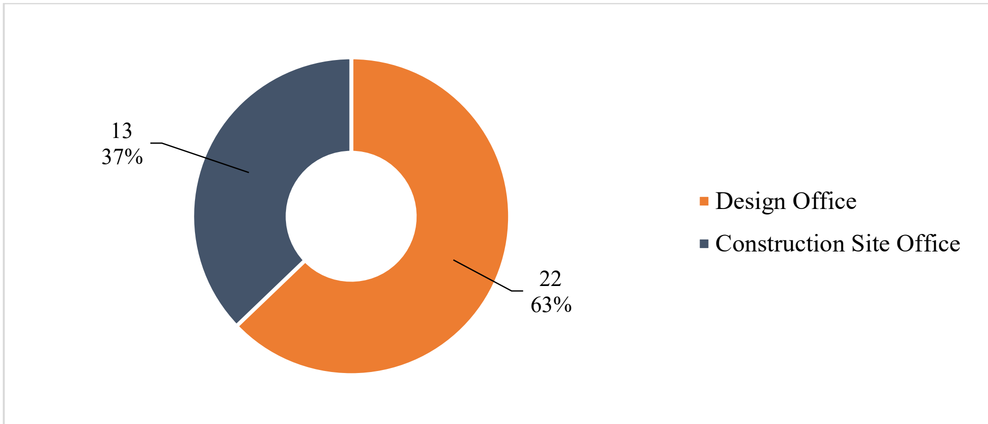


Figure 4.1 Workplace profile of participants in questionnaire

Figure 4.2 illustrate the job description of the respondents. The job descriptions were determined according to the structuring of the design and site offices. While the participants working in the design office were asked about the tasks they were involved in, the participants working in the site offices were asked about their titles. Accordingly, it is seen that most of the participants in the design office are involved in construction and preliminary project preparation, while most of the participants in the site office are group supervisors.

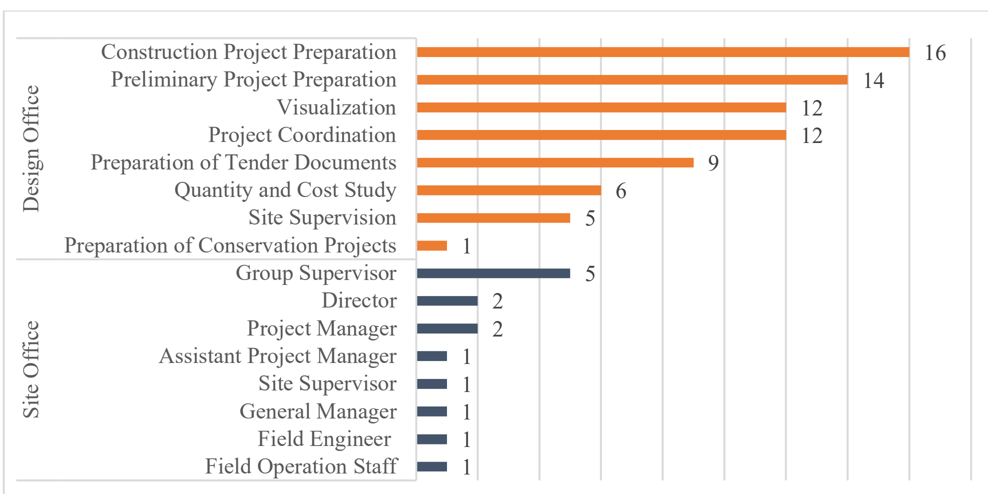


Figure 4.2 Job description of questionnaire participants

It was observed that most of the participants had less than 15 years of experience. Only 9% have more than 25 years of experience, while 11% have between 16 and 25 years of experience (Figure 4.3).

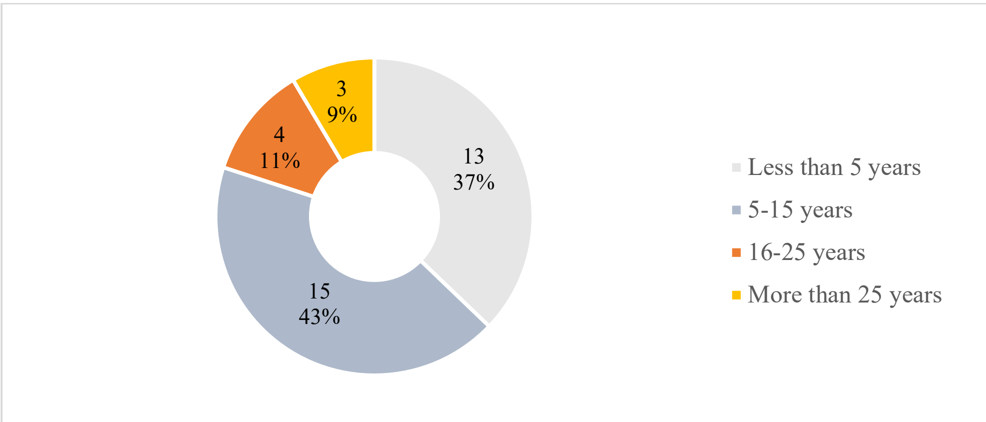


Figure 4.3 Year of experience of respondents

Finally, in this section, the respondents were asked to indicate the scale of the work carried out by the company they work for. 40% of the employees stated that they work on local projects, 43% on international projects, and 6% on both local and international projects (Figure 4.4).

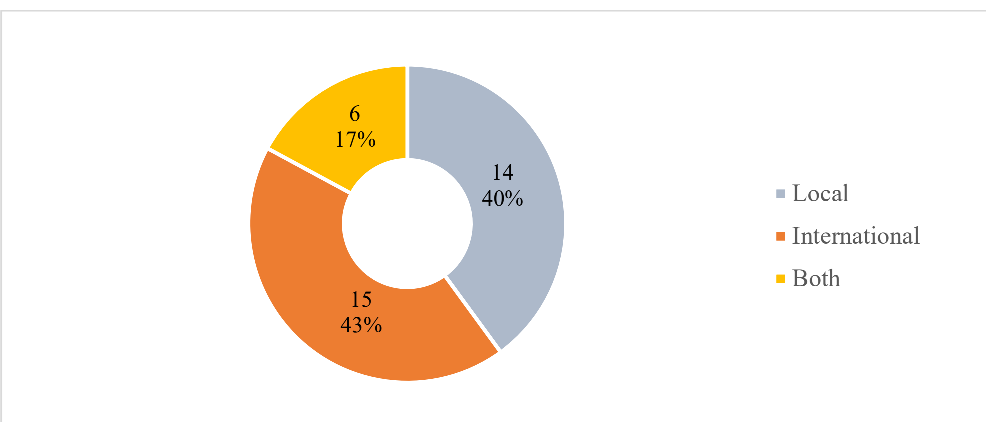


Figure 4.4 Scale of the work carried out by the company of participants

### 4.2.2 Causes of Construction Waste generation

The aim of the second section was to collect the respondents' opinions on the causes of waste generation. In line with these objectives, the answers collected from the submitted questions are analyzed in detail below.

In order to reveal the importance of waste minimization while designing and programming a construction project, respondents were asked to rate the importance of several factors related to construction projects. The results (Figure 4.5) show that construction cost is rated as the most important factor, with a mean value of 4.1 out of 5. Construction time, which has a direct impact on construction cost, was the next most important factor with a very close result. Among the five factors, waste minimization was rated as the least important factor, with an average score of 3.3. This result reaffirms other studies in the literature that the construction sector gives less importance to waste minimization compared to other issues. (Jaillon et al., 2009)

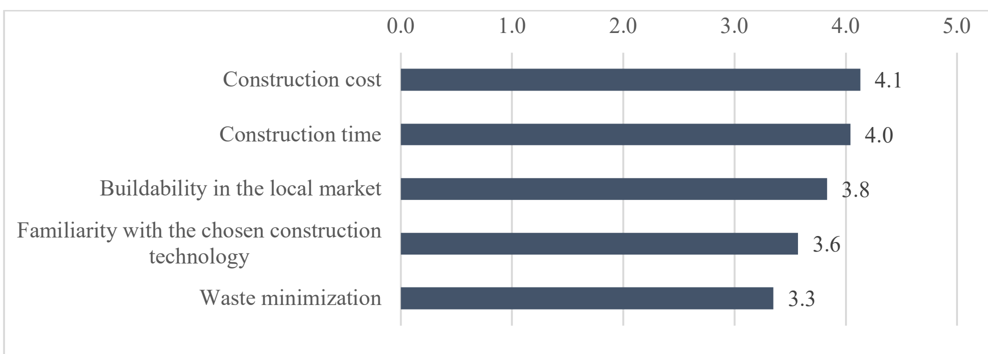


Figure 4.5 The importance of several factors while designing/planning a project

As shown in Figure 4.6, respondents evaluate that the decisions made during site management and operations have the greatest impact on waste generation. Contracting and preparation of tender documents are the two stages with the lowest impact on waste generation, with a mean of 1.4 and 1.8, respectively.

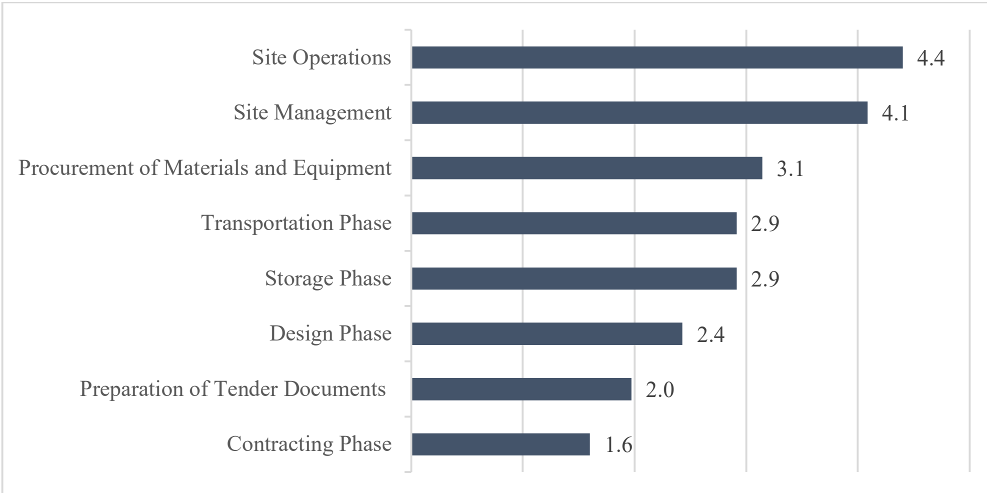


Figure 4.6 Assessment of the impact of construction phases on waste generation

In addition to stages, participants were asked to evaluate several tasks related to those mentioned phases of construction. Using data from the literature, the activities in the stages that were responsible for waste generation were separated and detailed one by one, and the participants were asked to evaluate each of these activities. The results for all stages are collected and illustrated in Figure 4.7. It can be seen that all mentioned activities of the site operation stage get the highest importance score while contract and tender phase activities get the lowest importance score.

"Cutting/preparation of materials to uneconomical dimensions", which is one of three most important cause of construciton waste in Turkey according to Polat et al. (2017), was identified as the most important factor in this study. In addition, "Design and construction detail errors," "Ignoring standard material dimensions," "Ignoring constructability," "Over-ordering due to bill of quantity errors," and "Site irregularity" were considered necessary by the participants.

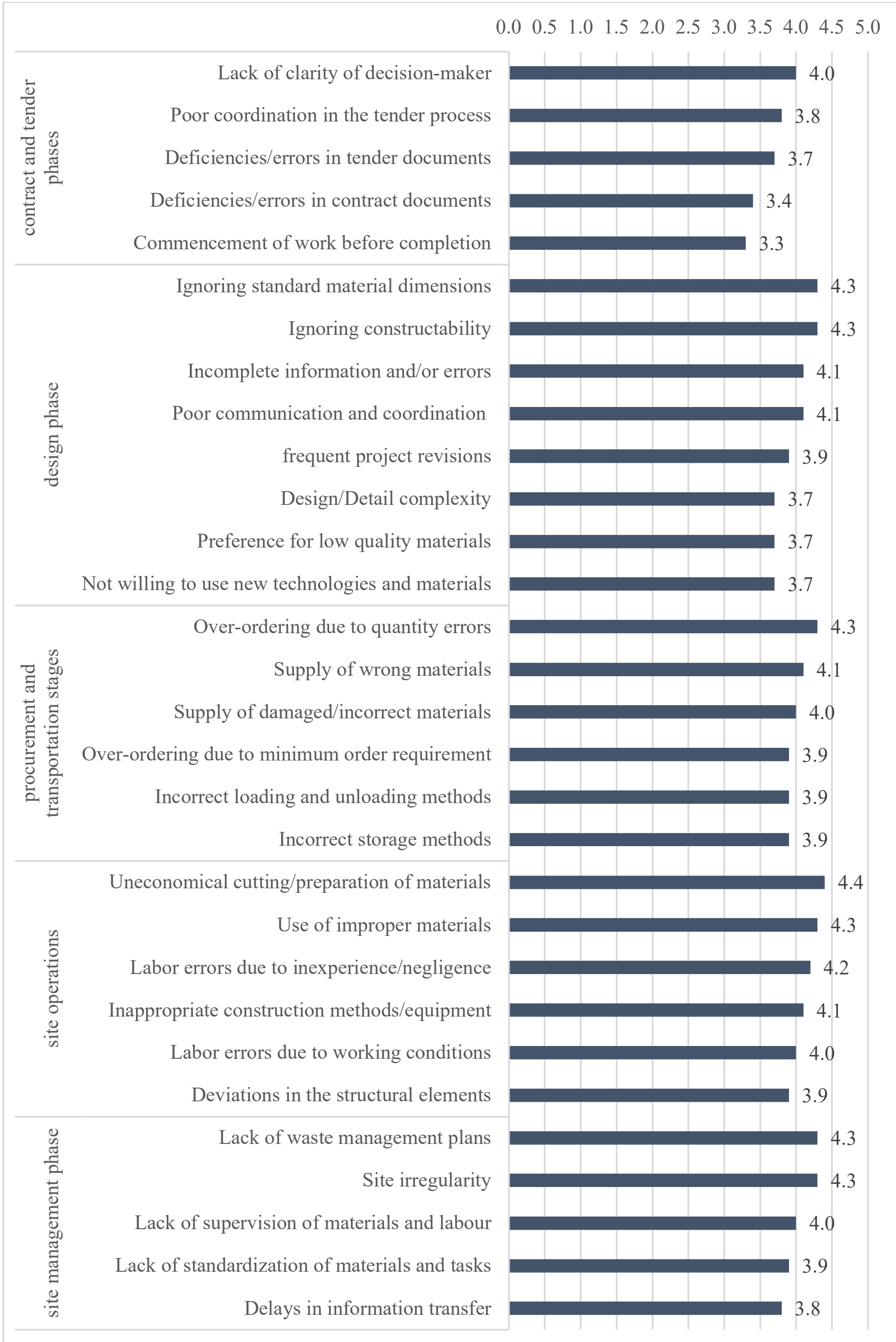


Figure 4.7 Assessment of the impact of construction activities on waste generation

The relevant questions asked in this section were cross-analyzed (Figure 4.8). In line with the results of the previous question, tasks in the site operation and site management phases are considered the most important. However, When the degree of importance given to construction phases is compared with the degree of importance given to construction works in that phase, a difference is observed.

When the phases are broken down into tasks in more detail, it is seen that the respondents rate the impact of these tasks on waste generation higher. When evaluated individually as a task, none of the tasks had a mean below 3 points, whereas when assessed as a phase, all phases except site operation and site management were evaluated as less important.

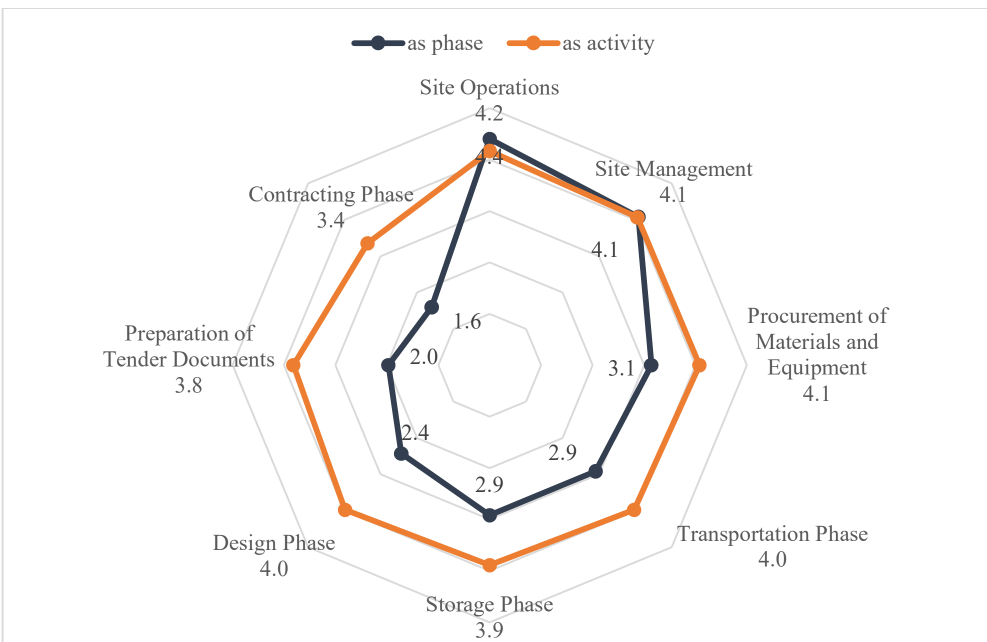


Figure 4.8 Comparison of the importance of phases and activities in that phase

### 4.2.3 CWM Strategies and Applicability in Turkey

The third section was designed to understand the participants' familiarity with waste management and their perspective on waste management strategies.

First, they were asked if they are implementing any waste management strategies while designing, planning, or conducting construction projects. Only 6 of 35 participants responded as yes. The rest either said no or had no information on such strategies (Figure 4.9).

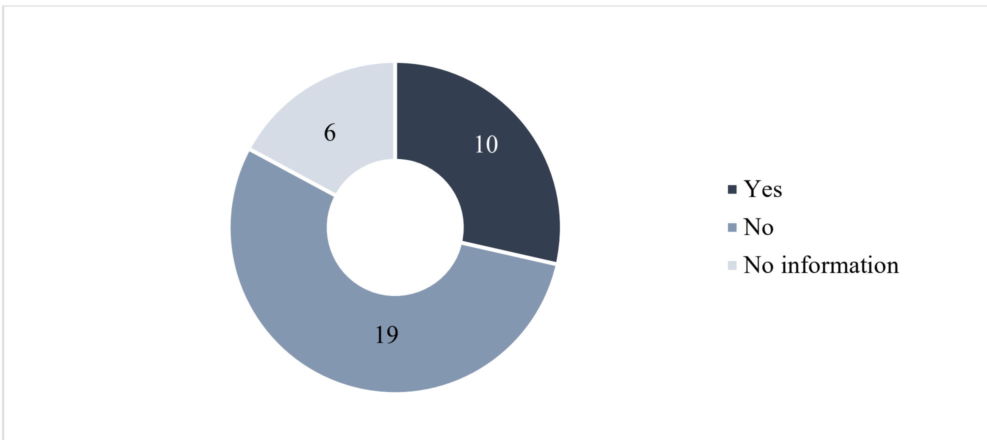


Figure 4.9 Participants' implementation of waste management strategies

Later, they were asked if the company they are working for has a waste management department or a consultant who is responsible for waste minimization. In addition, they were asked do they use waste prediction tools while designing the project or planning the construction and if they have any training on CWM.

As seen in Figure 4.10, only two positive answers were given to all three questions, and when the answers are analyzed in detail, it is seen that the same two people answered yes to all three questions. From this result, it can be inferred that these three questions are interconnected and that the waste management department, waste estimation programs, and education are promoted together.

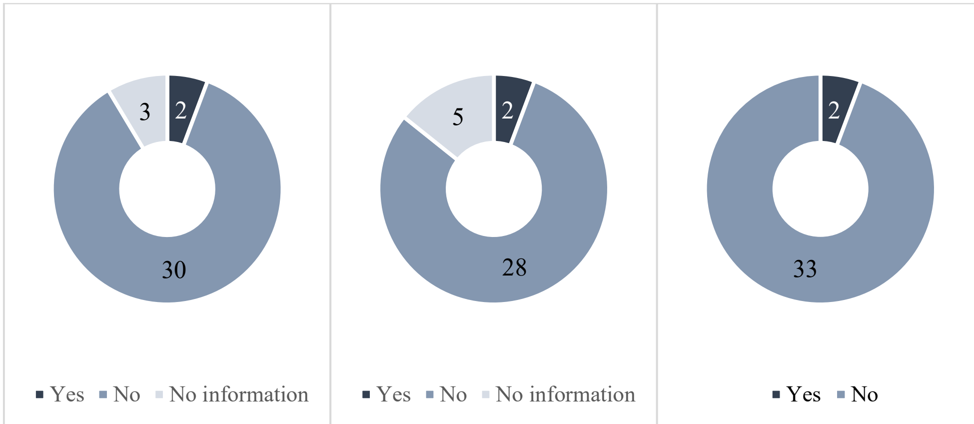


Figure 4.10 Presence of waste management department (left), Use of waste estimation programs (middle), Training on waste minimization (right)

Furthermore, participants who answered yes were asked to provide information about the content of the training they received. One of the respondents, who is an employee of the design office, stated that s/he received training on optimization, process management, and minimum material usage, while the other respondent working in the construction site office noted that s/he received a 10-hour training on ISO 14001 Environmental Management Systems.

Then, it was asked to evaluate the impact of several waste management strategies on the reduction of construction waste. Thus, it was aimed to understand which practices would be more efficient for waste minimization in Turkey. The answers are presented in Figure 4.11. Regulations, increased penalties and contractual obligations were rated as the 3 most important strategies.

When the strategies are grouped under two categories, governmental and business, by considering the literature review grouping, it is seen that governmental strategies generally have higher importance than business strategies. Conducting effective and frequent site inspections is the most emphasized business strategy. 23 out of 35 respondents marked the highest importance for this strategy.

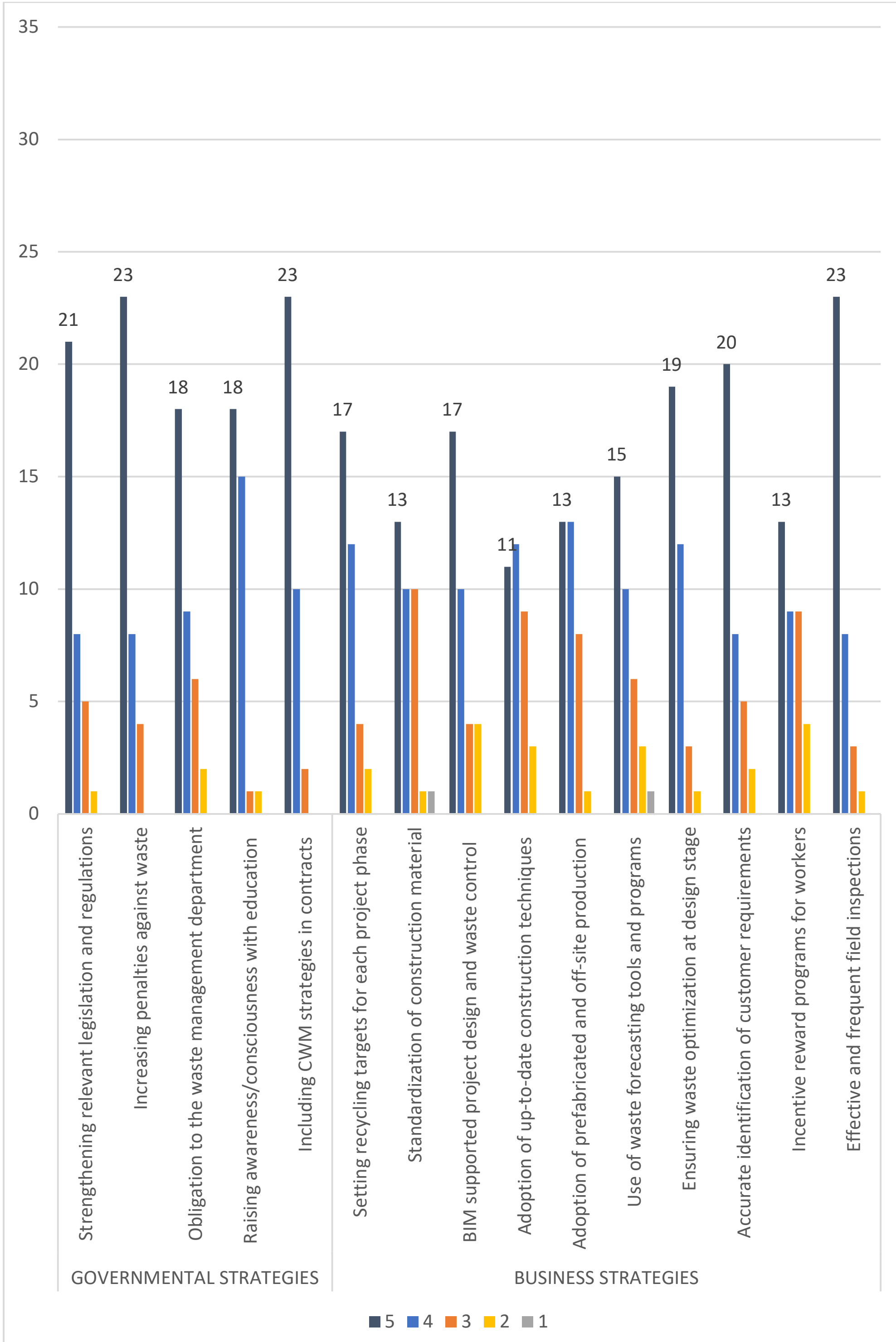


Figure 4.11 Evaluating the effectiveness of waste management strategies

In the last question on waste control strategies, participants were asked to evaluate the statements that were seen as barriers to the implementation of the CWM strategies. Figure 4.12 illustrates the number of answers given to each statement.

19 of 35 respondents either agreed or strongly agreed that waste is an inevitable outcome of construction activities, while 8 of them disagreed or strongly disagreed. This shows a lack of commitment that construction waste can be reduced.

The statement “Regulations and legislation on construction waste are not sufficient” has the highest strong agreement among all statements. Almost all participants agree or strongly agree with the item. This result is in line with the previous findings of the group discussions.

The other two items that respondents agreed with the most were that there is not enough knowledge and information in the sector and that extra time and labor are required to implement waste management strategies. The fact that only 2 out of 35 people have received training on waste management systems supports this observation.

Participants generally disagreed with the negative statements directed at prefabrication which are “Use of prefabricated products increases construction time” and “Prefabricated sector is not mature enough to be widely used”. (Figure 4.12) When this result is evaluated together with the high effectiveness of “Adoption of prefabricated and off-site production” as a waste management strategy (Figure 4.11). It can be suggested that prefabrication and off-site construction could be one of the appropriate solutions for construction waste management in Turkey.

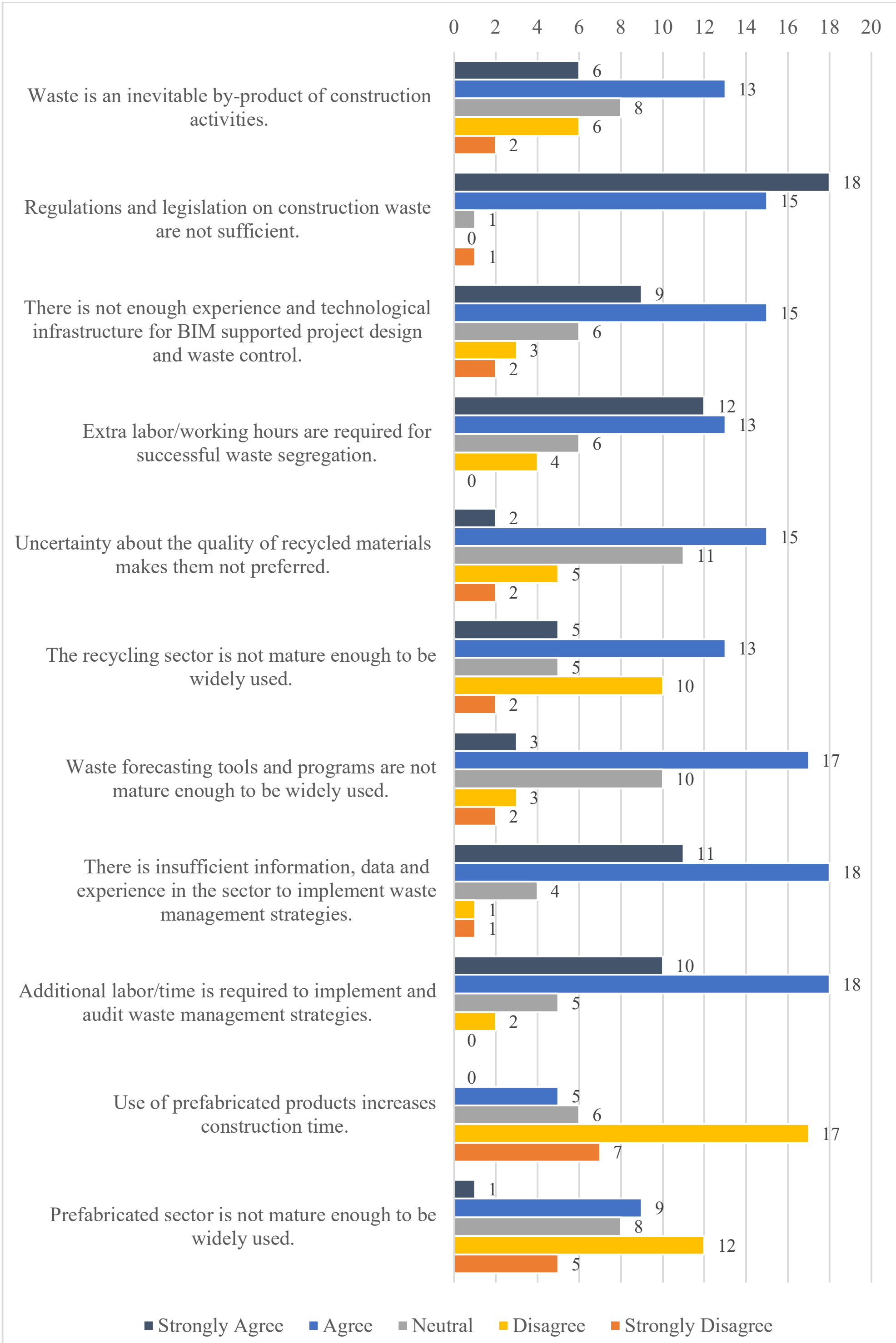


Figure 4.12 Assessment of barriers to waste management strategies

### 4.2.4 Construction Automation and Robotics

Section 4 of the questionnaire focused on the respondents' familiarity with construction automation and robotic technologies.

Only one of the respondents has an experience with CAR. When the previous responses are analyzed, it is seen that this participant took part in international projects.

Additionally, participants with experience were asked to provide information about the projects in which they had used the CAR. The participant stated that s/he had the opportunity to work with field mapping tools and modular construction techniques quite frequently.

Then participants were asked whether they had participated in training on CAR and whether relevant training would be beneficial for them to understand their willingness. It was observed that only one person, who stated in the previous questions that they utilized CAR in previous projects, received training on the subject. S/he additionally notes that,

> *"I took part in many seminars and training on modular construction systems and modern construction processes. I gave training on the production and optimization of building elements within the BIM process."*

Moreover, results show that more than 90% of the participants are willing to attend training on CAR. 32 out of 35 respondents think that training on the subject would be beneficial for their professional life.

### 4.2.5 Applicability of CAR and Future Directions

The aim of the last section is to investigate if it is possible to implement CAR in the near future for the construction projects in Turkey and understand the applicability of CAR for CWM.

The first question of this section was, “Does the company you work for have plans to incorporate these technologies into its projects in the near future?”. There were no positive answers to this question. Participants either said no or that they did not know.

The next question was designed to understand the respondents' knowledge of the information technologies that users need to know to implement and improve the use of CAR. For this purpose, the relevant information technologies encountered in the literature were listed, and the participants were asked to mark the ones they knew to be used in the construction sector.

As can be seen in Figure 4.13, most of the respondents have information on BIM. The least known technologies are UAS and the digital twin, which have not yet become widespread in Turkey and have only recently entered the literature.

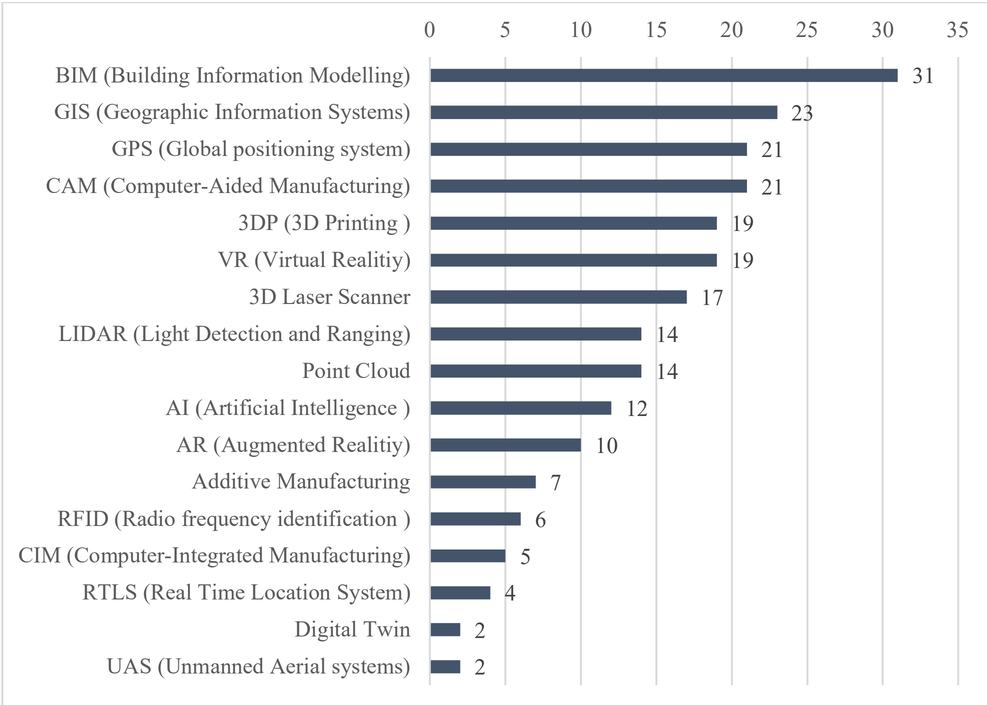


Figure 4.13 Participant's familiarity with the necessary and relevant information technologies to implement and improve the construction automation and robotics

When the respondents were asked about the work groups in which CAR can be used in Turkey, high adoption rates could not be obtained for any group (Figure 4.14).

The group with the highest feasibility is the assembly of prefabricated elements, which is also concluded in previous analyses that the use of prefabricated materials for CWM would be efficient. Another study done by Jaillon et al. (2009) also affirms the participants' view that prefabrication would be effective in reducing construction waste. Furthermore, the authors support the conclusion with a case study that resulted in a 52% waste reduction when prefabrication techniques were used.

The results are in line with the claims of Strukova et al. (2012) and Cai et al. (2020) demonstrating the applicability of CAR in site preparation.

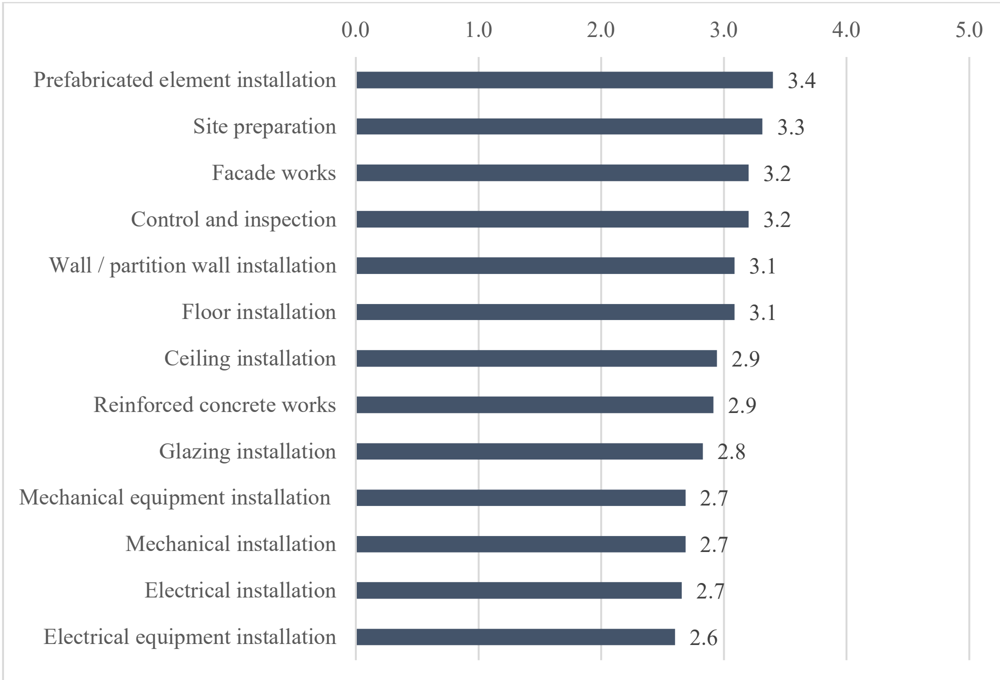


Figure 4.14 Evaluation of availability of construction automation and robotics in Turkey for the specified construction workgroups

Finally, participants were asked to evaluate several statements on the possible advantages of CAR. The results are presented in Figure 4.15.

The results show that the advantage "Reduces waste of raw materials and ingredients" has the highest agreement value. This supports that if CAR is implemented, it will be effective in reducing waste.

The next two advantages with the high agreement rates are the views that CAR will improve the quality, accuracy, and precision of the final product of the construction process and increase work efficiency, which are in line with the findings of Cai et al. (2020) and Oke et al.(2019) . These two advantages are directly related to construction waste, and their enhancement is expected to reduce construction waste.

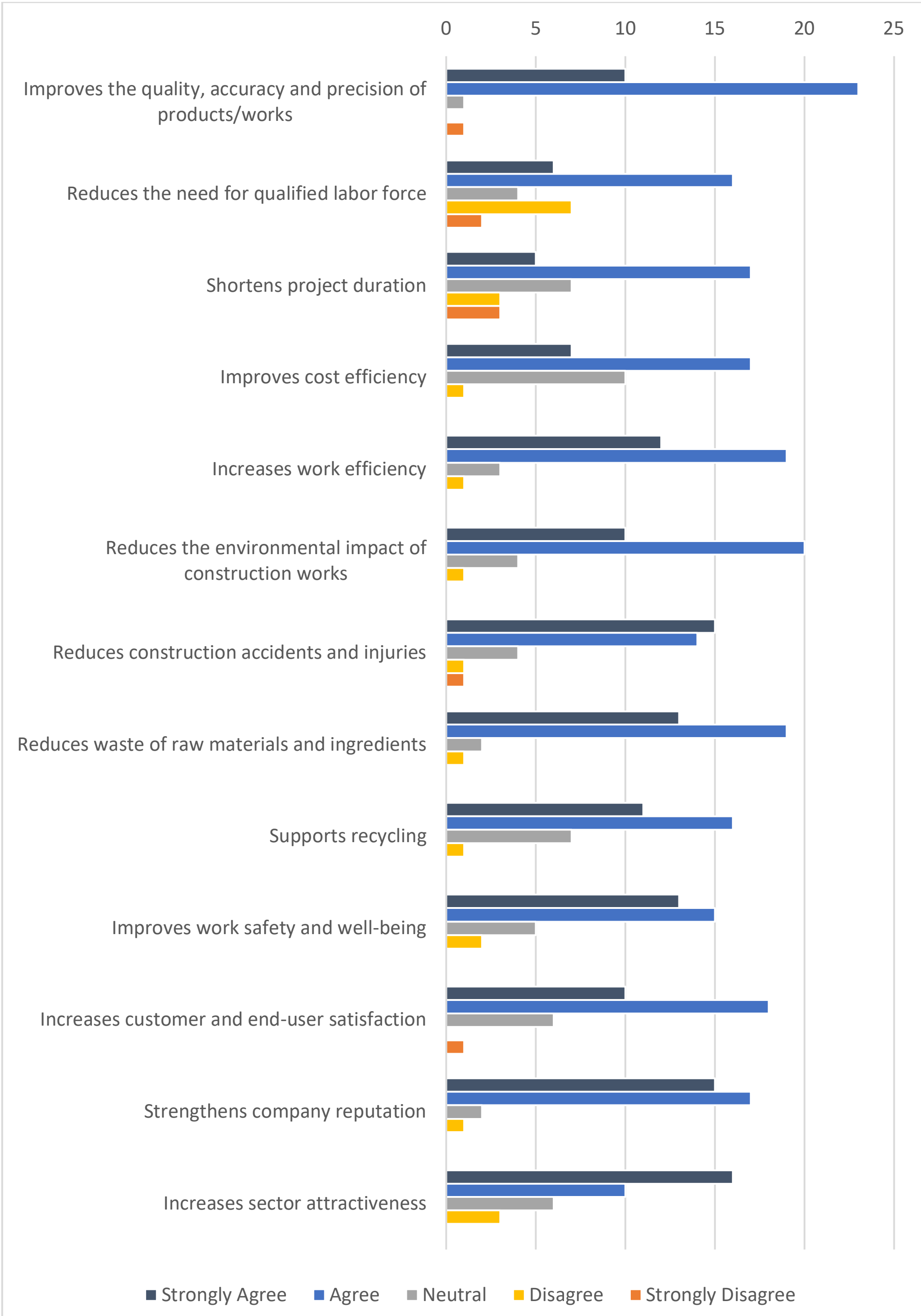


Figure 4.15 Evaluation of possible advantages of construction automation and robotics

### 4.2.6 Summary of Questionnaire Analysis

A comparison of the results collected through the questionnaire survey and the literature study shows that the conclusions reached in the literature summarize the general situation in Turkey.

Osmani et al. (2008) indicate that waste is seen as inevitable by the construction sector. The study, in line with that, has shown that waste is seen as an inevitable consequence of construction activities by more than the half of participants. Additionally, waste minimization is seen as a less important factor compared to the other factors mentioned in project design and planning.

Although respondents were aware of the impact of activities in site operations and management on waste generation, they underestimated the impact of activities in other phases. Nevertheless, site operation and management activities were considered to have the highest impact on waste generation. The most important waste generating factor is "Cutting/preparation of materials to uneconomical dimensions." In addition to several studies (Arslan et al., 2012; Formoso et al., 2002; Islam et al., 2019; Osmani, 2011; Osmani et al., 2008) supporting that result, findings of the study done by Polat et al. (2017) correlate on that; this is one of the main reasons of construction waste generation in Turkey.

From the literature review, it can be deduced that in the sector, there is a lack of information and experience on waste management and CAR system (Ajayi et al., 2015; Brosque, Galbally, et al., 2020; Linner et al., 2020; Osmani & Villoria-Sáez, 2019; L. Y. Shen & Tam, 2002). In line with that information, the results of the survey show that the majority of the respondents had no experience and training on waste management strategies and available CAR systems. Only a small minority who have worked on international projects have any experience and training on the subject. Despite this, most of the respondents indicated that they would be interested in related training.

The measures considered to be most effective in reducing construction waste are primarily governmental strategies, which is consistent with the results of the study done by Osmani et al. (2008). Adequate and effective site management was also seen to be important. These results can be interpreted in the following way: construction management should start with governmental measures, which should be transferred to higher levels of management and then implemented at lower levels.

The results of the study show that sufficient knowledge and infrastructure for the use of CAR have not yet been established in Turkey. However, if these systems are introduced into the construction industry in Turkey, they will have an impact on the efficiency and accuracy of construction works as well as waste reduction.

# CHAPTER 5

# CONCLUSION

It has been emphasized by many researchers, and data has been transferred and confirmed by the relevant institutions that a large part of the waste existing in the world is generated by the construction sector and that this situation continues unchanged today. For this reason, research have been carried out for decades to reduce construction waste, methods that can be applied have been extensively researched, but still, the reduction of construction waste is not at a level that can be considered successful. As the environmental consequences of these wastes become more evident and environmental consciousness grows, the importance of waste minimization and attention to the issue increases.

Another topic that has been the subject of a significant amount of research in the construction industry in recent times is construction technologies. The quantitative and qualitative benefits of this branch, referred to as construction automation and robotics, to the construction industry have been studied by many researchers. Many prototypes and simulation methods have been developed, discussions and surveys have been conducted.

Although these two topics have been extensively researched, there is not much research on the impact of construction automation and robotics on construction waste in particular. This multifactorial issue has been characterized by researchers as problematic and research has generally focused on prefabrication, modular construction and BIM supported construction. It is apparent that there is a gap in the literature and the potential adverse impacts of emerging technologies remain largely unknown.

This research was designed to address this knowledge gap in the construction industry in Turkey and aimed to investigate the impact of construction automation and robotics in reducing construction waste. The research conducted in this direction has shown that there is a lack of regulation and education/training on issues regarding construction waste in Turkey and that construction automation and robotics have not yet gained a place in the Turkish market. It was decided to proceed with survey and group discussion methods inspired by previous studies. Since awareness of the issues is not considered sufficient in the sector, the study not only focused on the effects of CAR on CWM but also tried to collect data separately for CAR and CWM in order to raise awareness and ensure data accuracy.

## 5.1 Conclusion

With respect to the research questions posed at the beginning of the study, the data acquired through literature review, group discussion and questionnaire were analyzed and the following answers were obtained.

Q1: What is the perspective of the construction sector in Turkey on the generation of construction waste?

While activities during site operations and management are seen as the phases with the highest impact on waste generation, the sector is not aware of the influence of decisions and mistakes made in other phases, e.g. design, tendering and documentation phases, on waste generation.

It was agreed by the participants that the highest waste generation occurred from tasks in the finishing works phase, and the most common reasons for construction waste generation are the “preparing/cutting the materials in uneconomical shapes/amount” for both group discussion and questionnaire participants.

In addition, more than half of the respondents consider waste as an unavoidable consequence of construction activities and waste minimization is the least considered factor while designing a project and planning the construction.

*Q2: Are construction waste management strategies being implemented in Turkey?*

It was observed that none of the group discussion participants, i.e. the workers actively engaged in the field, had received any training or information on waste management strategies. They only mentioned taking personal precautions directly proportional to their experience and duties.

In addition, it was also revealed that the higher educated sector employees who participated in the questionnaire also had insufficient training and knowledge. Only a few people who have worked on international projects have received training on the subject.

From these two pieces of information, it is concluded that there is a great lack of collective knowledge on construction waste minimization across the entire industry.

*Q4: What is the effectiveness of waste management strategies?*

Taking into account the findings of the survey, results consider that governmental strategies to be introduced in waste management would be more effective than business strategies and that in order to ensure the correct implementation of these governmental measures to the workers active in the field by the management level, effective and frequent on-site inspections should be prioritized, and workers' knowledge and awareness of waste should be enhanced through training and other instruments.

*Q4: Are construction automation and robotics being used in the construction industry in Turkey?*

Considering that only one of the participants who had been involved in international projects has had any experience with construction automation and robotics, it is concluded that there is no implementation of automation and robotic technologies in Turkey throughout the construction process.

*Q5: Can construction automation and robotics gain a share in Turkey's construction industry in the near future?*

Automation and robotics technologies are not expected to gain a substantial share in the Turkish construction market soon as the results of the study are showing a lack of fundamental knowledge and technical and economic infrastructure.

According to participants, the most common area where CAR technologies can be utilized in Turkey appears to be prefabrication and the most common technology that can be used in the implementation of these systems is observed to be BIM. These findings reveal why literature studies are more focused on such topics which are considered to be easier to implement.

*Q6: Can construction automation and robotics be applied to minimize construction waste in Turkey?*

The study shows that the most important benefit of implementing construction automation and robotics is that it improves work quality and accuracy. While this is known to have an indirect influence on waste generation, the direct benefit of reducing waste is the next following significant benefit of CAR.

Results indicate that, there is a lack of knowledge and legislation in the sector regarding construction waste and automation and robotics. To address this gap, systematization should be put in place, roles and responsibilities should be defined and individuals active in the sector should be trained.

Nevertheless, in order to achieve waste management with the help of CAR, these systems must first be accessible and feasible, which seems unlikely at the current stage of Turkey's construction sector.

In addition, due to the nature of the construction industry, it is impossible to eliminate waste with CAR and it is not possible to apply CAR for all waste types. For CAR to achieve maximum efficiency in waste management, the construction process should be handled with all stages and participants from start to finish, and construction automation and robotics should be evaluated by considering the entire construction system concerning environmental ethics.

## 5.2 Limitations of the Study

One of the limitations of the study is the population of the group discussions and questionnaires. Although care was taken to select groups of discussion and participants of the questionnaire with contrasting characteristics to better reflect the general population, any attempt to extrapolate the sample to the general population may in essence reflect the characteristics of the participants. In addition to the characteristics of the respondents, the number of participants may also limit the results of the survey, as more participants will lead to more general and accurate results.

Another limitation of this research is the participants' narrow knowledge of the topics. Especially in the sections on construction automation and robotics, the broader knowledge of the participants could have led to more accurate results.

Despite all these limitations, the results obtained are consistent with those presented in literature studies and this study contributes to the understanding of CWM and CAR.

### 5.3 Recommendations for Further Studies

As a result of this research, the lack of knowledge in the sector has become apparent and the topic requires further investigation. Given the limitations of the current study, further studies with more participants would provide a better understanding of CWM and CAR. Due to the underdevelopment of CAR technologies in Turkey, simulation or quantification methods could not be adopted and this study only focused on collecting sector opinion. In future research, a more detailed benefits and barriers study could be conducted with a wider range of participants, or quantitative research could be conducted with the help of case studies.

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# APPENDICES

## A. Group Discussion Questions (ENG-TR)

**<u>Research on Causes of Construction Waste and Utilization of Construction Automation and Robotics in Turkey</u>**

This study has been prepared for preliminary research for the thesis study titled Low Waste Strategies and Applicability of Construction Automation and Robotics Technologies in Turkey, which is intended to be completed at Middle East Technical University, Department of Architecture, Building Sciences Master's Program.

Within the scope of this study, construction waste is defined as "damaged, defective or excess materials and by-products of the construction process that cannot be used in accordance with the production purposes in construction".

Your responses will be kept completely anonymous and will be used for academic purposes only.

Thank you for your time.

1. What is your job description?
2. How long is your experience?
3. In your experience, which of the following 3 tasks has greater impact on waste generation during construction?
    - Site Preparation
    - Concrete Works
    - Mechanical Equipment Installation
    - Electrical Equipment Installation
    - Prefabricated Element Installation
    - Façade Works
    - Wall/Partition Wall Construction
    - Floor Installations
    - Ceiling Installations
    - Control And Supervision
4. Are construction waste control strategies applied in the works you participate in?
5. Do you have any training on construction waste minimization?
6. If yes, please indicate the duration and scope.
7. What measures do you take to minimize waste generated during site operations?
8. By which methods are the wastes generated during field operations separated and stored?

**<u>Türkiye’de İnşaat Atıklarının Nedenleri ve İnşaat Otomasyonu ve Robotik Kullanımı Üzerine Araştırma</u>**

Bu çalışma, Orta Doğu Teknik Üniversitesi Mimarlık Bölümü Yapı Bilimleri Yüksek Lisans Programı'nda tamamlanması hedeflenen Düşük Atık Stratejileri ve Türkiye'de İnşaat Otomasyonu ve Robotik Teknolojilerinin Uygulanabilirliği başlıklı tez çalışması için ön araştırma amacıyla hazırlanmıştır.

Bu çalışma kapsamında inşaat atığı, "inşaatta üretim amaçlarına uygun olarak kullanılamayan hasarlı, kusurlu veya fazla malzeme ve inşaat sürecinin yan ürünleri" olarak tanımlanmaktadır.

Yanıtlarınız tamamen anonim tutulacak ve sadece akademik amaçlar için kullanılacaktır.

Zaman ayırdığınız için teşekkürler.

1. İş tanımınız nedir?
2. Deneyim süreniz nedir?
3. Deneyimlerinize göre, belirtilen iş gruplarından atık üretimi üzerinde en çok etkiye sahip 3 iş grubu hangileridir?
    - Saha hazırlığı
    - Betonarme işleri
    - Mekanik tesisat ve ekipman montajı
    - Elektrik tesisat ve ekipman montajı
    - Prefabrike eleman montajı
    - Cephe imalatları
    - Duvar/Bölme imalatları
    - Zemin imalatları
    - Tavan imalatları
    - Kontrol ve denetim
4. Dahil olduğunuz işlerde inşaat atığı kontrol stratejileri uygulanıyor mu?
5. İnşaat atıklarının yönetilmesi konusunda herhangi bir eğitim aldınız mı?
6. Cevabınız evet ise lütfen kapsam ve süresini belirtiniz.
7. Saha operasyonları sırasında ortaya çıkan atıkları en aza indirmek için ne gibi önlemler alıyorsunuz?
8. Saha operasyonları sırasında ortaya çıkan atıklar hangi yöntemlerle ayrıştırılmakta ve depolanmaktadır?

## B. Group Discussion Raw Data

| | No. of Participants | Q1. What is your job description? | Q2. How long is your experience? | Q3. Are construction waste control strategies applied in the works you are involved in? | Q4. Do you have any training on construction waste minimization? | Q5. If yes, please indicate the duration and scope. |
|---|---|---|---|---|---|---|
| Group 1 | 5 | •Site Preparation<br>•Mechanical Installations | 5 to 35 | NO | NO | - |
| Group 2 | 8 | •Formwork<br>•Reinforcement<br>•Concrete works | 3 to 25 | NO | 1 | 1 year |
| Group 3 | 11 | •Formwork<br>•Water insulation | 2 to 20 | NO | NO | - |
| Group 4 | 9 | •Masonry<br>•Plaster<br>•Paint<br>•Ceramic finishes | 5 to 35 | NO | NO | - |

| | Q6. In your experience, what types of waste have you observed to be generated most during the whole construction process? |
|---|---|
| Group 1 | •Ceiling Installations<br>•Façade Works<br>•Site Preparations |
| Group 2 | •Wall/Partition Wall Construction<br>•Ceiling Installations<br>•Façade Works |
| Group 3 | •Wall/Partition Wall Construction<br>•Ceiling Installations<br>•Façade Works |
| Group 4 | •Façade works<br>•Wall/Partition Wall Construction<br>•Wall Finishes |

| | Q7. What measures do you take to minimize waste generated during site operations? |
|---|---|
| **Group 1** | • Cut and use the materials without any waste<br>• Ethics of the labor |
| **Group 2** | • Care is taken in material selection and measurement. |
| **Group 3** | • Materials to be reused (e.g., molding wood) are handled carefully and care is taken not to damage them.<br>• The material is treated sensitively. |
| **Group 4** | • Just in time delivery methods have been adopted.<br>• Attention is paid to the shelf life of purchased materials.<br>• In fine work, the layout is made taking into account the dimensions of the material, materials are cut in such a way that minimum waste is generated.<br>• Employees are informed about environmental pollution and asked to take care.<br>• Weather conditions are also taken into account when preparing the materials. |

| | Q8. By which methods are the wastes generated during field operations separated and stored? |
|---|---|
| **Group 1** | • Sorting is done according to type of material.<br>• Materials to be sold back are stored in a protected area. |
| **Group 2** | • No specific storage system.<br>• The waste is sorted as reusables, recyclables, and others.<br>• Containers are used for storage of the waste. |
| **Group 3** | • The storage is done according to the usage duration of the materials. If a material is kept for a long time, they cover it with a tarp.<br>• There is no special storage area.<br>• While plastic waste is recycled, some of the leftover materials are sold. The rest is incinerated or buried. |
| **Group 4** | • There is no special storage area.<br>• Care is taken to ensure that materials that may be harmful to the environment (e.g., synthetic, and solvent-containing materials) do not contaminate the soil or water.<br>• Incorrect application and improper stacking of material is quite common. |

## C. Questionnaire (ENG-TR)

**Research on Causes of Construction Waste and Utilization of Construction Automation and Robotics in Turkey**

This questionnaire has been prepared for preliminary research purposes for the thesis study titled "AN INVESTIGATION INTO THE IMPLEMENTATION OF CONSTRUCTION AUTOMATION AND ROBOTICS TECHNOLOGIES FOR CONSTRUCTION WASTE MANAGEMENT ", which is planned to be completed at Middle East Technical University, Department of Architecture, Building Sciences Master's Program.

The questionnaire consists of 5 main sections. These are

1. Demographic Information
2. Reasons of Construction Waste
3. Construction Waste Management Strategies and Applicability in Turkey
4. Construction Automation and Robotics
5. Applicability of Construction Automation and Robotics in Turkey

The survey takes approximately 15 minutes to complete.

Within the scope of this study, construction waste is defined as "damaged, defective or surplus materials and by-products of the construction process that cannot be used for their intended purpose in construction". Construction automation and robotics technologies are defined as "the use of self-managing mechanical and electronic devices that use intelligent control to automatically carry out construction tasks and operations". Concrete examples of construction automation and robotics technologies are presented in the study.

Your responses will be kept completely anonymous and will only be used for academic purposes. You can send your questions and comments about the survey to melek.kilickan@metu.edu.tr. Thank you for your time.

Section 1 Demographic Information

This section includes questions to measure demographic information.

Q1. Specify your job description.

(Design Office workers)

- Preliminary Project Preparation
- Implementation Project Preparation
- Visualization
- Site Supervision
- Quantity and Cost Study
- Preparation of Tender Documents
- Preparation of Conservation Projects
- Project Coordination

(Site Office workers)

- o General Manager
- o Director
- o Project Manager
- o Assistant Project Manager
- o Site Supervisor
- o Group Supervisor
- o Field Engineer
- o Field Operation Staff
- o Construction Technician
- o Procurement Specialist
- o Occupational Safety Specialist
- o Quality Control Engineer
- o Consultant

Q2. Please indicate your length of experience.

- o Less than 5 years
- o 5-15 years
- o 16-25 years
- o More than 25 years

Q3. On what scale does the company you work for provide services?

- o Local
- o International

<u>Section 2 Reasons of Construction Waste</u>

This section of the study is prepared to evaluate the reasons of construction waste.

Q4. What is the importance of the following factors during the design or planning of a project?

| | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| Construction cost | O | O | O | O | O |
| Construction time | O | O | O | O | O |
| Familiarity with the chosen construction technology | O | O | O | O | O |
| Buildability in the local market | O | O | O | O | O |
| Waste minimization | O | O | O | O | O |

Q5. Assess the impact of the following construction processes on waste generation.

| | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| Contracting process | O | O | O | O | O |
| Design process | O | O | O | O | O |
| Preparation of tender documents | O | O | O | O | O |
| Procurement of materials and equipment | O | O | O | O | O |
| Transportation process | O | O | O | O | O |
| Storage process | O | O | O | O | O |
| Site Management | O | O | O | O | O |
| Site Operations | O | O | O | O | O |

Q6. Evaluate the impact of works in contract and tender phases on waste generation.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Deficiencies/errors in contract documents | ○ | ○ | ○ | ○ | ○ |
| Commencement of work before completion of contract | ○ | ○ | ○ | ○ | ○ |
| Deficiencies/errors in tender documents | ○ | ○ | ○ | ○ | ○ |
| Poor coordination in the tender process | ○ | ○ | ○ | ○ | ○ |
| Lack of clarity of decision-maker | ○ | ○ | ○ | ○ | ○ |

Q7. Evaluate the impact of works during the design phase on waste generation.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| frequent project revisions | ○ | ○ | ○ | ○ | ○ |
| Incomplete information and/or errors in details and drawings | ○ | ○ | ○ | ○ | ○ |
| Design/Detail complexity | ○ | ○ | ○ | ○ | ○ |
| Preference for low quality materials during the design phase | ○ | ○ | ○ | ○ | ○ |
| Ignoring standard material dimensions during the design phase | ○ | ○ | ○ | ○ | ○ |
| Ignoring constructability during the design process | ○ | ○ | ○ | ○ | ○ |
| Poor communication and coordination between authors during the design process | ○ | ○ | ○ | ○ | ○ |
| Not willing to use new technologies and materials | ○ | ○ | ○ | ○ | ○ |

Q8. Evaluate the impact of works in procurement and transportation stages on waste generation.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Over-ordering due to bill of quantity errors | ○ | ○ | ○ | ○ | ○ |
| Over-ordering due to minimum order requirement | ○ | ○ | ○ | ○ | ○ |
| Supply of materials not conforming to specifications and design | ○ | ○ | ○ | ○ | ○ |
| Supply of damaged/incorrect materials due to supplier | ○ | ○ | ○ | ○ | ○ |
| Incorrect loading and unloading methods to and/or within the site | ○ | ○ | ○ | ○ | ○ |
| Incorrect storage methods | ○ | ○ | ○ | ○ | ○ |

Q9. Evaluate the impact of works during field operations on waste generation.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Use of inappropriate construction methods/equipment | ○ | ○ | ○ | ○ | ○ |
| Use of improper materials | ○ | ○ | ○ | ○ | ○ |
| Labor errors due to inexperience/negligence | ○ | ○ | ○ | ○ | ○ |
| Labor errors due to inappropriate working conditions (e.g. poor lighting) | ○ | ○ | ○ | ○ | ○ |
| Cutting/preparation of materials to uneconomical dimensions | ○ | ○ | ○ | ○ | ○ |
| Deviations in the dimensions of structural elements | ○ | ○ | ○ | ○ | ○ |

Q10. Evaluate the impact of works during field management on waste generation.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Lack of standardization of materials and tasks | ○ | ○ | ○ | ○ | ○ |
| Lack of supervision of materials and labor | ○ | ○ | ○ | ○ | ○ |
| Lack of waste management plans | ○ | ○ | ○ | ○ | ○ |
| Delays in information transfer | ○ | ○ | ○ | ○ | ○ |
| Site irregularity | ○ | ○ | ○ | ○ | ○ |

Q11. Evaluate the impact of the construction works grouped below on waste generation at the site.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Site preparation | O | O | O | O | O |
| Reinforced concrete works | O | O | O | O | O |
| Mechanical equipment installation | O | O | O | O | O |
| Mechanical installation | O | O | O | O | O |
| Electrical equipment installation | O | O | O | O | O |
| Electrical installation | O | O | O | O | O |
| Prefabricated element installation | O | O | O | O | O |
| Facade works | O | O | O | O | O |
| Wall / partition wall installation | O | O | O | O | O |
| Floor installation | O | O | O | O | O |
| Ceiling installation | O | O | O | O | O |
| Glazing installation | O | O | O | O | O |
| Control and inspection | O | O | O | O | O |

Section 3 Waste Management Strategies and Applicability

This section of the study is prepared to evaluate the applicability of waste management strategies in Turkey.

Q12. Are construction waste control strategies implemented in the works you are involved in?

- Yes
- No
- No information

Q13. Is there a construction waste strategy department in the company you work for?

- Yes
- No
- No information

Q14. Are construction waste estimation programs used in the works you are involved in?

- Yes
- No
- No information

Q15. If yes, please specify in which scale.

- Local
- International

Q16. Do you have any training on construction waste minimization?

- Yes
- No

Q17. If yes, please indicate the duration and scope.

………………………………………………………………………………………………………………

Q18. Evaluate the impact of these strategies on reducing construction waste.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Strengthening relevant legislation and regulations | ○ | ○ | ○ | ○ | ○ |
| Increasing penalties against waste | ○ | ○ | ○ | ○ | ○ |
| Obligation to the waste management department | ○ | ○ | ○ | ○ | ○ |
| Raising awareness/consciousness with education | ○ | ○ | ○ | ○ | ○ |
| Including CWM strategies in contracts | ○ | ○ | ○ | ○ | ○ |
| Setting recycling targets for each project phase | ○ | ○ | ○ | ○ | ○ |
| Standardization of construction material | ○ | ○ | ○ | ○ | ○ |
| BIM supported project design and waste control | ○ | ○ | ○ | ○ | ○ |
| Adoption of up-to-date construction techniques | ○ | ○ | ○ | ○ | ○ |
| Adoption of prefabricated and off-site production | ○ | ○ | ○ | ○ | ○ |
| Use of waste forecasting tools and programs | ○ | ○ | ○ | ○ | ○ |
| Ensuring waste optimization at design stage | ○ | ○ | ○ | ○ | ○ |
| Accurate identification of customer requirements | ○ | ○ | ○ | ○ | ○ |
| Incentive reward programs for workers | ○ | ○ | ○ | ○ | ○ |
| Effective and frequent field inspections | ○ | ○ | ○ | ○ | ○ |

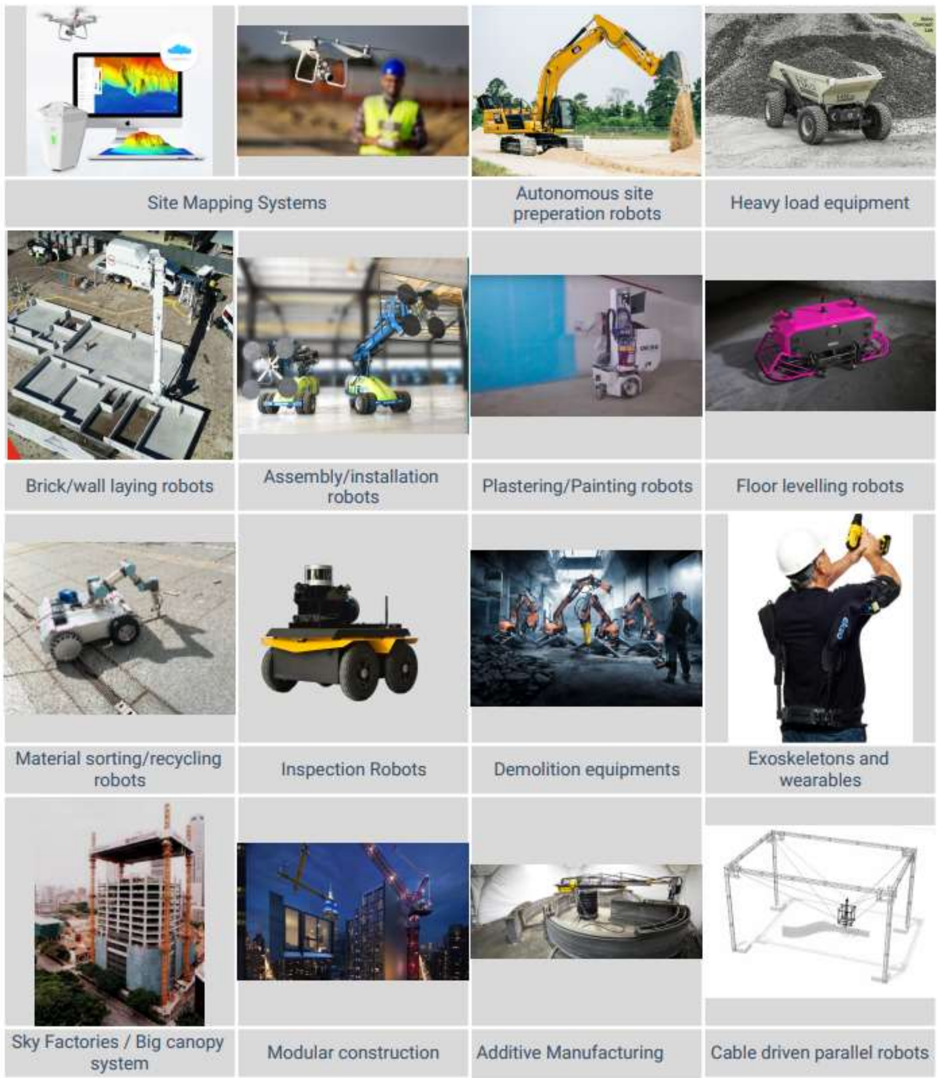
Q19. Evaluate the statements indicated.

| | **Strongly Disagree** | **Disagree** | **Neutral** | **Agree** | **Strongly Agree** |
|---|---|---|---|---|---|
| Waste is an inevitable by-product of construction activities. | ○ | ○ | ○ | ○ | ○ |
| Regulations and legislation on construction waste are not sufficient. | ○ | ○ | ○ | ○ | ○ |
| There is not enough experience and technological infrastructure for BIM supported project design and waste control. | ○ | ○ | ○ | ○ | ○ |
| Extra labor/working hours are required for successful waste segregation. | ○ | ○ | ○ | ○ | ○ |
| Uncertainty about the quality of recycled materials makes them not preferred. | ○ | ○ | ○ | ○ | ○ |
| The recycling sector is not mature enough to be widely used. | ○ | ○ | ○ | ○ | ○ |
| Waste forecasting tools and programs are not mature enough to be widely used. | ○ | ○ | ○ | ○ | ○ |
| There is insufficient information, data and experience in the sector to implement waste management strategies. | ○ | ○ | ○ | ○ | ○ |
| Additional labor/time is required to implement and audit waste management strategies. | ○ | ○ | ○ | ○ | ○ |
| Use of prefabricated products increases construction time. | ○ | ○ | ○ | ○ | ○ |
| Prefabricated sector is not mature enough to be widely used. | ○ | ○ | ○ | ○ | ○ |

Section 4 Construction Automation and Robotics

This section includes questions designed to assess the sector's knowledge and views on construction automation and robotics technologies.

Please review the following example technologies before answering the questions.



Q20. Have you ever been involved in a project where construction automation and robotics technologies were applied?

- Yes
- No

Q21. If yes, please indicate the duration and scope.

……………………………………………………………………………………………………………………

Q22. Have you attended a training, seminar or event related to construction automation or the use of robotics?

- Yes
- No

Q23. If yes, please indicate the duration and scope.

……………………………………………………………………………………………………………………

Q24. Would it be useful for you to take a training on construction automation or the use of robotics?

- Yes
- No

Q25. Does the company you work for have plans to incorporate these technologies into its projects in the near future?

- Yes
- No
- No information

Q26. If yes, please specify in what kind of projects and for what purpose.

……………………………………………………………………………………………………………………

Section 5 Applicability of Construction Automation and Robotics in Turkey

This section includes questions designed to assess the applicability of construction automation and robotics technologies in Turkey.

Q27. Please mark the following information technologies that you know are used in the construction sector.

- GIS (Geographic Information Systems)
- GPS (Global positioning system)
- RFID (Radio frequency identification)
- RTLS (Real Time Location System)
- LIDAR (Light Detection and Ranging)
- 3DP (3D Printing)
- BIM (Building Information Modelling)
- Point Cloud
- CAM (Computer-Aided Manufacturing)
- CIM (Computer-Integrated Manufacturing)
- AI (Artificial Intelligence)
- AR (Augmented Reality)
- Digital Twin
- VR (Virtual Reality)
- Additive Manufacturing
- UAS (Unmanned Aerial systems)
- 3D Laser Scanner

Q28. Evaluate the availability of construction automation and robotics technologies in Turkey for the specified work groups.

| | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| Site preparation | ○ | ○ | ○ | ○ | ○ |
| Reinforced concrete works | ○ | ○ | ○ | ○ | ○ |
| Mechanical equipment installation | ○ | ○ | ○ | ○ | ○ |
| Mechanical installation | ○ | ○ | ○ | ○ | ○ |
| Electrical equipment installation | ○ | ○ | ○ | ○ | ○ |
| Electrical installation | ○ | ○ | ○ | ○ | ○ |
| Prefabricated element installation | ○ | ○ | ○ | ○ | ○ |
| Facade works | ○ | ○ | ○ | ○ | ○ |
| Wall / partition wall installation | ○ | ○ | ○ | ○ | ○ |
| Floor installation | ○ | ○ | ○ | ○ | ○ |
| Ceiling installation | ○ | ○ | ○ | ○ | ○ |
| Glazing installation | ○ | ○ | ○ | ○ | ○ |
| Control and inspection | ○ | ○ | ○ | ○ | ○ |

Q29. Evaluate the possible advantages of construction automation and robotics technologies.

| | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
|---|---|---|---|---|---|
| Improves the quality, accuracy, and precision of products/works | O | O | O | O | O |
| Reduces the need for qualified labor force | O | O | O | O | O |
| Shortens project duration | O | O | O | O | O |
| Improves cost efficiency | O | O | O | O | O |
| Increases work efficiency | O | O | O | O | O |
| Reduces the environmental impact of construction works (such as water, air, noise pollution) | O | O | O | O | O |
| reduces construction accidents and injuries | O | O | O | O | O |
| Reduces waste of raw materials and ingredients | O | O | O | O | O |
| Supports recycling | O | O | O | O | O |
| Improves work safety and well-being | O | O | O | O | O |
| Increases customer and end-user satisfaction | O | O | O | O | O |
| Strengthens company reputation | O | O | O | O | O |
| Increases sector attractiveness | O | O | O | O | O |

<u>This is the end of the survey.</u>

Thank you for your participation and valuable contributions. You can send your questions and comments about the survey to melek.kilickan@metu.edu.tr.

**<u>İnşaat Atıkları Oluşum Sebepleri ve İnşaat Teknolojilerinin Kullanılması Üzerine Çalışma</u>**

Bu anket, Orta Doğu Teknik Üniversitesi, Mimarlık Bölümü, Yapı Bilimleri Yüksek Lisans Programında tamamlanması planlanan, "TÜRKİYEDE İNŞAAT ATIK YÖNETİMİ İÇİN İNŞAAT OTOMASYON VE ROBOTİK TEKNOLOJİLERİNİN KULLANILABİLİRLİĞİ ÜZERİNE BİR ARAŞTIRMA" adlı tez çalışması için ön araştırma amacıyla hazırlanmıştır.

Anket 5 ana bölümden oluşmaktadır. Bunlar:

1. Demografik Bilgi
2. İnşaat Atıklarının Oluşum Sebepleri
3. Düşük Atık Stratejileri ve Uygulanabilirliği
4. İnşaat Otomasyon ve Robotik Teknolojileri
5. İnşaat Otomasyon ve Robotik Teknolojilerinin Türkiye'de Uygulanabilirliği

Anket tamamlanması yaklaşık 15 dakika sürmektedir.

Bu çalışma kapsamında, İnşaat atıklar "inşaatta üretim amaçlarına uygun olarak kullanılamayan; hasarlı, kusurlu veya fazla olan malzemeler ile inşaat süreci sonunda ortaya çıkan yan ürünler" olarak tanımlanmıştır. İnşaat otomasyon ve robotik teknolojileri terimi ise "inşaat görevlerini ve işlemlerini otomatik olarak yürütmek için akıllı kontrol kullanan, kendi kendini yöneten mekanik ve elektronik cihazların kullanımı" olarak tanımlanmaktadır. İnşaat otomasyon ve robotik teknolojilerine dair somut örnekler çalışma içerisinde sunulmuştur.

Yanıtlarınız tamamen anonim olarak saklanacak ve yalnızca akademik amaçlar için kullanılacaktır. Anketle ilgili soru ve görüşlerinizi melek.kilickan@metu.edu.tr adresine iletebilirsiniz. Zaman ayırdığınız için teşekkürler.

Bölüm 1 Demografik Bilgi

Bu bölüm, demografik bilgileri ölçmeye dayalı sorular içermektedir.

S1. Görev tanımınızı belirtiniz.

(Tasarım ofisi çalışanları)

- Avan Proje Hazırlanması
- Uygulama Projesi Hazırlanması
- Görselleştirme
- Görselleştirme
- Metraj ve Maliyet Çalışması
- İhale Dokümanlarının Hazırlanması
- Koruma Projelerinin Hazırlanması
- Proje Koordinasyonu

(Saha ofisi çalışanları)

- Genel Müdür
- Direktör
- Proje Müdürü
- Şantiye Şefi
- Grup Şefi
- Saha Mühendisi
- Saha Operasyon Elemanı
- İnşaat Teknikeri
- Satın Alma Uzmanı
- İş Güvenlik Uzmanı
- Kalite Kontrol Mühendisi
- Danışman

S2. Deneyim sürenizi belirtiniz.

- 5 yıldan az
- 5-15 yıl arası
- 16-25 yıl arası
- 25 yıldan fazla

S3. Çalışanı olduğunuz şirket hangi ölçekte hizmet vermektedir?

- Yerel
- Uluslararası

Bölüm 2 İnşaat Atıklarının Oluşum Sebepleri

Bu bölüm inşaat atıklarının oluşum sebeplerini değerlendirmek üzere hazırlanmış sorular içermektedir.

S4. Bir yapının şantiye sürecinin planlanmasında aşağıda belirtilen etkenlerin size göre önemi nedir?

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Yapım maliyeti | ○ | ○ | ○ | ○ | ○ |
| İnşaat süresi | ○ | ○ | ○ | ○ | ○ |
| Seçilen inşaat teknolojisine aşinalık | ○ | ○ | ○ | ○ | ○ |
| Yerel pazarda inşa edilebilirlik | ○ | ○ | ○ | ○ | ○ |
| Atıkların azaltılması | ○ | ○ | ○ | ○ | ○ |

S5. Aşağıda belirtilen inşaat süreçlerinin atık oluşumundaki etkisini değerlendiriniz.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Sözleşme süreci | ○ | ○ | ○ | ○ | ○ |
| Tasarım süreci | ○ | ○ | ○ | ○ | ○ |
| İhale dokümanlarının hazırlanması | ○ | ○ | ○ | ○ | ○ |
| Malzeme ve ekipman tedariki | ○ | ○ | ○ | ○ | ○ |
| Nakliyat süreci | ○ | ○ | ○ | ○ | ○ |
| Depolama süreci | ○ | ○ | ○ | ○ | ○ |
| Saha Yönetimi | ○ | ○ | ○ | ○ | ○ |
| Saha Operasyonları | ○ | ○ | ○ | ○ | ○ |

S6. Sözleşme ve ihale aşamalarındaki işlerin atık oluşumuna etkisini değerlendiriniz.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Sözleşme belgelerindeki eksikler/hatalar | ○ | ○ | ○ | ○ | ○ |
| Sözleşme tamamlanmadan işin başlaması | ○ | ○ | ○ | ○ | ○ |
| İhale dokümanlarında eksikler/hatalar | ○ | ○ | ○ | ○ | ○ |
| İhale sürecinde zayıf koordinasyon | ○ | ○ | ○ | ○ | ○ |
| Karar merciinin netleşmemesi | ○ | ○ | ○ | ○ | ○ |

S7. Tasarım aşamasındaki işlerin atık oluşumuna etkisini değerlendiriniz.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Çok sık proje revizyonu | ○ | ○ | ○ | ○ | ○ |
| Uygulama detay ve çizimlerinde eksik bilgi ve/veya hata | ○ | ○ | ○ | ○ | ○ |
| Tasarım/Detay karmaşıklığı | ○ | ○ | ○ | ○ | ○ |
| Tasarım aşamasında düşük kalite malzeme tercihi | ○ | ○ | ○ | ○ | ○ |
| Tasarım aşamasında standart malzeme boyutlarının dikkate alınmaması | ○ | ○ | ○ | ○ | ○ |
| Tasarım sürecinde inşa edilebilirliği göz ardı etmek | ○ | ○ | ○ | ○ | ○ |
| Tasarım sürecinde müellifler arasında zayıf iletişim ve koordinasyon | ○ | ○ | ○ | ○ | ○ |
| Yeni teknoloji ve malzemeleri kullanmaya istekli olmama | ○ | ○ | ○ | ○ | ○ |

S8. Tedarik ve nakliye aşamalarındaki işlerin atık oluşumuna etkisini değerlendiriniz.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Metraj hatalarından dolayı fazla sipariş | ○ | ○ | ○ | ○ | ○ |
| Minimum sipariş zorunluluğu nedeniyle fazla sipariş | ○ | ○ | ○ | ○ | ○ |
| Spesifikasyonlara ve tasarıma uygun olmayan malzemelerin tedariki | ○ | ○ | ○ | ○ | ○ |
| Tedarikçiden kaynaklı hasarlı/hatalı malzeme temini | ○ | ○ | ○ | ○ | ○ |
| Sahaya ve/veya saha içinde hatalı yükleme ve boşaltma yöntemleri | ○ | ○ | ○ | ○ | ○ |
| Hatalı depolama yöntemleri | ○ | ○ | ○ | ○ | ○ |

S9. Saha yönetimi aşamasındaki işlerin atık oluşumuna etkisini değerlendiriniz.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Malzeme ve görev standardizasyonunun eksikliği | ○ | ○ | ○ | ○ | ○ |
| Malzeme ve işçilik denetim eksikliği | ○ | ○ | ○ | ○ | ○ |
| Atık yönetim planlarının eksikliği | ○ | ○ | ○ | ○ | ○ |
| Bilgi aktarımındaki gecikmeler | ○ | ○ | ○ | ○ | ○ |
| Saha düzensizliği | ○ | ○ | ○ | ○ | ○ |

S10. Saha operasyonları aşamasındaki işlerin atık oluşumuna etkisini değerlendiriniz.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Uygun olmayan inşaat yöntemi/ekipman kullanımı | ○ | ○ | ○ | ○ | ○ |
| Hatalı malzeme kullanımı | ○ | ○ | ○ | ○ | ○ |
| Deneyimsizlik/ihmalden kaynaklı işçi hataları | ○ | ○ | ○ | ○ | ○ |
| Uygunsuz çalışma şartlarından kaynaklanan işçi hataları (örn. zayıf aydınlatma) | ○ | ○ | ○ | ○ | ○ |
| Malzemelerin ekonomik olmayan boyutlarda kesilmesi/hazırlanması | ○ | ○ | ○ | ○ | ○ |
| Yapısal elemanların boyutlarında sapmalar | ○ | ○ | ○ | ○ | ○ |

S11. Aşağıda gruplandırılmış olan inşaat işlerinin saha içerisinde atık oluşumuna etkisini değerlendiriniz.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Saha hazırlığı | ○ | ○ | ○ | ○ | ○ |
| Betonarme işleri | ○ | ○ | ○ | ○ | ○ |
| Mekanik ekipman montajı | ○ | ○ | ○ | ○ | ○ |
| Mekanik tesisat | ○ | ○ | ○ | ○ | ○ |
| Elektrik ekipman montajı | ○ | ○ | ○ | ○ | ○ |
| Elektrik tesisatı | ○ | ○ | ○ | ○ | ○ |
| Prefabrike eleman montajı | ○ | ○ | ○ | ○ | ○ |
| Cephe imalatları | ○ | ○ | ○ | ○ | ○ |
| Duvar/Bölme duvar imalatları | ○ | ○ | ○ | ○ | ○ |
| Zemin imalatları | ○ | ○ | ○ | ○ | ○ |
| Asma tavan imalatları | ○ | ○ | ○ | ○ | ○ |
| Kapı ve pencere montajı | ○ | ○ | ○ | ○ | ○ |
| Kontrol ve denetim | ○ | ○ | ○ | ○ | ○ |

Bölüm 3 Düşük Atık Stratejileri ve Uygulanabilirliği

Bu bölüm uygulanabilir atık yönetim stratejilerini değerlendirmek üzere hazırlanmış sorular içermektedir.

S12. Dahil olduğunuz işlerde inşaat atık kontrol stratejileri uygulanıyor mu?

- Evet
- Hayır
- Bilgim yok

S13. Çalışmış olduğunuz şirkette inşaat atık strateji departmanı bulunuyor mu?

- Evet
- Hayır
- Bilgim yok

S14. Yer aldığınız işlerde inşaat atık tahmin programları kullanılıyor mu?

- Evet
- Hayır
- Bilgim yok

S15. Cevabınız evet ise hangi ölçekteki işlerde olduğunu belirtiniz.

- Yerel
- Uluslararası

S16. İnşaat atıklarının azaltılması konusunda almış olduğunuz bir eğitim var mı?

- Evet
- Hayır

S17. Cevabınız evet ise süresini ve kapsamını belirtiniz.

……………………………………………………………………………………………………………………

S18. Belirtilen stratejilerin inşaat atıklarının azaltılmasındaki etkisini değerlendiriniz.

| | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| İlgili mevzuat ve yönetmeliklerin güçlendirilmesi | ○ | ○ | ○ | ○ | ○ |
| Hafriyat ve atıklara karşı cezai yaptırımların artırılması | ○ | ○ | ○ | ○ | ○ |
| Proje sürecinde atık strateji departmanı/danışmanı zorunluluğu | ○ | ○ | ○ | ○ | ○ |
| Eğitim destekli bilinçlenme ve farkındalık oluşturulması | ○ | ○ | ○ | ○ | ○ |
| Sözleşmelere inşaat atık yönetim stratejilerinin dahil edilmesi | ○ | ○ | ○ | ○ | ○ |
| Her proje aşaması için geri dönüşüm hedeflerinin belirlenmesi | ○ | ○ | ○ | ○ | ○ |
| İnşaat malzeme boyut ve kalitesinin standartlaştırılması | ○ | ○ | ○ | ○ | ○ |
| BIM destekli projelendirme ve atık kontrolü yapılması | ○ | ○ | ○ | ○ | ○ |
| Güncel inşaat tekniklerinin benimsenmesi | ○ | ○ | ○ | ○ | ○ |
| Prefabrike ve saha dışı üretimin benimsenmesi | ○ | ○ | ○ | ○ | ○ |
| Atık tahmin araç ve programlarının kullanımı | ○ | ○ | ○ | ○ | ○ |
| Tasarım ve planlama aşamasında atık optimizasyonu | ○ | ○ | ○ | ○ | ○ |
| Müşteri gereksinim ve taleplerinin doğru belirlenmesi | ○ | ○ | ○ | ○ | ○ |
| İşçiler arasında teşvik ödül programlarının uygulanması | ○ | ○ | ○ | ○ | ○ |
| Etkin ve sık saha denetimi uygulanması | ○ | ○ | ○ | ○ | ○ |

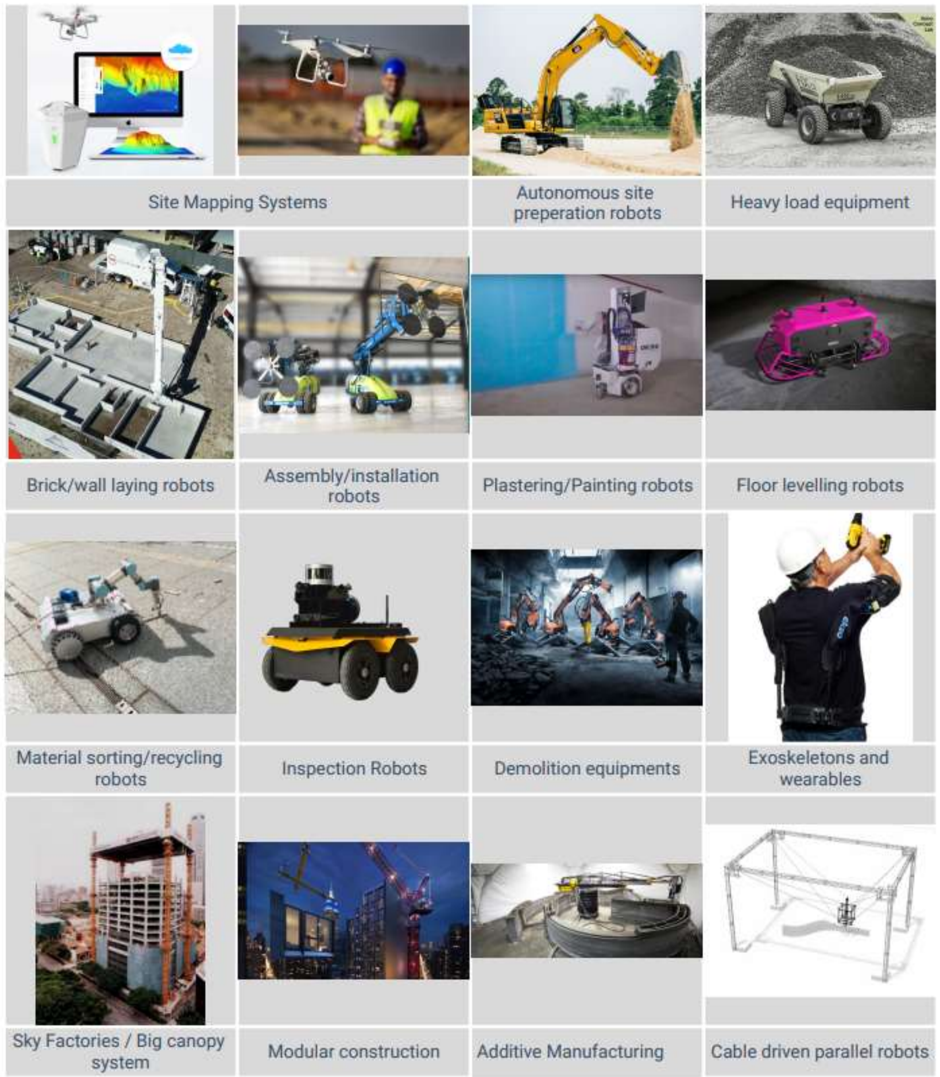
S19. Belirtilen stratejilerin inşaat atıklarının azaltılmasındaki etkisini değerlendiriniz.

| | **Kesinlikle Katılmıyorum** | **Katılmıyorum** | **Emin Değilim** | **Katılıyorum** | **Kesinlikle Katılıyorum** |
|---|---|---|---|---|---|
| Atık inşaat aktivitelerinin kaçınılmaz bir yan ürünüdür. | ○ | ○ | ○ | ○ | ○ |
| İnşaat atıklarına dair yönetmelik ve mevzuat yeterli değildir. | ○ | ○ | ○ | ○ | ○ |
| BIM destekli projelendirme ve atık kontrolü için yeterli deneyim ve teknolojik altyapı yoktur. | ○ | ○ | ○ | ○ | ○ |
| Başarılı bir atık ayrımı yapılabilmesi için ekstra iş gücü/çalışma saati gereklidir. | ○ | ○ | ○ | ○ | ○ |
| Geri dönüştürülmüş malzemelerin kalitesi konusundaki belirsizlik tercih edilmemelerine neden olmaktadır. | ○ | ○ | ○ | ○ | ○ |
| Geri dönüşüm sektörü yaygın olarak kullanılacak olgunlukta değildir. | ○ | ○ | ○ | ○ | ○ |
| Atık tahmin araç ve programları yaygın olarak kullanılacak olgunlukta değildir. | ○ | ○ | ○ | ○ | ○ |
| Atık yönetim stratejilerinin uygulanabilmesi için sektörde yeterli bilgi, veri ve deneyim bulunmamaktadır. | ○ | ○ | ○ | ○ | ○ |
| Atık yönetim stratejilerinin uygulanabilmesi ve denetimi için ek iş gücü/zaman gereklidir. | ○ | ○ | ○ | ○ | ○ |
| Prefabrike ürünlerin kullanımı inşaat süresini artırmaktadır. | ○ | ○ | ○ | ○ | ○ |
| Prefabrike sektörü yaygın olarak kullanılacak olgunlukta değildir. | ○ | ○ | ○ | ○ | ○ |

Bölüm 4 İnşaat Otomasyon ve Robotik Teknolojileri

Bu bölüm sektörün inşaat otomasyonu ve robotik teknolojilerine dair bilgi ve görüşlerini değerlendirmek üzere hazırlanmış sorular içermektedir.

Lütfen soruları yanıtlamadan önce aşağıda bulunan örnek teknolojileri inceleyiniz




S20. Daha önce inşaat otomasyonu ve robotik teknolojilerinin uygulandığı bir projede yer aldınız mı?

- Evet
- Hayır

S21. Cevabınız evet ise, proje türü ve teknoloji türünü lütfen belirtiniz.

……………………………………………………………………………………………………………………

S22. İnşaat otomasyonu veya robotiklerin kullanımı ile ilgili bir eğitim, seminer veya etkinliğe katıldınız mı?

- Evet
- Hayır

S23. Cevabınız evet ise, süresini ve kapsamını lütfen belirtiniz.

……………………………………………………………………………………………………………………

S24. İnşaat otomasyonu veya robotiklerin kullanımı ile ilgili bir eğitim almak sizin için faydalı olur mu?

- Evet
- Hayır

S25. Çalışanı olduğunuz şirketin yakın gelecekte bu teknolojileri projelerine dahil etme planı var mıdır?

- Evet
- Hayır
- Bilgim yok

S26. Cevabınız evet ise, ne tür projelerde, hangi amaçla kullanılacağını belirtiniz.

……………………………………………………………………………………………………………………

Bölüm 5 İnşaat Otomasyon ve Robotik Teknolojilerinin Türkiye'de Uygulanabilirliği

Bu bölüm Türkiye'de inşaat otomasyon ve robotik teknolojilerinin uygulanabilirliğini değerlendirmek üzere hazırlanmış sorular içermektedir.

S27. Aşağıdaki bilgi teknolojilerinden inşaat sektöründe kullanıldığını bildiklerinizi işaretleyiniz.

- GIS (Coğrafi Bilgi Sistemleri-Geographic Information Systems)
- GPS (Küresel Konumlanma Sistemi-Global positioning system)
- RFID (Radyo Frekanslı Tanımlama-Radio frequency identification )
- RTLS (Gerçek Zamanlı Konum Takip Sistemi-Real Time Location System)
- LIDAR (Lazer alan tarayıcı-Light Detection and Ranging)
- 3DP (3 Boyutlu Baskı -3D Printing)
- BIM (Yapı Bilgi Modellemesi-Building Information Modelling)
- Nokta Bulutu (Point Cloud)
- CAM (Bilgisayar Destekli Üretim-Computer-Aided Manufacturing)
- CIM (Bilgisayar Bütünleşik İmalat-Computer-Integrated Manufacturing)
- AI (Yapay Zeka-Artificial Intelligence )
- AR (Artırılmış Gerçeklik-Augmented Realitiy)
- Digital Twin (Dijital İkiz)
- VR (Sanal Gerçeklik-Virtual Realitiy)
- Katmanlı Üretim (Additive Manufacturing)
- UAS (İnsansız Hava Araçları-Unmanned Aerial systems)
- 3B Lazer Tarayıcı (3D Laser Scanner)

S28. Belirlenen iş grupları için Türkiye'deki inşaat otomasyonu ve robotik teknolojilerinin kullanılabilirliğini değerlendirin.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Saha hazırlığı | O | O | O | O | O |
| Betonarme işleri | O | O | O | O | O |
| Mekanik ekipman montajı | O | O | O | O | O |
| Mekanik tesisat | O | O | O | O | O |
| Elektrik ekipman montajı | O | O | O | O | O |
| Elektrik tesisatı | O | O | O | O | O |
| Prefabrike eleman montajı | O | O | O | O | O |
| Cephe imalatları | O | O | O | O | O |
| Duvar/Bölme duvar imalatları | O | O | O | O | O |
| Zemin imalatları | O | O | O | O | O |
| Asma tavan imalatları | O | O | O | O | O |
| Kapı ve pencere montajı | O | O | O | O | O |
| Kontrol ve denetim | O | O | O | O | O |

S29. İnşaat otomasyon ve robotik teknolojilerinin olası avantajlarını değerlendiriniz.

| | Kesinlikle Katılmıyorum | Katılmıyorum | Emin Değilim | Katılıyorum | Kesinlikle Katılıyorum |
|---|---|---|---|---|---|
| Ürünlerin/işlerin kalite, doğruluk ve hassasiyetini artırır | O | O | O | O | O |
| Nitelikli iş gücü ihtiyacının azalmasını sağlar | O | O | O | O | O |
| Proje süresini kısaltır | O | O | O | O | O |
| Maliyet verimliliğini artırır | O | O | O | O | O |
| İş verimliliğini arttırır | O | O | O | O | O |
| İnşaat işlerinin çevresel etkilerini azaltır (Su, hava, gürültü kirliliği gibi) | O | O | O | O | O |
| İnşaat kaza ve yaralanmalarını azaltır | O | O | O | O | O |
| Ana madde ve malzeme israfını azaltır | O | O | O | O | O |
| Geri dönüşümü destekler | O | O | O | O | O |
| İş güvenliği ve refahı artırır | O | O | O | O | O |
| Müşteri ve son kullanıcı memnuniyetini arttırır | O | O | O | O | O |
| Şirket itibarını güçlendirir | O | O | O | O | O |
| Sektör çekiciliğini arttırır | O | O | O | O | O |

<u>Anket burada sonlanmıştır.</u>

Katılımınız ve değerli katkılarınız için teşekkür ederim. Anketle ilgili soru ve görüşlerinizi melek.kilickan@metu.edu.tr adresine iletebilirsiniz.

# D. Questionnaire Raw Data

| Specify your job description. | Preliminary Project Preparation | Implementation Project Preparation | Visualization | Site Supervision | Quantity and Cost Study | Preparation of Tender Documents | Preparation of Conservation Projects | Project Coordination | General Manager | Director | Project Manager | Assistant Project Manager | Site Supervisor | Group Supervisor | Field Engineer | Field Operation Staff | Construction Technician | Procurement Specialist | Occupational Safety Specialist | Quality Control Engineer | Consultant | Please indicate your length of experience. | Less than 5 years | 5-15 years | 16-25 years | More than 25 years | On what scale does the company you work for provide services? | Local | International |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 0 | 1 |
| | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 1 | 1 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 0 | 1 |
| | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 0 | 0 | 0 | | 1 | 1 |
| | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 0 | 0 | 0 | | 1 | 1 |
| | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 1 | 0 |
| | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 1 | 0 |
| | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 0 | 0 | 0 | | 0 | 1 |
| | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 0 | 0 | 0 | | 0 | 1 |
| | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 1 | 0 |
| | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 0 | 0 | 0 | | 0 | 1 |
| | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 1 | 0 |
| | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 1 | 0 |
| | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 0 | 0 | 0 | | 0 | 1 |
| | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 0 | 0 | 0 | | 1 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 0 | 0 | 0 | | 0 | 1 |
| | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 0 | 0 | 0 | | 1 | 0 |
| | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 0 | 0 | 0 | | 1 | 0 |
| | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 0 | 0 | 0 | | 1 | 0 |
| | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 0 | 0 | 0 | | 1 | 1 |
| | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 1 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 1 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 1 | 0 | | 1 | 1 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 1 | 0 | | 0 | 1 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 1 | 1 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 0 | 1 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 1 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 1 | 0 | | 0 | 1 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 1 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 0 | 1 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 1 | | 0 | 1 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 1 | | 0 | 1 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 1 | | 0 | 1 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 1 | 0 | | 0 | 1 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 0 | 0 | 0 | | 1 | 0 |
| | **14** | **16** | **12** | **5** | **6** | **9** | **1** | **12** | **1** | **2** | **2** | **1** | **1** | **5** | **1** | **1** | **0** | **0** | **0** | **0** | **0** | | **13** | **15** | **4** | **3** | | **20** | **21** |

| What is the importance of the following factors during the design of a building? | Construction cost | Construction time | Familiarity with the chosen construction technology | Buildability in the local market | Waste minimization | Assess the impact of the following construction processes on waste generation. | Contracting process | Design process | Preparation of tender documents | Procurement of materials and equipment | Transportation process | Storage process | Site Management | Site Operations | Evaluate the impact of works in contract and tender phases on waste generation. | Deficiencies/errors in contract documents | Commencement of work before completion of contract | Deficiencies/errors in tender documents | Poor coordination in the tender process | Lack of clarity of decision-maker |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 4 | 5 | 5 | 3 | | 5 | 3 | 0 | 5 | 5 | 5 | 5 | 5 | | 5 | 5 | 5 | 3 | 3 |
| | 4 | 4 | 4 | 4 | 2 | | 2 | 2 | 2 | 4 | 4 | 4 | 4 | 4 | | 4 | 3 | 3 | 4 | 4 |
| | 3 | 5 | 4 | 2 | 4 | | 0 | 2 | 5 | 3 | 4 | 3 | 3 | 3 | | 2 | 2 | 5 | 4 | 5 |
| | 3 | 4 | 5 | 5 | 5 | | 3 | 2 | 2 | 5 | 4 | 4 | 5 | 5 | | 5 | 2 | 5 | 5 | 5 |
| | 4 | 3 | 4 | 5 | 3 | | 3 | 4 | 5 | 4 | 4 | 4 | 5 | 5 | | 5 | 4 | 4 | 5 | 3 |
| | 4 | 4 | 4 | 4 | 5 | | 3 | 4 | 3 | 5 | 5 | 3 | 5 | 5 | | 3 | 3 | 3 | 3 | 5 |
| | 5 | 5 | 5 | 5 | 3 | | 0 | 1 | 1 | 5 | 3 | 4 | 5 | 5 | | 5 | 5 | 5 | 5 | 5 |
| | 4 | 2 | 3 | 4 | 3 | | 0 | 1 | 0 | 3 | 2 | 1 | 4 | 5 | | 2 | 3 | 3 | 4 | 4 |
| | 4 | 5 | 5 | 4 | 3 | | 2 | 2 | 3 | 5 | 5 | 5 | 5 | 5 | | 5 | 4 | 5 | 4 | 5 |
| | 4 | 2 | 3 | 5 | 3 | | 2 | 1 | 3 | 4 | 4 | 4 | 5 | 5 | | 4 | 5 | 5 | 5 | 5 |
| | 4 | 4 | 1 | 1 | 4 | | 0 | 1 | 0 | 2 | 2 | 3 | 3 | 3 | | 1 | 4 | 1 | 2 | 5 |
| | 5 | 4 | 4 | 5 | 3 | | 3 | 3 | 4 | 5 | 2 | 5 | 4 | 4 | | 5 | 3 | 5 | 4 | 4 |
| | 3 | 3 | 1 | 5 | 3 | | 0 | 3 | 3 | 5 | 3 | 3 | 5 | 5 | | 5 | 3 | 5 | 5 | 3 |
| | 3 | 2 | 4 | 2 | 2 | | 0 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | | 1 | 1 | 1 | 2 | 2 |
| | 3 | 4 | 3 | 4 | 4 | | 1 | 1 | 1 | 1 | 3 | 0 | 4 | 5 | | 4 | 3 | 5 | 4 | 4 |
| | 4 | 4 | 4 | 4 | 4 | | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | | 4 | 4 | 5 | 5 | 5 |
| | 4 | 2 | 3 | 5 | 4 | | 0 | 1 | 1 | 1 | 1 | 2 | 3 | 4 | | 2 | 3 | 2 | 2 | 4 |
| | 3 | 2 | 2 | 3 | 3 | | 1 | 3 | 2 | 3 | 4 | 4 | 5 | 5 | | 3 | 3 | 3 | 4 | 4 |
| | 4 | 4 | 5 | 4 | 3 | | 5 | 5 | 4 | 5 | 4 | 3 | 5 | 5 | | 4 | 5 | 4 | 4 | 5 |
| | 5 | 4 | 3 | 5 | 3 | | 5 | 5 | 4 | 5 | 3 | 4 | 3 | 4 | | 5 | 3 | 4 | 5 | 3 |
| | 2 | 2 | 3 | 4 | 4 | | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | | 2 | 2 | 3 | 4 | 4 |
| | 3 | 4 | 4 | 2 | 4 | | 0 | 2 | 0 | 1 | 1 | 1 | 5 | 5 | | 1 | 2 | 2 | 2 | 5 |
| | 5 | 5 | 4 | 4 | 4 | | 0 | 4 | 1 | 2 | 2 | 2 | 4 | 5 | | 3 | 3 | 3 | 3 | 2 |
| | 4 | 5 | 3 | 3 | 1 | | 3 | 3 | 1 | 1 | 1 | 2 | 5 | 5 | | 3 | 2 | 3 | 4 | 5 |
| | 4 | 5 | 5 | 3 | 2 | | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5 | | 4 | 5 | 3 | 5 | 3 |
| | 5 | 5 | 4 | 4 | 4 | | 0 | 0 | 0 | 1 | 2 | 2 | 5 | 5 | | 2 | 3 | 3 | 3 | 3 |
| | 5 | 5 | 4 | 5 | 4 | | 0 | 4 | 2 | 2 | 2 | 1 | 3 | 5 | | 5 | 2 | 5 | 2 | 2 |
| | 5 | 5 | 4 | 4 | 4 | | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 4 | | 3 | 4 | 4 | 4 | 4 |
| | 5 | 4 | 3 | 4 | 4 | | 1 | 3 | 4 | 4 | 1 | 1 | 1 | 1 | | 4 | 3 | 4 | 3 | 4 |
| | 5 | 5 | 3 | 3 | 3 | | 2 | 5 | 3 | 3 | 3 | 3 | 5 | 5 | | 3 | 3 | 3 | 3 | 3 |
| | 4 | 5 | 4 | 4 | 4 | | 1 | 3 | 3 | 4 | 4 | 3 | 4 | 4 | | 3 | 3 | 4 | 3 | 4 |
| | 5 | 5 | 4 | 4 | 4 | | 1 | 1 | 1 | 2 | 3 | 1 | 3 | 5 | | 1 | 2 | 1 | 4 | 5 |
| | 5 | 5 | 4 | 3 | 3 | | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 5 | | 4 | 4 | 5 | 5 | 5 |
| | 5 | 5 | 4 | 4 | 4 | | 4 | 5 | 1 | 5 | 2 | 4 | 4 | 4 | | 5 | 5 | 5 | 5 | 5 |
| | 4 | 3 | 4 | 5 | 2 | | 2 | 3 | 3 | 3 | 4 | 5 | 5 | 5 | | 3 | 4 | 3 | 3 | 3 |
| | **4.1** | **4.0** | **3.7** | **3.9** | **3.4** | | **1.6** | **2.4** | **2.0** | **3.1** | **2.9** | **2.9** | **4.1** | **4.4** | | **3.4** | **3.3** | **3.7** | **3.8** | **4.0** |

| Evaluate the impact of works during the design phase on waste generation. | frequent project revisions | Incomplete information and/or errors in details and drawings | Design/Detail complexity | Preference for low quality materials during the design phase | Ignoring standard material dimensions during the design phase | Ignoring constructability during the design process | Poor communication and coordination between authors during the design process | Not willing to use new technologies and materials | Evaluate the impact of works in procurement and transportation stages on waste genera | Over-ordering due to quantity errors | Over-ordering due to minimum order requirement | Supply of materials not conforming to specifications and design | Supply of damaged/incorrect materials due to supplier | Incorrect loading and unloading methods to and/or within the site | Incorrect storage methods | Evaluate the impact of works during field operations on waste generation. | Use of inappropriate construction methods/equipment | Use of improper materials | Labor errors due to inexperience/negligence | Labor errors due to inappropriate working conditions (e.g. poor lighting) | Cutting/preparation of materials to uneconomical dimensions | Deviations in the dimensions of structural elements |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 5 | 3 | 4 | 5 | 5 | 3 | 3 | | 5 | 5 | 5 | 4 | 5 | 5 | | 5 | 5 | 3 | 3 | 5 | 5 |
| | 4 | 4 | 3 | 3 | 4 | 4 | 3 | 4 | | 4 | 4 | 4 | 4 | 4 | 4 | | 4 | 4 | 4 | 4 | 4 | 3 |
| | 4 | 5 | 3 | 2 | 2 | 3 | 3 | 3 | | 5 | 4 | 5 | 5 | 4 | 4 | | 3 | 4 | 4 | 4 | 4 | 3 |
| | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 3 | | 3 | 5 | 5 | 5 | 5 | 4 | | 5 | 5 | 5 | 5 | 5 | 5 |
| | 5 | 4 | 3 | 3 | 5 | 3 | 4 | 5 | | 5 | 4 | 4 | 3 | 2 | 4 | | 4 | 4 | 5 | 3 | 4 | 3 |
| | 4 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | | 5 | 5 | 5 | 5 | 5 | 5 | | 5 | 5 | 5 | 5 | 5 | 5 |
| | 5 | 4 | 3 | 3 | 4 | 4 | 4 | 4 | | 3 | 4 | 2 | 4 | 5 | 5 | | 5 | 3 | 3 | 4 | 4 | 4 |
| | 3 | 4 | 5 | 4 | 4 | 3 | 4 | 5 | | 4 | 4 | 3 | 3 | 4 | 4 | | 3 | 4 | 4 | 3 | 4 | 3 |
| | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | | 5 | 4 | 4 | 5 | 5 | 5 | | 5 | 5 | 5 | 5 | 5 | 4 |
| | 3 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | | 4 | 2 | 4 | 5 | 4 | 5 | | 5 | 5 | 5 | 3 | 4 | 4 |
| | 3 | 4 | 2 | 4 | 5 | 4 | 5 | 2 | | 5 | 4 | 4 | 3 | 3 | 2 | | 5 | 5 | 4 | 4 | 5 | 3 |
| | 4 | 5 | 4 | 3 | 5 | 5 | 4 | 3 | | 5 | 3 | 4 | 5 | 5 | 5 | | 4 | 5 | 5 | 4 | 5 | 3 |
| | 4 | 4 | 3 | 3 | 5 | 5 | 4 | 4 | | 3 | 3 | 3 | 5 | 5 | 5 | | 5 | 5 | 5 | 5 | 5 | 4 |
| | 2 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | | 4 | 4 | 4 | 4 | 4 | 4 | | 3 | 4 | 4 | 5 | 5 | 5 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | | 4 | 4 | 4 | 3 | 3 | 2 | | 3 | 3 | 3 | 4 | 3 | 4 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | | 5 | 5 | 5 | 5 | 5 | 5 | | 5 | 5 | 5 | 5 | 5 | 5 |
| | 4 | 3 | 3 | 4 | 4 | 4 | 3 | 2 | | 4 | 3 | 4 | 2 | 2 | 3 | | 4 | 2 | 5 | 4 | 4 | 3 |
| | 4 | 5 | 5 | 4 | 5 | 5 | 4 | 3 | | 4 | 4 | 4 | 4 | 5 | 4 | | 3 | 3 | 4 | 4 | 4 | 5 |
| | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 4 | | 5 | 5 | 4 | 4 | 4 | 3 | | 4 | 4 | 4 | 5 | 5 | 5 |
| | 5 | 4 | 3 | 4 | 5 | 5 | 3 | 4 | | 5 | 3 | 4 | 5 | 5 | 4 | | 5 | 5 | 4 | 3 | 5 | 2 |
| | 2 | 2 | 3 | 3 | 1 | 3 | 3 | 3 | | 3 | 2 | 3 | 3 | 2 | 2 | | 2 | 3 | 2 | 2 | 3 | 3 |
| | 5 | 5 | 5 | 2 | 5 | 5 | 5 | 4 | | 5 | 5 | 4 | 2 | 3 | 2 | | 3 | 5 | 5 | 5 | 5 | 5 |
| | 4 | 4 | 4 | 2 | 5 | 5 | 5 | 3 | | 5 | 5 | 3 | 5 | 5 | 4 | | 4 | 5 | 5 | 4 | 4 | 5 |
| | 5 | 5 | 5 | 3 | 5 | 5 | 5 | 3 | | 5 | 5 | 5 | 5 | 5 | 5 | | 5 | 5 | 3 | 3 | 4 | 2 |
| | 4 | 3 | 4 | 3 | 5 | 4 | 5 | 5 | | 5 | 2 | 4 | 5 | 5 | 5 | | 5 | 5 | 5 | 5 | 5 | 5 |
| | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 3 | | 1 | 2 | 2 | 3 | 3 | 4 | | 2 | 2 | 3 | 3 | 3 | 4 |
| | 3 | 3 | 2 | 5 | 5 | 5 | 2 | 4 | | 5 | 2 | 5 | 2 | 1 | 1 | | 4 | 5 | 2 | 2 | 5 | 2 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | | 5 | 4 | 4 | 4 | 5 | 5 | | 4 | 4 | 4 | 5 | 4 | 5 |
| | 5 | 4 | 3 | 3 | 2 | 2 | 3 | 1 | | 2 | 1 | 3 | 1 | 1 | 1 | | 2 | 3 | 4 | 3 | 4 | 1 |
| | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | | 5 | 5 | 5 | 5 | 5 | 5 | | 5 | 5 | 5 | 5 | 5 | 5 |
| | 3 | 4 | 4 | 4 | 3 | 3 | 4 | 4 | | 3 | 4 | 4 | 4 | 4 | 3 | | 4 | 4 | 4 | 3 | 3 | 3 |
| | 3 | 4 | 4 | 3 | 5 | 5 | 5 | 3 | | 5 | 4 | 5 | 5 | 3 | 3 | | 5 | 5 | 4 | 4 | 5 | 5 |
| | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | | 5 | 5 | 5 | 5 | 3 | 4 | | 5 | 5 | 5 | 3 | 5 | 5 |
| | 4 | 5 | 4 | 3 | 4 | 4 | 4 | 4 | | 5 | 5 | 5 | 4 | 4 | 5 | | 5 | 5 | 5 | 5 | 5 | 5 |
| | 5 | 5 | 3 | 5 | 5 | 5 | 4 | 3 | | 5 | 5 | 4 | 4 | 5 | 5 | | 5 | 5 | 5 | 5 | 5 | 5 |
| | **3.9** | **4.1** | **3.7** | **3.7** | **4.3** | **4.3** | **4.1** | **3.7** | | **4.3** | **3.9** | **4.1** | **4.0** | **3.9** | **3.9** | | **4.1** | **4.3** | **4.2** | **4.0** | **4.4** | **3.9** |

| Evaluate the impact of works in the field management phase on waste generation. | Lack of standardization of materials and tasks | Lack of supervision of materials and labour | Lack of waste management plans | Delays in information transfer | Site irregularity | Evaluate the impact of the construction works grouped on waste generation. | Site preparation | Reinforced concrete works | Mechanical equipment installation | Mechanical installation | Electrical equipment installation | Electrical installation | Prefabricated element installation | Facade works | Wall / partition wall installation | Floor installation | Ceiling installation | Glazing installation | Control and inspection |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 4 | 5 | 4 | 4 | | 5 | 4 | 3 | 3 | 3 | 3 | 1 | 3 | 4 | 3 | 4 | 2 | 5 |
| | 4 | 4 | 4 | 4 | 4 | | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 4 | 3 | 4 | 4 | 3 | 3 |
| | 3 | 3 | 5 | 4 | 5 | | 2 | 4 | 4 | 3 | 4 | 3 | 3 | 4 | 4 | 5 | 5 | 3 | 3 |
| | 5 | 5 | 5 | 4 | 5 | | 3 | 4 | 5 | 5 | 5 | 5 | 2 | 5 | 4 | 4 | 3 | 2 | 4 |
| | 5 | 5 | 5 | 3 | 2 | | 5 | 5 | 3 | 3 | 3 | 3 | 4 | 4 | 3 | 4 | 2 | 3 | 4 |
| | 5 | 5 | 5 | 5 | 5 | | 5 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 4 |
| | 3 | 5 | 5 | 4 | 5 | | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 3 | 3 |
| | 4 | 3 | 5 | 3 | 4 | | 2 | 2 | 4 | 3 | 4 | 3 | 4 | 4 | 4 | 4 | 3 | 2 | 3 |
| | 5 | 5 | 5 | 4 | 4 | | 4 | 3 | 3 | 2 | 3 | 2 | 2 | 4 | 4 | 4 | 4 | 3 | 3 |
| | 5 | 4 | 5 | 5 | 5 | | 3 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 4 | 4 | 4 |
| | 3 | 2 | 3 | 2 | 3 | | 3 | 3 | 4 | 4 | 3 | 3 | 2 | 2 | 2 | 4 | 3 | 2 | 3 |
| | 4 | 5 | 5 | 3 | 4 | | 4 | 4 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 5 | 4 | 3 | 4 |
| | 4 | 5 | 5 | 4 | 5 | | 5 | 3 | 3 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 5 |
| | 4 | 4 | 5 | 5 | 5 | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 3 | 2 | 2 | 2 | 2 |
| | 5 | 5 | 3 | 4 | 5 | | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 2 | 3 |
| | 4 | 4 | 5 | 4 | 4 | | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | 3 | 4 | 4 | 4 | 4 | | 3 | 2 | 2 | 3 | 2 | 3 | 3 | 4 | 3 | 3 | 3 | 4 | 2 |
| | 3 | 4 | 5 | 4 | 5 | | 4 | 3 | 3 | 2 | 2 | 2 | 1 | 4 | 3 | 3 | 3 | 3 | 4 |
| | 5 | 4 | 5 | 4 | 5 | | 5 | 4 | 4 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | 5 | 4 | 5 | 3 | 4 | | 5 | 5 | 3 | 4 | 3 | 4 | 2 | 3 | 3 | 4 | 3 | 3 | 4 |
| | 3 | 3 | 2 | 3 | 3 | | 3 | 3 | 2 | 2 | 3 | 3 | 2 | 3 | 3 | 2 | 3 | 3 | 3 |
| | 3 | 5 | 5 | 5 | 5 | | 5 | 3 | 2 | 1 | 1 | 1 | 1 | 3 | 4 | 3 | 1 | 1 | 5 |
| | 4 | 4 | 5 | 5 | 5 | | 4 | 4 | 2 | 4 | 2 | 4 | 4 | 4 | 5 | 5 | 5 | 3 | 5 |
| | 3 | 5 | 3 | 4 | 4 | | 4 | 4 | 2 | 2 | 2 | 2 | 1 | 2 | 4 | 3 | 3 | 2 | 3 |
| | 4 | 3 | 5 | 4 | 5 | | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 4 | 3 | 4 | 3 | 3 |
| | 3 | 3 | 4 | 3 | 4 | | 2 | 3 | 2 | 2 | 3 | 3 | 3 | 4 | 5 | 4 | 5 | 3 | 5 |
| | 2 | 2 | 3 | 1 | 4 | | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 5 | 5 | 5 | 1 | 1 |
| | 4 | 5 | 3 | 4 | 4 | | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | 3 | 4 | 4 | 4 | 3 | | 1 | 2 | 2 | 3 | 2 | 3 | 2 | 4 | 2 | 3 | 3 | 3 | 2 |
| | 5 | 5 | 5 | 5 | 5 | | 2 | 4 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | 3 | 4 | 5 | 4 | 4 | | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 3 | 4 | 4 |
| | 4 | 4 | 3 | 4 | 4 | | 3 | 4 | 3 | 3 | 3 | 3 | 2 | 4 | 4 | 3 | 4 | 3 | 4 |
| | 3 | 3 | 4 | 4 | 3 | | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 5 | 4 | 5 | 1 | 3 |
| | 4 | 4 | 4 | 3 | 5 | | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 3 | 4 | 3 | 5 |
| | 4 | 3 | 3 | 3 | 4 | | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 2 | 4 | 4 | 4 | 3 | 5 |
| | **3.9** | **4.0** | **4.3** | **3.8** | **4.3** | | **3.5** | **3.4** | **2.9** | **3.1** | **3.0** | **3.1** | **2.6** | **3.5** | **3.7** | **3.6** | **3.5** | **2.8** | **3.6** |

| Are construction waste control strategies implemented in the works you are involved in | Yes | No | No information | Is there a construction waste strategy department in the company you work for? | Yes | No | No information | Are construction waste estimation programs used in the works you are involved in? | Yes | No | No information | If yes, please specify in which scale. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 0 | 0 | | 0 | 0 | 1 | | 0 | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 0 | 1 | | 0 | 0 | 1 | | 0 | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 0 | 1 | | 0 | 1 | 0 | | 0 | 0 | 1 | |
| | 0 | 0 | 1 | | 0 | 1 | 0 | | 0 | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 0 | 1 | | 0 | 0 | 1 | | 0 | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 0 | 1 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 1 | 0 | 0 | | 1 | 0 | 0 | | 1 | 0 | 0 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 1 | 0 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 0 | 1 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 1 | 0 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 1 | 0 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 1 | 0 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 1 | 0 | 0 | | 1 | 0 | 0 | | 1 | 0 | 0 | |
| | 1 | 0 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 1 | 0 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 1 | 0 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | |
| | **10** | **19** | **6** | | **2** | **30** | **3** | | **2** | **28** | **5** | |

| Are construction waste control strategies implemented in the works you are involved in | Yes | No | No information | Is there a construction waste strategy department in the company you work for? | Yes | No | No information | Are construction waste estimation programs used in the works you are involved in? | Yes | No | No information | If yes, please specify in which scale. | Local | International | Do you have any training on construction waste minimisation? | Yes | No | If yes, please indicate the duration and scope. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 0 | 0 | | 0 | 0 | 1 | | 0 | 0 | 1 | | 0 | 0 | | 1 | 0 | Training is provided on optimization and pro management and minimum material usa |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 0 | 1 | | 0 | 0 | 1 | | 0 | 0 | 1 | | 0 | 0 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 0 | 1 | | 0 | 1 | 0 | | 0 | 0 | 1 | | 0 | 0 | | 0 | 1 | |
| | 0 | 0 | 1 | | 0 | 1 | 0 | | 0 | 0 | 1 | | 0 | 0 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 0 | 1 | | 0 | 0 | 1 | | 0 | 0 | 1 | | 0 | 0 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 0 | 1 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 1 | 0 | 0 | | 1 | 0 | 0 | | 1 | 0 | 0 | | 0 | 1 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 1 | 0 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 0 | 1 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 1 | 0 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 1 | 0 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 1 | 0 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 1 | 0 | 0 | | 1 | 0 | 0 | | 1 | 0 | 0 | | 0 | 1 | | 0 | 1 | |
| | 1 | 0 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 1 | 0 | ISO 14001 10 Saat |
| | 1 | 0 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 1 | 0 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 1 | 0 | | 0 | 0 | | 0 | 1 | |
| | **10** | **19** | **6** | | **2** | **30** | **3** | | **2** | **28** | **5** | | **0** | **2** | | **2** | **33** | |

| Evaluate the impact of these strategies on reducing construction waste | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Strengthening relevant legislation and regulations | Increasing penal sanctions against excavation and waste | Requirement of a waste strategy department/consultant during the project process | Raising awareness and raising consciousness through education | Including construction waste management strategies in contracts | Setting recycling targets for each project phase | standardization of construction material size and quality | BIM supported project design and waste control | Adoption of up-to-date construction techniques | Adoption of prefabricated and off-site production | Use of waste forecasting tools and programs | Ensuring waste optimization at the design and planning stage | Accurate identification of customer requirements and demands | implementation of incentive reward programs among workers | Implement effective and frequent field inspections |
| 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 3 | 5 | 5 | 5 | 4 | 3 | 5 |
| 4 | 4 | 3 | 4 | 4 | 3 | 4 | 4 | 3 | 4 | 4 | 3 | 3 | 3 | 4 |
| 5 | 5 | 4 | 5 | 5 | 5 | 3 | 4 | 3 | 2 | 4 | 4 | 4 | 3 | 4 |
| 4 | 5 | 4 | 5 | 5 | 5 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 5 | 5 | 5 | 5 | 5 | 4 | 3 | 5 | 4 | 3 | 4 | 4 | 4 | 3 | 5 |
| 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 3 | 5 | 5 | 5 | 5 | 5 |
| 5 | 5 | 4 | 4 | 4 | 5 | 3 | 4 | 3 | 4 | 5 | 5 | 5 | 5 | 5 |
| 5 | 4 | 5 | 5 | 4 | 4 | 3 | 5 | 4 | 4 | 5 | 4 | 4 | 4 | 5 |
| 5 | 5 | 5 | 4 | 5 | 5 | 5 | 4 | 5 | 4 | 5 | 5 | 5 | 4 | 5 |
| 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 5 | 5 | 5 | 4 | 5 | 3 | 3 | 5 | 3 | 5 | 5 | 4 | 4 | 5 | 5 |
| 5 | 5 | 5 | 4 | 5 | 5 | 3 | 5 | 5 | 4 | 4 | 5 | 4 | 4 | 5 |
| 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 5 |
| 4 | 4 | 5 | 5 | 5 | 3 | 2 | 2 | 4 | 4 | 4 | 4 | 3 | 4 | 4 |
| 3 | 3 | 2 | 2 | 3 | 2 | 3 | 2 | 4 | 5 | 2 | 2 | 2 | 2 | 3 |
| 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 2 | 5 | 3 | 4 | 4 | 5 | 3 | 3 | 3 | 3 | 4 | 4 | 5 | 4 | 4 |
| 3 | 4 | 5 | 5 | 5 | 4 | 4 | 5 | 4 | 4 | 3 | 5 | 5 | 4 | 5 |
| 5 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 5 | 5 | 5 | 4 | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 4 | 5 | 3 | 5 |
| 4 | 3 | 5 | 5 | 5 | 4 | 5 | 5 | 2 | 5 | 4 | 5 | 5 | 3 | 4 |
| 3 | 5 | 3 | 5 | 5 | 4 | 5 | 3 | 4 | 3 | 3 | 5 | 5 | 3 | 5 |
| 5 | 5 | 5 | 4 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 3 | 4 | 2 | 5 | 3 | 2 | 5 | 4 | 4 | 4 | 1 | 3 | 3 | 2 | 5 |
| 4 | 5 | 4 | 4 | 5 | 5 | 3 | 3 | 3 | 3 | 3 | 5 | 2 | 5 | 5 |
| 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 4 | 4 | 2 | 3 |
| 5 | 5 | 3 | 3 | 4 | 4 | 5 | 2 | 2 | 4 | 2 | 4 | 3 | 3 | 3 |
| 4 | 5 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 4 | 5 | 3 | 4 |
| 4 | 4 | 4 | 5 | 4 | 4 | 1 | 2 | 2 | 4 | 3 | 4 | 5 | 4 | 2 |
| 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 4 | 3 | 4 | 4 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 5 |
| 5 | 4 | 4 | 4 | 4 | 4 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 5 | 5 | 3 | 4 | 4 | 4 | 5 | 3 | 3 | 3 | 3 | 5 | 5 | 4 | 4 |
| 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 5 | 5 | 5 | 4 | 5 | 3 | 4 | 5 | 3 | 3 | 2 | 3 | 3 | 2 | 5 |
| **4.4** | **4.5** | **4.2** | **4.4** | **4.6** | **4.3** | **3.9** | **4.1** | **3.9** | **4.1** | **4.0** | **4.4** | **4.3** | **3.9** | **4.5** |

| Evaluate the statements indicated. | Waste is an inevitable by-product of construction activities. | regulations and legislation on construction waste are not sufficient. | There is not enough experience and technological infrastructure for BIM supported project design an | Extra labor/working hours are required for successful waste segregation. | Uncertainty about the quality of recycled materials makes them not preferred. | The recycling sector is not mature enough to be widely used. | Waste forecasting tools and programs are not mature enough to be widely used. | There is insufficient information, data and experience in the sector to implement waste management s | Additional labor/time is required to implement and audit waste management strategies. | Use of prefabricated products increases construction time. | Prefabricated sector is not mature enough to be widely used. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 4 | 2 | 5 | 3 | 2 | 4 | 4 | 5 | 1 | 3 |
| | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 4 | 2 | 2 |
| | 4 | 4 | 5 | 4 | 3 | 4 | 2 | 4 | 4 | 2 | 4 |
| | 5 | 5 | 2 | 4 | 3 | 2 | 2 | 4 | 4 | 1 | 2 |
| | 4 | 5 | 4 | 3 | 4 | 2 | 3 | 4 | 4 | 3 | 3 |
| | 3 | 4 | 3 | 3 | 2 | 4 | 3 | 3 | 4 | 2 | 2 |
| | 3 | 5 | 5 | 3 | 1 | 2 | 3 | 5 | 2 | 1 | 1 |
| | 3 | 5 | 4 | 3 | 2 | 3 | 3 | 4 | 4 | 2 | 2 |
| | 3 | 5 | 4 | 5 | 4 | 4 | 4 | 5 | 5 | 2 | 3 |
| | 4 | 5 | 2 | 2 | 3 | 4 | 4 | 5 | 3 | 3 | 2 |
| | 3 | 5 | 3 | 5 | 4 | 3 | 3 | 3 | 4 | 2 | 3 |
| | 4 | 5 | 5 | 3 | 3 | 2 | 3 | 4 | 3 | 3 | 2 |
| | 2 | 5 | 4 | 5 | 2 | 2 | 2 | 4 | 4 | 2 | 2 |
| | 2 | 4 | 5 | 5 | 4 | 3 | 3 | 2 | 5 | 2 | 3 |
| | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 4 | 2 | 4 |
| | 1 | 5 | 5 | 5 | 5 | 1 | 1 | 5 | 5 | 3 | 3 |
| | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 3 |
| | 2 | 4 | 4 | 5 | 4 | 5 | 4 | 5 | 5 | 4 | 5 |
| | 2 | 4 | 4 | 3 | 4 | 4 | 4 | 3 | 4 | 2 | 4 |
| | 4 | 5 | 4 | 4 | 3 | 2 | 3 | 3 | 3 | 2 | 1 |
| | 1 | 4 | 3 | 5 | 3 | 2 | 4 | 5 | 5 | 1 | 1 |
| | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 |
| | 2 | 4 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 2 |
| | 5 | 4 | 1 | 2 | 2 | 2 | 4 | 5 | 4 | 2 | 2 |
| | 4 | 3 | 4 | 4 | 3 | 3 | 5 | 5 | 5 | 3 | 4 |
| | 4 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | 4 | 5 | 3 | 5 | 2 | 4 | 3 | 4 | 4 | 2 | 2 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | 3 | 4 | 3 | 5 | 4 | 5 | 3 | 5 | 5 | 1 | 2 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 3 | 3 | 3 |
| | 5 | 5 | 5 | 4 | 4 | 5 | 4 | 4 | 4 | 1 | 2 |
| | 3 | 5 | 3 | 2 | 3 | 4 | 4 | 4 | 3 | 4 | 4 |
| | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 1 | 4 |
| | 4 | 5 | 4 | 5 | 3 | 3 | 4 | 4 | 5 | 2 | 1 |
| | **3.4** | **4.4** | **3.7** | **3.9** | **3.3** | **3.3** | **3.5** | **4.1** | **4.0** | **2.3** | **2.7** |

| Evaluate the statements indicated. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Prefabricated sector is not mature enough to be widely used. | Neutral | Disagree | Agree | Disagree | Neutral | Disagree | Strongly Disagree | Disagree | Neutral | Disagree | Neutral | Disagree | Disagree | Neutral | Agree | Neutral | Neutral | Strongly Agree | Agree | Strongly Disagree | Strongly Disagree | Strongly Disagree | Disagree | Disagree | Agree | Agree | Disagree | Agree | Disagree | Agree | Neutral | Disagree | Agree | Agree | Strongly Disagree |
| Use of prefabricated products increases construction time. | Strongly Disagree | Disagree | Disagree | Strongly Disagree | Neutral | Disagree | Strongly Disagree | Disagree | Disagree | Neutral | Disagree | Neutral | Disagree | Disagree | Disagree | Neutral | Disagree | Agree | Disagree | Disagree | Strongly Disagree | Disagree | Disagree | Disagree | Neutral | Agree | Disagree | Agree | Strongly Disagree | Agree | Neutral | Strongly Disagree | Agree | Strongly Disagree | Disagree |
| Additional labor/time is required to implement and audit waste management strategies. | Strongly Agree | Agree | Agree | Agree | Agree | Agree | Disagree | Agree | Strongly Agree | Neutral | Agree | Neutral | Agree | Strongly Agree | Agree | Strongly Agree | Agree | Strongly Agree | Agree | Neutral | Strongly Agree | Disagree | Agree | Agree | Strongly Agree | Agree | Agree | Agree | Strongly Agree | Agree | Neutral | Agree | Neutral | Strongly Agree | Strongly Agree |
| There is insufficient information, data and experience in the sector to implement waste management strategies. | Agree | Agree | Agree | Agree | Agree | Neutral | Strongly Agree | Agree | Strongly Agree | Strongly Agree | Neutral | Agree | Agree | Disagree | Strongly Agree | Strongly Agree | Agree | Strongly Agree | Neutral | Neutral | Strongly Agree | Strongly Disagree | Agree | Strongly Agree | Strongly Agree | Agree | Agree | Agree | Strongly Agree | Agree | Agree | Agree | Agree | Strongly Agree | Agree |
| Waste forecasting tools and programs are not mature enough to be widely used. | Agree | Agree | Disagree | Disagree | Neutral | Neutral | Neutral | Neutral | Agree | Agree | Neutral | Neutral | Disagree | Neutral | Strongly Agree | Strongly Disagree | Agree | Agree | Agree | Neutral | Agree | Strongly Disagree | Agree | Agree | Strongly Agree | Agree | Neutral | Agree | Neutral | Agree | Agree | Agree | Agree | Strongly Agree | Agree |
| The recycling sector is not mature enough to be widely used. | Disagree | Disagree | Agree | Disagree | Disagree | Agree | Disagree | Neutral | Agree | Agree | Neutral | Disagree | Disagree | Neutral | Strongly Agree | Strongly Disagree | Agree | Strongly Agree | Agree | Disagree | Disagree | Strongly Disagree | Agree | Disagree | Neutral | Agree | Agree | Agree | Strongly Agree | Agree | Agree | Strongly Agree | Agree | Strongly Agree | Neutral |
| Uncertainty about the quality of recycled materials makes them not preferred. | Neutral | Agree | Neutral | Neutral | Agree | Disagree | Strongly Disagree | Disagree | Agree | Neutral | Agree | Neutral | Disagree | Agree | Agree | Strongly Agree | Agree | Agree | Agree | Neutral | Neutral | Strongly Disagree | Agree | Disagree | Neutral | Agree | Disagree | Agree | Agree | Agree | Neutral | Agree | Neutral | Strongly Agree | Neutral |
| Extra labor/working hours are required for successful waste segregation. | Strongly Agree | Agree | Agree | Agree | Neutral | Neutral | Neutral | Neutral | Strongly Agree | Disagree | Strongly Agree | Neutral | Strongly Agree | Strongly Agree | Agree | Strongly Agree | Agree | Strongly Agree | Neutral | Agree | Strongly Agree | Disagree | Agree | Disagree | Agree | Agree | Strongly Agree | Agree | Strongly Agree | Agree | Agree | Agree | Disagree | Strongly Agree | Strongly Agree |
| There is not enough experience and technological infrastructure for BIM supported project design and waste control. | Disagree | Agree | Strongly Agree | Disagree | Agree | Neutral | Strongly Agree | Agree | Agree | Disagree | Neutral | Strongly Agree | Agree | Strongly Agree | Strongly Agree | Strongly Agree | Agree | Agree | Agree | Agree | Neutral | Strongly Disagree | Strongly Agree | Strongly Disagree | Agree | Agree | Neutral | Agree | Neutral | Agree | Agree | Strongly Agree | Neutral | Strongly Agree | Agree |
| regulations and legislation on construction waste are not sufficient. | Agree | Agree | Agree | Strongly Agree | Strongly Agree | Agree | Strongly Agree | Strongly Agree | Strongly Agree | Strongly Agree | Strongly Agree | Strongly Agree | Strongly Agree | Agree | Strongly Agree | Strongly Agree | Agree | Agree | Agree | Strongly Agree | Agree | Strongly Disagree | Agree | Agree | Neutral | Strongly Agree | Strongly Agree | Agree | Agree | Agree | Agree | Strongly Agree | Strongly Agree | Strongly Agree | Strongly Agree |
| Waste is an inevitable by-product of construction activities. | Strongly Agree | Agree | Agree | Strongly Agree | Agree | Neutral | Neutral | Neutral | Neutral | Agree | Neutral | Agree | Disagree | Disagree | Strongly Agree | Strongly Disagree | Neutral | Disagree | Disagree | Agree | Strongly Disagree | Disagree | Disagree | Strongly Agree | Agree | Agree | Agree | Agree | Neutral | Agree | Agree | Strongly Agree | Neutral | Strongly Agree | Agree |

| Have you ever been involved in a project where construction automation and robotics technologies were applied? | | If yes, please indicate the duration and scope. | Have you attended a training, seminar or event related to construction automation or th of robotics? | | If yes, please indicate the duration and scope. | Would it be useful for you to take a training on construction automation or the use of robotics? | | Does the company you work for have plans to incorporate these technologies into its projects in the near future? | | | If yes, please specify in what kind of projects and for what purpose. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Yes | No | | Yes | No | | Yes | No | Yes | No | No information | |
| 1 | 0 | I have had the opportunity to work with field mapping tools and modular construction techniques quite frequently in the companies I work for and in our own business. | 1 | 0 | I took part in many seminars and trainings on modular construction systems and modern construction processes. gave training on the production and optimization of build elements within the BIM process. | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 1 | 0 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 1 | 0 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 1 | 0 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 1 | 0 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 1 | 0 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 1 | 0 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 1 | 0 | |
| 0 | 1 | | 0 | 1 | | 0 | 1 | 0 | 1 | 0 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 1 | 0 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 1 | 0 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 1 | 0 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 1 | 0 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 1 | 0 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 1 | 0 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 1 | 0 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 0 | 1 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 0 | 1 | 0 | 1 | 0 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 0 | 1 | |
| 0 | 1 | | 0 | 1 | | 1 | 0 | 0 | 0 | 1 | |
| **1** | **34** | | **1** | **34** | | **32** | **3** | **0** | **16** | **19** | |

| Please mark the following information technologies that you know used in the construction sector. | GIS (Geographic Information Systems) | GPS (Global positioning system) | RFID (Radio frequency identification ) | RTLS (Real Time Location System) | LIDAR (Light Detection and Ranging) | 3DP (3D Printing ) | BIM (Building Information Modelling) | Point Cloud | CAM (Computer-Aided Manufacturing) | CIM (Computer-Integrated Manufacturing) | AI (Artificial Intelligence ) | AR (Augmented Realitiy) | Digital Twin | VR (Virtual Realitiy) | Additive Manufacturing | UAS (Unmanned Aerial systems) | 3D Laser Scanner |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 |
| | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 |
| | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 |
| | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 |
| | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 |
| | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 |
| | **23** | **21** | **6** | **4** | **14** | **19** | **31** | **14** | **21** | **5** | **12** | **10** | **2** | **19** | **7** | **2** | **17** |

| Evaluate the availability of construction automation and robotics technologies in Turke the specified work groups. | Site preparation | Reinforced concrete works | Mechanical equipment installation | Mechanical installation | Electrical equipment installation | Electrical installation | Prefabricated element installation | Facade works | Wall / partition wall installation | Floor installation | Ceiling installation | Glazing installation | Control and inspection |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 5 | 3 | 3 | 3 | 3 | 5 | 5 | 4 | 3 | 2 | 2 | 5 |
| | 4 | 4 | 3 | 3 | 3 | 3 | 4 | 4 | 3 | 4 | 4 | 3 | 4 |
| | 3 | 4 | 3 | 3 | 3 | 3 | 4 | 2 | 2 | 2 | 2 | 2 | 3 |
| | 4 | 5 | 3 | 3 | 3 | 3 | 5 | 3 | 4 | 4 | 4 | 3 | 5 |
| | 5 | 5 | 3 | 4 | 3 | 4 | 3 | 4 | 4 | 4 | 5 | 3 | 4 |
| | 5 | 5 | 3 | 3 | 3 | 3 | 5 | 3 | 5 | 5 | 3 | 3 | 3 |
| | 3 | 5 | 3 | 3 | 3 | 3 | 5 | 5 | 3 | 3 | 3 | 5 | 3 |
| | 4 | 5 | 3 | 4 | 3 | 4 | 3 | 3 | 3 | 4 | 4 | 3 | 4 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 4 | 5 | 4 | 4 | 3 |
| | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 2 |
| | 3 | 2 | 1 | 1 | 1 | 1 | 3 | 4 | 4 | 3 | 4 | 3 | 3 |
| | 4 | 5 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 4 | 4 | 3 |
| | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 3 | 4 |
| | 3 | 3 | 3 | 2 | 2 | 2 | 4 | 4 | 4 | 3 | 3 | 3 | 3 |
| | 2 | 2 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 3 | 3 | 3 | 3 |
| | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 2 |
| | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | 5 | 5 | 4 | 5 | 4 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 3 |
| | 4 | 1 | 1 | 1 | 1 | 1 | 4 | 1 | 4 | 3 | 3 | 1 | 4 |
| | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 4 | 2 | 2 | 2 | 2 | 2 | 4 | 2 | 2 | 4 | 2 | 2 | 4 |
| | 2 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 2 | 1 | 1 | 1 | 3 |
| | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 3 | 1 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 4 | 4 | 5 |
| | 2 | 2 | 3 | 3 | 2 | 3 | 2 | 4 | 4 | 3 | 4 | 4 | 2 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | 3 | 3 | 4 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 4 |
| | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | 3 | 1 | 1 | 1 | 1 | 1 | 5 | 5 | 1 | 1 | 1 | 5 | 1 |
| | 3 | 1 | 3 | 3 | 3 | 3 | 5 | 3 | 3 | 2 | 2 | 2 | 4 |
| | 2 | 1 | 2 | 1 | 2 | 1 | 3 | 3 | 3 | 3 | 3 | 2 | 4 |
| | **3.3** | **2.9** | **2.7** | **2.7** | **2.6** | **2.7** | **3.4** | **3.2** | **3.1** | **3.1** | **2.9** | **2.8** | **3.2** |

| Evaluate the possible advantages of construction automation and robotics technologies. | Improves the quality, accuracy and precision of products/works | Reduces the need for qualified labor force | Shortens project duration | Improves cost efficiency | increases work efficiency | reduces the environmental impact of construction works (such as water, air, noise pollution) | reduces construction accidents and injuries | Reduces waste of raw materials and ingredients | Supports recycling | improves work safety and well-being | Increases customer and end-user satisfaction | Strengthens company reputation | Increases sector attractiveness |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 2 | 2 | 2 | 4 | 4 | 4 | 4 | 2 | 5 | 4 | 4 | 5 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 |
| | 3 | 4 | 3 | 3 | 4 | 3 | 4 | 4 | 3 | 2 | 3 | 3 | 2 |
| | 5 | 4 | 2 | 3 | 3 | 4 | 5 | 5 | 5 | 5 | 3 | 5 | 5 |
| | 4 | 4 | 4 | 5 | 5 | 4 | 5 | 5 | 4 | 5 | 4 | 5 | 5 |
| | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 |
| | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 |
| | 4 | 4 | 4 | 3 | 5 | 3 | 5 | 5 | 5 | 4 | 4 | 4 | 5 |
| | 5 | 5 | 4 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | 5 | 5 | 4 | 5 | 5 | 4 | 5 | 4 | 4 | 4 | 5 | 5 | 5 |
| | 5 | 3 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | 4 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 3 | 5 | 4 | 4 | 5 |
| | 4 | 3 | 4 | 4 | 4 | 5 | 4 | 5 | 4 | 4 | 4 | 4 | 4 |
| | 4 | 2 | 3 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 3 | 4 |
| | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 3 | 5 | 5 | 5 | 5 | 5 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | 4 | 3 | 4 | 4 | 4 | 4 | 2 | 3 | 3 | 3 | 3 | 4 | 3 |
| | 4 | 4 | 2 | 4 | 2 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 5 | 4 | 4 | 4 | 4 |
| | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 4 | 5 | 4 | 5 | 5 |
| | 4 | 1 | 1 | 3 | 5 | 4 | 4 | 4 | 5 | 3 | 5 | 5 | 5 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 3 | 3 | 4 | 3 |
| | 4 | 2 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 3 |
| | 5 | 2 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 3 |
| | 4 | 4 | 4 | 3 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 4 |
| | 5 | 5 | 3 | 4 | 4 | 3 | 3 | 4 | 4 | 3 | 5 | 5 | 3 |
| | 4 | 4 | 5 | 4 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 |
| | 4 | 2 | 3 | 4 | 4 | 2 | 1 | 2 | 3 | 2 | 3 | 2 | 2 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | 4 | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | 1 | 1 | 1 | 3 | 3 | 3 | 4 | 4 | 3 | 3 | 1 | 5 | 5 |
| | 5 | 4 | 1 | 3 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | 4 | 2 | 3 | 3 | 4 | 5 | 5 | 4 | 3 | 5 | 4 | 5 | 5 |
| **Avarag** | **4.2** | **3.5** | **3.5** | **3.9** | **4.2** | **4.1** | **4.2** | **4.3** | **4.1** | **4.1** | **4.0** | **4.3** | **4.1** |

| Evaluate the possible advantages of construction automation and robotics technologies. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Increases sector attractiveness | Strongly Agree | Agree | Disagree | Strongly Agree | Strongly Agree | Strongly Agree | Neutral | Strongly Agree | Strongly Agree | Strongly Agree | Strongly Agree | Strongly Agree | Agree | Agree | Strongly Agree | Agree | Neutral | Strongly Agree | Agree | Strongly Agree | Strongly Agree | Neutral | Neutral | Disagree | Neutral | Agree | Neutral | Agree | Disagree | Agree | Agree | Agree | Strongly Agree | Strongly Agree | Strongly Agree |
| Strengthens company reputation | Agree | Agree | Neutral | Strongly Agree | Strongly Agree | Agree | Agree | Agree | Strongly Agree | Strongly Agree | Strongly Agree | Agree | Agree | Neutral | Strongly Agree | Agree | Agree | Strongly Agree | Agree | Strongly Agree | Strongly Agree | Agree | Agree | Agree | Strongly Agree | Strongly Agree | Strongly Agree | Agree | Disagree | Agree | Agree | Agree | Strongly Agree | Strongly Agree | Strongly Agree |
| Increases customer and end-user satisfaction | Agree | Agree | Neutral | Neutral | Agree | Strongly Agree | Agree | Agree | Strongly Agree | Strongly Agree | Strongly Agree | Agree | Agree | Agree | Strongly Agree | Agree | Neutral | Strongly Agree | Agree | Agree | Strongly Agree | Neutral | Neutral | Agree | Agree | Strongly Agree | Strongly Agree | Agree | Neutral | Agree | Agree | Agree | Strongly Disagree | Strongly Agree | Agree |
| improves work safety and well-being | Strongly Agree | Agree | Disagree | Strongly Agree | Strongly Agree | Strongly Agree | Agree | Agree | Strongly Agree | Agree | Strongly Agree | Strongly Agree | Agree | Agree | Strongly Agree | Agree | Neutral | Strongly Agree | Agree | Strongly Agree | Neutral | Neutral | Agree | Agree | Agree | Strongly Agree | Neutral | Agree | Disagree | Agree | Agree | Agree | Neutral | Strongly Agree | Strongly Agree |
| Supports recycling | Disagree | Neutral | Neutral | Strongly Agree | Agree | Strongly Agree | Agree | Strongly Agree | Strongly Agree | Agree | Strongly Agree | Neutral | Agree | Agree | Strongly Agree | Agree | Neutral | Strongly Agree | Strongly Agree | Agree | Strongly Agree | Agree | Agree | Agree | Agree | Strongly Agree | Agree | Agree | Neutral | Agree | Agree | Agree | Neutral | Strongly Agree | Neutral |
| Reduces waste of raw materials and ingredients | Agree | Agree | Agree | Strongly Agree | Strongly Agree | Strongly Agree | Agree | Strongly Agree | Strongly Agree | Agree | Strongly Agree | Strongly Agree | Strongly Agree | Agree | Neutral | Agree | Neutral | Strongly Agree | Agree | Strongly Agree | Agree | Agree | Agree | Agree | Agree | Strongly Agree | Agree | Strongly Agree | Disagree | Agree | Agree | Agree | Agree | Strongly Agree | Agree |
| reduces construction accidents and injuries | Agree | Agree | Agree | Strongly Agree | Strongly Agree | Strongly Agree | Agree | Strongly Agree | Strongly Agree | Strongly Agree | Strongly Agree | Strongly Agree | Agree | Neutral | Strongly Agree | Agree | Disagree | Strongly Agree | Neutral | Strongly Agree | Agree | Neutral | Agree | Agree | Agree | Strongly Agree | Neutral | Strongly Agree | Strongly Disagree | Agree | Agree | Agree | Agree | Strongly Agree | Strongly Agree |
| reduces the environmental impact of construction works (such as water, air, noise pollution) | Agree | Agree | Neutral | Agree | Agree | Strongly Agree | Agree | Neutral | Strongly Agree | Agree | Strongly Agree | Agree | Strongly Agree | Agree | Strongly Agree | Agree | Agree | Strongly Agree | Agree | Strongly Agree | Agree | Agree | Agree | Agree | Agree | Agree | Neutral | Strongly Agree | Disagree | Agree | Agree | Agree | Neutral | Strongly Agree | Strongly Agree |
| increases work efficiency | Agree | Agree | Agree | Neutral | Strongly Agree | Strongly Agree | Agree | Strongly Agree | Strongly Agree | Strongly Agree | Strongly Agree | Strongly Agree | Agree | Agree | Strongly Agree | Agree | Agree | Disagree | Agree | Strongly Agree | Strongly Agree | Agree | Agree | Strongly Agree | Agree | Agree | Agree | Strongly Agree | Agree | Agree | Agree | Agree | Neutral | Neutral | Agree |
| Improves cost efficiency | Disagree | Agree | Neutral | Neutral | Strongly Agree | Strongly Agree | Agree | Neutral | Neutral | Strongly Agree | Strongly Agree | Strongly Agree | Agree | Agree | Strongly Agree | Agree | Agree | Agree | Agree | Agree | Neutral | Agree | Neutral | Strongly Agree | Agree | Neutral | Agree | Agree | Agree | Agree | Agree | Agree | Neutral | Neutral | Neutral |
| Shortens project duration | Disagree | Agree | Neutral | Disagree | Agree | Agree | Agree | Agree | Agree | Agree | Neutral | Strongly Agree | Agree | Neutral | Strongly Agree | Agree | Agree | Disagree | Agree | Strongly Agree | Strongly Disagree | Agree | Neutral | Strongly Agree | Agree | Agree | Neutral | Strongly Agree | Neutral | Agree | Agree | Agree | Strongly Disagree | Strongly Disagree | Neutral |
| Reduces the need for qualified labor force | Disagree | Agree | Agree | Agree | Agree | Strongly Agree | Neutral | Agree | Strongly Agree | Strongly Agree | Neutral | Strongly Agree | Neutral | Disagree | Agree | Agree | Neutral | Agree | Agree | Strongly Agree | Strongly Disagree | Agree | Disagree | Disagree | Agree | Agree | Strongly Agree | Agree | Disagree | Agree | Disagree | Agree | Strongly Disagree | Agree | Disagree |
| Improves the quality, accuracy and precision of products/works | Strongly Agree | Agree | Neutral | Strongly Agree | Agree | Strongly Agree | Agree | Agree | Strongly Agree | Strongly Agree | Strongly Agree | Agree | Agree | Agree | Agree | Agree | Agree | Agree | Agree | Strongly Agree | Agree | Agree | Agree | Strongly Agree | Agree | Agree | Strongly Agree | Agree | Agree | Agree | Agree | Agree | Strongly Disagree | Strongly Agree | Agree |