An insight of the Industry 4.0 adoption in the Dutch construction and development industry

Exploratory research into barriers that are withholding adopting I4.0 and potential interventions to overcome them

Douwe Cees Schoemaker

"You cannot wait until a house burns down to buy fire insurance on it. We cannot wait until there are massive dislocations in our society to prepare for the Fourth Industrial Revolution."

Robert J. Shiller,
2013 Nobel laureate in economics,
Professor of Economics,
Yale University

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by

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Preface

In front is my master thesis giving insights into adopting Industry 4.0 technologies (e.g. Artificial Intelligence, Internet of Things and Digital Twins) in the Dutch Construction and Development Industry. There was a multitude of reasons why I chose this direction resulting in this topic. Firstly, my growing interest in real estate and especially in real estate development. During my studies at the Technical University of Delft, I had several internships and assignments within this field. As a result, I got most of my inspiration and joy from the early stages of real estate projects, especially from the development phases.

Second, my interest in smart innovations and thus complex technologies. These technologies are developing rapidly and have the potential, for example, to solve climate problems or create a better living environment. However, I had the impression that rapidly developing technologies with potential benefits and the actual adoption of innovative technologies is lacking. I, therefore, believe that we need to innovate the traditional building sector proactively. Especially now, as our environment finds itself in a vulnerable state. The real estate sector is making a significant contribution to this problem and therefore, I want to unite my interests to this topic.

The result of this thesis could not be achieved without the help of others. First, I would like to take this opportunity to thank my mentors Tom Daamen and Paul Chain. They have been inspiring me with critical and motivational feedback throughout the process. Secondly, I would like to thank all the survey, interview, and focus group participants who gained the data needed to write this thesis. The interviews, survey and focus group have given me new insight into this topic.

Douwe Cees Schoemaker

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Executive summary

Introduction

Today the giants of the digital industry deal in data. The estimated amount of data on the internet is heavingly increasing and this pace will only accelerate more as construction technologies advance (World Economic Forum, High Scalability). The digital revolution pushes forward all aspects of life at an ever-faster pace (Allen & Shakanta, 2016). Some defining trends will influence it for the following decades, such as urbanization, the housing shortage in the Netherlands, COVID-19 and sustainability.

As 55% of the world's population lives in urban areas today, a proportion is expected to increase to 68% by 2050 (UN DESA, 2018). Moreover, roughly 75% of global economic activity is urban, and as the urban population grows, so will the urban share of global GDP and investments. Therefore cities will change and urban development needs to speed up.

The supply of sufficient housing is currently one of the most significant problems in the Dutch housing market. From 2013 onwards, there was a sharp decline in the number of new buildings realized. By 2030, only the Netherlands needs an extra 1 million dwellings and by 2050, 2 million dwellings (Servaas van der Laan, 2020). Building many homes in a short period is essential! However, the current requirements for new construction, such as sustainability, do not make it any easier.

COVID-19 makes the role of the digital revolution even more critical. It seems that organizations utilizing digital solutions were better positioned than their competitors during the crisis. Top of mind of many companies when thinking of restoring operations and building the company to deal with future crises as COVID-19 is using digital technologies (Mc Kinsey, 2020). Digital technologies have a high potential to impact economic development positively and contribute to the sustainable development of cities of developing countries and emerging economies (B. Müller & P. Schiappacasse, 2015). The necessity for sustainable solutions is a global phenomenon that can no longer be ignored, especially in real estate. For example, the built environment generates 40% of the global energy consumption. Besides, it generates around 30% of the global CO2 emissions (JLL, 2020). Therefore the real estate industry must become more sustainable (van Driel & van Zuijlen, 2016). Annemarie van Doorn, director of DGBC (Dutch Green Building Council), states that the transition to a more sustainable built environment cannot wait any longer (Vastgoed Journaal, 2020).

The emerging digital revolution could play an essential role in the above trends. Innovative Industry 4.0 (I4.0) technologies are being developed more and more and there is talk of a fourth revolution or Industry 4.0. This research relies on the following understanding of Industry 4.0: After mechanization, mass production and the rise of computer technology and automation, the fourth industrial revolution has started as automated systems are connected, exchange data and eventually operate autonomously

through their analytical and self-learning capabilities.

The construction and development industry is one of the sectors lagging in modern industrial digital tools (J. Maier,2017). As a result, I4.0 is still far from being used to its full potential in the construction and development industry. Compared to other industries, such as business services, manufacturing, finance, transport, and utilities, the construction and development industry still lags in investing in I4.0 technologies (Underwood and Isikdag, 2011).

The construction sector seems to lag as there are still many barriers. It will continue to grow as long as there is (s)low adoption of technology and a lack of innovative processes in construction (Zabidin et al., 2020). It seems some barriers ensure the growing gap between Industry 4.0 and the construction and development industry. It turns out that despite the significant and plethora of advantages offered by Industry 4.0 for enhancing the construction and development industry's performance (Bebelaar et al., 2018; Ghosh et al., 2020), a review of extant literature demonstrates conspicuous deficiencies with the existing research undertaken. Furthermore, it seems there is a notable disconnect between academic endeavours and industry practice (Maskuriy et al., 2019). Therefore, the problem statement for this research is as follows:

There seems to be a mismatch between the enormous potential I4.0 technologies have and the extent adopted within the construction and development industry. According to the literature, the growing interest in I4.0 and its potential advantages are not stimulating companies to adopt.

Research questions & Methodology

The main research question that is answered in this research is: "Are barriers withholding adopting Industry 4.0 (I4.0) technologies (e.g. artificial intelligence (AI), internet of things (IoT) and Digital Twins (DT)) within the Dutch construction and development industry, and if so, can these barriers be overcome?" In order to answer this question a series of sub-questions are adopted. These sub-questions are stated as follows:

1. What are the main adopted I4.0 technologies in the Dutch CDI?
2. Is there a malfunctioning adoption of I4.0 in the Dutch CDI?
3. What are the barriers that are withholding Dutch organizations from adopting I4.0 in the CDI?
4. What are the main drivers of organizations to adopt I4.0 in the Dutch CDI?
5. What stakeholders work in the Design Engineering phase with I4.0 in the Dutch CDI?

In order to structure the report and answer the sub questions four different phases have been adopted. In phase one, the first impressions from the literature regarding the topic are explained and the main concepts of the main research question are explained based on the literature. Phase two delves further into the Industry 4.0 literature regarding the CDI. The most widely adopted and discussed I4.0 technologies in the CDI literature are introduced. In addition, the main barriers and advantages

achieved with the respective technologies are examined. It concludes with the first conclusions on the generic research questions formulated before the literature review. Subsequently,more specific research questions are drawn for the further phases of the research. Phase three explains the results of the survey and interviews. Based on these results, conclusions are made that will be put up for discussion during the focus group in phase four. The final phase consists of the conclusions, discussion, recommendations, reflection, and appendices.

In the first two phases, a literature review is conducted. The data collected in the literature study yielded standardised information about research topics. To do this effectively, a narrative literature review was conducted. The literature review resulted in a better understanding of the topics. As a result, a 'narrative review' of the literature is more suitable than a systematic review for this type of research (Bryman, 2016, p. 110). That is why a narrative literature review is conducted in this research. By this, a large amount of helpful information was found in a short period. In addition to the literature study, a survey, interviews and a focus group were used in the following phases. Many data was collected because 43 respondents completed the survey. In addition, more depth could be added to the research during the interviews and focus group. This will also come to the fore in the phases mentioned below.

Phase one: First impressions and literature

In phase one, through literature review and exploratory interviews, the first impressions of the literature were drawn and the first interviews resulted in the first understanding of I4.0. In addition, the thoughts from others helped to formulate the first understandings of what barriers are withholding CDI stakeholders from adopting I4.0, currently used I4.0 technologies and the advantages.

Phase two: Understanding I4.0 in CDI

For understanding I4.0 in the CDI more extensive literature is needed. So a good understanding of the advantages, barriers and main adopted I4.0 technologies. From these findings, a distinction is made of the most common barriers, advantages and technologies. These are used for the survey and to make the research more specific.

I4.0 technologies

A selection of the most common I4.0 technologies in the CDI is made. The literature review shows that there are many different technologies applied within the CDI. Therefore, to delineate the research which is essential, several I4.0 technologies are selected that are now understood to be increasingly used. Below is a selection of nine technologies that will explain the characteristics and functionality. In addition, consideration was made whether the technologies in the DE phase are applicable or can be applied. The following I4.0 technologies are included in the research:

- Augmented reality (AR)
- Blockchain
- Geographic information system (GIS)
- Artificial intelligence (AI)

- Sensors
- Internet of Things (IoT)
- Simulation/Digital twin (DT)
- Autonomous robots
- Big data & analytics

Barriers

A more extensive literature review has led to twelve common barriers for adopting I4.0 in the construction and development industry. These barriers are explained and are included in the survey. The twelve common barriers for adopting I4.0 conducted from literature are the following:

- Challenge in value-chain integration
- Challenges in ensuring data quality
- Disruption to existing jobs)
- High investment
- Labour market inequality
- Lack of digital strategy alongside resource scarcity
- Lack of clarity regarding economic benefit
- Lack of digital skills
- Lack of infrastructure
- Lack of internal digital culture and training
- Resistance to change
- Risk of security breaches

Advantages

Industry 4.0 was initially aimed at boosting revenue growth, productivity and competitiveness. However, it is also increasingly being used for environmental and sustainable solutions (Bonilla et al., 2018). The following benefits are the result of the literature review and will be considered in further research:

- Improved product quality
- Production processes are improved
- Positive feedback from customers
- Energy efficiency
- Increase of company image
- Competitiveness
- Increased of efficiency
- Increase communication in the organization
- Increasing decision making

Adoption

The growth of the construction industry increased the demand for digital technologies. I4.0 technologies in the construction industry have increased in recent years. This is primarily due to the immense potential of I4.0 for improving the performance of construction projects and structuring their underlying management processes. However, most organizations are still in the early stages of preparations for I4.0. Thus, while there is a growing interest, the barriers are still withholding organizations to adopt I4.0 technologies. Often small and medium enterprises (SMEs) are challenged financially or with liquidity which may delay adoption until they can build the foundations or find the required financial muscle to invest. Further research will have to show whether this is also one of the more significant barriers within the Dutch construction sector and what can be done about it. Conclusions will also have to be drawn as to whether the adoption in the construction and development industry is still (s)low in the Netherlands. However,the use and interest of innovative technologies is increasing and enables digitization, automation, and integration of the construction processes at all phases of the construction and development value chain (Oesterreich and Teuteberg, 2016). As a result, I4.0 technologies have impacted the construction sector since 2009 and might change the construction and development industry with a significant impact (Barreto et al., 2017; Li and Yang, 2017; Trompisch, 2017; Wagner et al., 2017). It is essential to look at the adoption in the development phases as the D&E phase of the construction and development industry in the Netherlands, as there is still little attention for this in the literature.

Phase three: I4.0 adoption Dutch CDI

After gaining the first impressions of the construction and development industry in general, this phase aims to obtain a deeper understanding of the Dutch construction and development industry concerning the adoption of I4.0. The current 4.0 adoption in the Dutch market is analysed through surveys to parties involved in Dutch C&DI. Through this survey, a more in-depth analysis could be made about the barriers and drivers of I4.0. After analyzing the survey about the I4.0 adoption in general, the research focuses into the D&E phase by conducting several interviews.

Survey

Sensors and Big data & analytics are adopted the most among the proposed technologies. Autonomous robots and Blockchain are still the least adopted in the Dutch C&DI industry. Looking only at the respondents who are also active in the D&E phase, it appears that Sensors and Big data & analytics are still adopted the most. Autonomous robots and Blockchain are still the least adopted. However, the adoption of Autonomous robots of all respondents compared to the D&E phase active respondents is increased by 87%. Blockchain is less adopted in the D&E phase, dropping by 7%. The average adoption of all technologies is 39% among all respondents. Looking only at the respondents who are active in the D&E phase, the average adoption rises to 49%. The respondents added no technologies and concluded that no common used technologies are missing. What is evident from the results is that few companies are already actually seeing or utilizing the benefits when using the technologies.

It could be concluded that more than three quarters think that the mentioned I4.0 technologies will

have a significant impact in the coming years on the C&DI industry and they have the adoption on the agenda for the coming years if not already there. So it seems that there is still considerable growth in the adoption of the technologies ahead. To speak of a malfunctioning adoption is not to say.

The most significant barriers to adopting I4.0 technologies in the Dutch C&DI are the lack of clarity on economic benefit, the challenge in the value chain integration, lack of digital culture and training and high investments. These are considered the most prominent barriers when analyzing all respondents and when analyzing the D&E active respondents. Labour market inequality and the disruption of existing jobs do not seem to be barriers withholding companies to adopt I4.0 technologies.

The two main drivers for adopting I4.0 technologies in the Dutch C&DI are the increase of efficiency and creating new value for greater competitiveness. The respondents active in the D&E phase score the drivers respectively higher.

The stakeholders that participated in the survey and are active in the D&E phase with I4.0 technologies are the following: consultancies, ICT providers, investors and project developers. The municipality, for example, is active in the D&E phase but not yet active with I4.0 technologies.

Interviews

The most significant barriers that emerged from the interviews next to the survey results are the scaling-up problem in the Netherlands, the municipal processes and policies and the cooperation between stakeholders in the entire chain. Many fingers point towards the public parties that everyone within the C&DI could benefit from this, including themselves, if they would approach some things differently. The lack of economic benefit needs to be better elaborated and made transparent by the ICT providers to adopt I4.0 technologies faster. The ICT providers themselves also confirm this problem, that the proof of value needs to be worked out well. However, the ICT providers expect their customers, such as project developers, to develop more expertise and are more open to innovations. This still seems to be a big problem from the interviews, but it is being worked on. That the Netherlands is progressive in adopting I4.0 technologies was also confirmed in all interviews, but the progressive is not continued when scaling up is needed. This often creates the impression that, for example, an alderman is working innovatively but does not experience the ultimate impact and potential benefits of the innovations. This problem occurs more often in the smaller municipalities than in the larger ones where more support, attention and money are spent.

Furthermore, the processes of the projects are complex because there are many stakeholders involved and they do not work together in a multidisciplinary way, mainly at the public parties. Implementing something within the policy is not easy and fast because there are so many links between them that it takes a long time to change the policy. Where are the problems here and where are there opportunities to address this? Working together and transparently and building trust is also a barrier within current projects. Let alone when complex I4.0 technologies are involved, they are currently often too complex for many to see the economic benefit, let alone that they have to delve into the underlying technologies.

Phase four: Insights and potential interventions for adopting I4.0 in the Dutch CDI

In phase four, several propositions were formulated based on the survey and the interviews conducted. First, the propositions are presented to stakeholders in the CDI, especially from public bodies. These include the most significant barriers and are addressed within the focus group. Furthermore, there will focus on what to do to overcome these. Direct results are presented to see how the focus group responds.

Focus group

The focus group confirmed that ICT providers are still often unable to make the direct economic benefit concrete. There is often too much attention to the underlying running I4.0 technologies and how they work. It is much more important to make clear why the underlying I4.0 technologies are running. When it does not provide immediate benefits, the customers of ICT providers are often sceptical. Social responsibility is not yet a primary motivation and therefore, aspects such as security or cost reduction should yield immediate benefits. On the other hand, the digital knowledge gap is high in the C&DI.

The C&DI is also not an easy industry as more strict restrictions are imposed on sustainability, safety and circularity. For developing I4.0 technologies, these strict rules often hold back developments, while these technologies can gain a lot after further developments in these areas. Furthermore, adopting I4.0 technologies is still complex, but the training and after-care of I4.0 technologies are experienced as inadequate. However, the ICT providers think that this also has to do with the closed mindset against changing now and the little knowledge in the field of innovation. Besides the economic advantage, which is confirmed as a significant barrier, the government processes and policies are often cited.

It is suggested from the focus group that the Netherlands is not so progressive at all and that it just depends on whom you compare the Netherlands too. That the processes and changing policies in a municipality appears to be very slow is confirmed in the focus group. This has to do with the structure and responsibilities in the municipalities. It is said that the organization is too big and incoherent. At the same time, it is also said that the government should become more extensive and more commercial to make faster steps considering innovations. More employees at the municipalities also mean more knowledge which is essential to innovate. In the Netherlands, the adoption of I4.0 technologies by the municipality must first be put out to tender and then assessed by the Municipal Council. The Council will then have to approve it and release the budget. When these steps are completed, the I4.0 technology should be adopted and used optimally. This may take years with many uncertainties. There are democratic council elections at least every four years that can also lead to new aldermen with new plans and visions. Furthermore, the I4.0 technologies are innovating rapidly, so the Netherlands will only lag more by waiting. In addition, the fact that governments are full of people with no knowledge of technologies and are open for innovations makes it challenging to create support for complex technologies that, in the civil servant's eyes, will only result in them cutting their fingers. They also point to the municipalities as the client with the wrong mindset and attitude. Tenders are often won by the cheapest bidder, leaving the developers and builders to bear the risks. This also prevents parties from innovating. Innovating means investing.

Within the C&DI in the Netherlands, there are many different officials from the municipality involved in a project. For example, many different specialists are involved (e.g. a water specialist, a green specialist and a safety specialist). All these specialists have their interests and do not work in a multi-disciplinary way, resulting in poor coordination and delays within the process. On the other hand, the project developer only submits safety documents during the FD (final design). Because of this, civil servants sometimes have to make a final decision immediately while they see the document for the first time. Suppose project developers give the specialists insight at an earlier stage or submit various documents earlier, for example, in the PD (preliminary design). In that case, this could reduce the delays that the projects sometimes incur.

The focus group also revealed that innovation initiatives could not simply be submitted directly to The Council. This would mean that the entire structure within the organization would have to change and this is not possible in the short term. Scandinavia has mentioned as an example that municipalities are larger and more commercial organizations where lower bodies are allowed to make decisions and are offered more financial resources. This results in better adoption of I4.0 technologies and fewer delays during projects.

A simplified pathway during projects in the C&DI could undoubtedly contribute to growth in innovations. At the moment, everything is set up in a fixed trajectory in which many steps have to be gone through, such as a schematic design, preliminary design and a final design. All have to be approved before there is the possibility of a permit being granted. Only then can demolition or construction begin. Many documents during the design phases are not delivered until the final design, which means that civil servants have not seen the pieces before and must immediately give final approval. When there is a lack of clarity in the documents, they are often rejected. This often causes many delays.

Involving various parties earlier in the process could therefore eliminate delays such as these. However, involving parties at earlier stages can also cause delays because parties get involved and often do not speak the same 'language', which takes time. This has to do with different starting points or interests. For example, a project developer aims for maximum profit as his primary objective and a contractor aims for high-quality service. The difference in language also has to do with specializing in different fields. For example, a BIM model from an installation consultant is different from a BIM from an architect. Giving each other insight earlier and explaining how each other's work fit together could help a lot. There must also be the will to understand each other but also to innovate. Finally, there must be active participation to make a move to innovate more. It is referred to that the participation of governments is essential to innovate. Participation is innovation in a nutshell.

Trusting each other to exchange data does not seem to be the most significant task. Nevertheless, understanding each other's data and dealing with it correctly is not easy because there is little uniformity. Applying technological innovations, therefore, requires social innovation and system change. Because that is what is needed to get further than just the 'one pilot where innovation is applied as often happens in municipalities. Many changes will have to be made in order to get going.

Conclusions

This research aims to provide an answer to the main research question: "Are barriers withholding adopting Industry 4.0 (I4.0) technologies (e.g. AI, IoT and Digital Twins) within the Dutch construction and development industry, and can these barriers be overcome?"

The focus was on the specific barriers in the Dutch construction and development industry with the focus on the D&E phase. In the research, many different barriers emerge. The barriers differ per stakeholder and the extent to which they experience the barrier or not. The literature review introduced several barriers to withholding adopting I4.0 technologies. These were included in the interviews. The interviews mainly confirmed the most striking barriers from the survey and added some significant ones. The research's propositions in the focus group result consist of seven significant barriers that are considered withholding the Dutch construction and development industry. Almost nobody denies that the I4.0 technologies will change the Dutch C&DI. However, adoption is still (s)low while it has the potential to contribute positively to the companies adopting I4.0 technologies is also can contribute to the previously mentioned trends in the introduction. An increase in adopting I4.0 technologies in the D&E phase can contribute positively to the increase in urbanization to make this run more smoothly. Furthermore, the I4.0 technologies can contribute to a reduction in work and accelerate the creation of a design that considers future maintenance, sustainability, and circularity, which could contribute to the Dutch housing shortage. The most significant barriers in the Dutch C&DI have been summarized into four barriers and are the following:

- Lack of clarity on economic benefit
- The challenge in the value chain integration and collaboration
- Elections and municipal policies and processes
- Scalability

During the research, these barriers explain why they are experienced as a barrier. Furthermore, recommendations and potential interventions are introduced that might help overcome the barriers in the Dutch C&DI. However, these are not demonstrable and proven to overcome the barriers but arise from interviews and the focus group with experts from the industry.

Reading Guide

This research will focus on understanding the most significant barriers to the adoption of Industry 4.0 (I4.0) technologies (e.g. AI, IoT and Digital Twins) within the Dutch construction and development industry (C&DI). In addition, it will look at what can be done to overcome these barriers. Table 1 describes the phases in which the thesis is broadly structured.

The first chapters, the introduction phase, introduce the topic, address the research questions and elaborate on the methodology In phase one, the first impressions from the literature regarding the topic are explained and the main concepts of the main research question are explained based on the literature. Phase two delves further into the Industry 4.0 literature regarding the C&DI. The most widely adopted and discussed I4.0 technologies in the C&DI literature are introduced. In addition, the main barriers and advantages achieved with the respective technologies are examined. It concludes with the first conclusions on the generic research questions formulated before the literature review. Subsequently, more specific research questions are drawn for the further phases of the research. Phase three explains the results of the survey and interviews. Based on these results, conclusions are made that will be put up for discussion during the focus group in phase four. The final phase consists of the conclusions, discussion, recommendations, reflection, and appendices.

Phase	Chapters	Topics
Introduction	1-3	Introduction, Research questions, methodology and explanation of the most important terms from the main research question
Phase one	4-5	First impressions and literature
Phase two	6-9	Understanding I4.0 in the C&DI with the main adopted technologies, most significant barriers and potential benefits.
Phase three	10-12	Results of the survey and interviews
Phase four	13	Focus group
Conclusions and more	14-17	Conclusion, Discussion, Recommendations, Reflection and The comprehensive results and data from the study in the appendices

Table 1: Reading guide

Abstract

There seems to be a mismatch between the enormous potential of Industry 4.0 (I4.0) and the extent to which it is adopted in the construction and development industry C&DI. According to the literature, the growing interest in I4.0 and its potential benefits are not stimulating companies to adopt it.

There is little to no research covering adopting I4.0 technologies in the Dutch C&DI. Usually, the focus is on different industries. When research focuses on the C&DI, it often investigates the construction or the maintenance phase. In addition, these researches mainly focus on the barriers of adopting Industry 4.0, and not on what interventions could be taken to increase the adoption in practice. This has resulted in the following main research question:

Are barriers withholding adopting Industry 4.0 (I4.0) technologies (e.g. artificial intelligence (AI), internet of things (IoT) and Digital Twins (DT)) within the Dutch construction and development industry, and if so, can these barriers be overcome?

Due to the topic's nascent character, mainly qualitative research is conducted. Literature is reviewed in combination with exploratory interviews and a focus group. In addition, a quantitative study was set up to support the qualitative research through a survey. A selection of twelve barriers to withholding adopting I4.0 technologies has been identified from the literature review. As a result of the survey, the lack of clarity on economic benefit and the challenge in the value chain integration emerged as the two most significant barriers. The most frequently adopted I4.0 technologies in the Netherlands are sensors and big data & analytics.

The interviews and focus group made it possible to look in-depth at the previously found results, revealing several significant barriers. In addition, potential interventions have been identified to overcome the barriers. In conclusion, these interventions have been discussed in more detail, followed by recommendations. For example, municipalities should participate more often in a Joint venture, which is a public-private partnership. Unfortunately, specific numbers of Dutch adoption are missing in the research. However, the recent experience and adoption of I4.0 technologies in the Dutch C&DI generate well-founded valuable insights. Lastly, the research stresses the importance of future research on the topic.

Keywords: Industry 4.0, Construction 4.0, construction and development industry, barriers, adoption and design & engineering phase

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List of abbreviations

AI	Artificial Intelligence
AR	Augmented Reality
AutR	Autonomous Robots
BIM	Building Information Modelling
BD&A	Big Data and Analytics
C&DI	Construction and Development Industry
CXO's	Chief X Officer
D&EAT	Design and Engineering Adopted Technologies
DT	Digital Twin
GAT	Generally Adopted Technologies
GDP	Gross Domestic Product
GIS	Geographic Information System
GR	Growth rate
IoT	Internet of Things
I4.0	Industry 4.0
PPP	Public-Private Partnership
VR	Virtual Reality

1

Introduction

Today the giants of the digital industry deal in data. Data can be seen as the oil of the digital era, as in the last century, the resource in question was oil. The amount of data in the world was estimated in 2020 to be 44 zettabytes (World Economic Forum). A zettabyte is 1,000 bytes to the seventh power. In other words, one zettabyte has 21 zeros. The estimated amount of data on the internet created every day in 2025 will be 463 exabytes (World Economic Forum, High Scalability) and this pace will only accelerate more as construction technologies advance.

The world can speak of data as it's a most valuable resource: no longer oil but data

As the digital revolution pushes forward all aspects of life at an ever-faster pace (Allen & Shakanta, 2016) it will influence and will be influenced by some defining trends for the next decades such as urbanization, the housing shortage in the Netherlands, COVID-19 and sustainability.

As 55% of the world's population lives in urban areas today, a proportion is expected to increase to 68% by 2050 (UN DESA, 2018). Roughly 75% of global economic activity is urban, and as the urban population grows, so will the urban share of global GDP and investments. Therefore cities will change and urban development needs to speed up.

The supply of sufficient housing is currently the most significant problem in the Dutch housing market. From 2013 onwards there was a sharp decline in the number of new buildings realised. In the last few years, production fluctuated around 50,000 homes yearly. The production, combined with an increase in the number of new households due to immigration and other reasons, increased the housing shortage by about 3.2% in 2018 (Statistical Bureau of Statistics Netherlands 2019).

Thus, the future does not look much brighter. By 2030, only the Netherlands needs an extra 1 million dwellings and by 2050, 2 million dwellings (Servaas van der Laan, 2020). In short, building many homes in a short period is essential! However, the current requirements for new construction, such as sustainability, do not make it any easier. That is why we will have to look for ways to build better homes faster.

COVID-19 makes the role of the digital revolution even more critical. It seems that organizations utilizing digital solutions were better positioned than their competitors during the crisis. Top of mind of many companies when thinking of restoring operations and building the company to deal with future crises as COVID-19 is using digital technologies. A recent McKinsey survey of supply-chain and manufacturing professionals found that 90% plan to invest in talent for digitization and 93% focus more

on the resilience of their supply chain (2020). However, the upswing in technology adoption may be asymmetrical due to the need to develop resilience for another crisis and the constraints performed by cash preservation.

Innovative technologies have a high potential to positively impact economic development and contribute to the sustainable development of cities of developing countries and emerging economies (B. Müller & P. Schiappacasse, 2015). The necessity for sustainable solutions is a global phenomenon that can no longer be ignored, especially in real estate. For example, the built environment generates 40% of the global energy consumption. Besides, it generates around 30% of the global CO2 emissions (JLL, 2020).

As the real estate industry is one of the most significant users and emitters of all industries, it must become more sustainable (van Driel & van Zuijlen, 2016). Annemarie van Doorn, director of DGBC (Dutch Green Building Council), states that the transition to a more sustainable built environment cannot wait any longer (Vastgoed Journaal, 2020). Furthermore, corporations increasingly focus on sustainability, causing corporations to act sustainably like private real estate developers. The corporations have accepted that they must do so to thrive or even survive (Senge et al., 2010), meaning the pressure on the organizations is growing. The Paris agreement has been introduced to push sustainability, and governments use policies such as a BENG-norm (Energy neutral buildings). This forces real estate organizations to develop more sustainably. Real estate developers need to answer the demand. As the current demand for sustainable solutions is rising in all real estate sectors, this is also pressuring the organizations to become more sustainable (JLL, 2020; JLL, 2019; CBRE Research, 2020).

The emerging digital revolution could play an essential role in trends such as those described above. Innovative smart technologies are being developed more and more and there is talk of a fourth revolution or Industry 4.0. Industrie 4.0 was launched at the Hannover Messe in 2011, as an German Federal Government initiative to strengthen the competitiveness of the German manufacturing industry (Lasi et al., 2014). The term 'Industry 4.0' (I4.0) has many synonyms and many different meanings. The Dutch government uses their ambitions to focus on digitization as 'Smart Industry'. In 2014, the Dutch government presented the report 'Smart Industry, Dutch Industry fit for the future' and in 2018, the Smart Industry Implementation Agenda 2018-2021. A lot of definitions of Industry 4.0 are proposed:

Some different definitions of I4.0:

The connection of people, things and systems creates dynamic, self-organising, real-time optimised value added connections within and across companies. These can be optimised according to different criteria such as costs, availability and consumption of resources (Plattform Industrie 4.0).

Therefore, the difference of this fourth wave of technological advances is the very close interaction between the physical, digital, and biological worlds (Syam & Sharma, 2018).

Technological advances decentralize business processes referring to Industry 4.0. It is characterized by technological innovations such as Machine to Machine (M2M) communications, Internet of Things (IoT), Cyber-Physical Systems (CPSs), artificial intelligence(AI) and Big Data & Analytics (BDA) (Brettel et al. 2014).

Important to note, I4.0 is not just about technologies, but it also looks at the impact on and role of society and workers. Think of the collaboration between man and machine as with collaborative robots or cobots, new required skill sets of factory workers amidst all these changes and, inevitably, the loss of jobs due to ongoing automation as mentioned – and how to tackle this significant challenge. Still, many feel that the 'human touch' is not emphasized in I4.0, hence the notion of Industry 5.0 (I-scoop).

Authors define 'Construction 4.0' (C4.0) as a pure and straightforward instantiation of the concept of I4.0 in the CDI (that is, the use of ubiquitous connectivity technologies for real-time decision-making). Others see it as a means of finding a coherent complementarity between the main emerging technological approaches in the construction industry. Still, others see it as a more encompassing approach beyond the simple technology framework to best meet the industry's current challenges (Innovation Spotlight, 2020).

This research relies on the following understanding of Industry 4.0 as it is the most commonly used term internationally and in literature: After mechanization, mass production and the rise of computer technology and automation, the fourth industrial revolution has started as automated systems are connected, exchange data and eventually operate autonomously through their analytical and self-learning capabilities.

1.1. Problem statement

Even though Dutch real estate developers see the necessity to innovate and develop (Haak & Heurkens, 2015), a translation of the pressure to actual actions does not always occur. The Fourth Industrial Revolution survey: At the intersection of readiness and responsibility was filled out by more than 2,000 C-suite executives across 19 countries. Researching how organizations are capitalizing on advanced technologies to help propel their businesses forward while acting in a more socially responsible way. Only 17% of the respondents say making influential Industry 4.0 technology investments is a priority for their organization. They were ranking it as the lowest among the 12 investment priorities (Deloitte, 2020). I4.0 technologies can disrupt and transform many different areas of business for the better. Why do executives not appear to be leveraging them as broadly across their organizations as they could?

"Companies are beginning to understand the massive impact of I4.0 and the role of technology in fundamentally transforming business models and processes. The challenge is figuring out how to realize and harness the benefits of the I4.0 future", says Ram Jambunathan, managing director of SAP.io. The advanced technologies of I4.0 (e.g. artificial intelligence (AI), the internet of things (IoT) and augmented reality (AR) discussed in chapter 6) are often associated with cost-cutting and profit-maximizing. However, the companies succeeding in using I4.0 understand the technologies that can help in all areas of the business (e.g. business strategy, societal impact and technological operations) (Deloitte Insights, 2020).

In the same survey, only 10% of the respondents said their organizations have comprehensive I4.0 strategies. Besides, more than 60% of CXO's said their organizations either have no I4.0 strategies or

are taking approaches to implementation. Moreover, they do not see the potential of I4.0 as a third of the respondents said integrating I4.0 was "not that important", and only 4% said it was "essential". It can be concluded from this that it does not seem that many companies implement I4.0 technologies as a priority and that the adoption is therefore low. How is this compared to the C&DI?

The construction and development industry is one of the sectors lagging in modern industrial digital tools (J. Maier,2017). As a result, I4.0 is still far from being used to its full potential in the construction sector. Compared to other industries, such as business services, manufacturing, finance, transport, and utilities, the construction industry still lags in investing in I4.0 technologies (Underwood and Isikdag, 2011).

The construction sector seems to lag as there are still many barriers. It will continue to grow as long as there is (s)low adoption of technology and a lack of innovative processes in construction (Zabidin et al., 2020). It seems some barriers ensure the growing gap between Industry 4.0 and the construction industry. However, I4.0 was rising in the construction industry and benefited from this development, which gave the term Construction 4.0 (Forcael et al., 2020). While the complexity of construction has led to its slow industrial evolution

To summarize, It turns out that despite the significant and plethora of advantages offered by Industry 4.0 for enhancing the construction industry's performance (Bebelaar et al., 2018; Ghosh et al., 2020), a review of extant literature demonstrates conspicuous deficiencies with the existing research undertaken. Furthermore, it seems there is a notable disconnect between academic endeavors and industry practice (Maskuriy et al., 2019). Therefore, the problem statement for this research is as follows:

There seems to be a mismatch between the enormous potential I4.0 has and the extent adopted within the construction and development industry. According to the literature, the growing interest in I4.0 and its potential advantages are not stimulating companies to adopt.

1.2. Scientific relevance

The concept of I4.0 in the construction industry has been widely researched in literature. Industry 4.0 is a topic that is increasingly being explored by academics, researchers, practitioners and other relevant stakeholders (Nascimento, 2018). Figure 1.1 shows that most selected publications were published in 2019 (23%) and 2020 (49%) related to the interconnection of Industry 4.0 and Construction 4.0 (Koslovska et al., 2021). This proves the growing interest in this area of research and is in line with the general trend of Industry 4.0 publications.

It has been proven that I4.0 can lead to many advantages. For example, given the importance of good management of the underlying processes in construction projects, any improved access to information (e.g., gains in automation and richer building information) can lead to more effective decision-making. This more effective decision-making could then facilitate these processes (Isikdag et al., 2012). Thus, resulting in cost savings, time saving, and improving quality and safety (Aripin et al., 2019). However, on the other hand, there are many barriers that I4.0 entails that result in (s)low adoption.

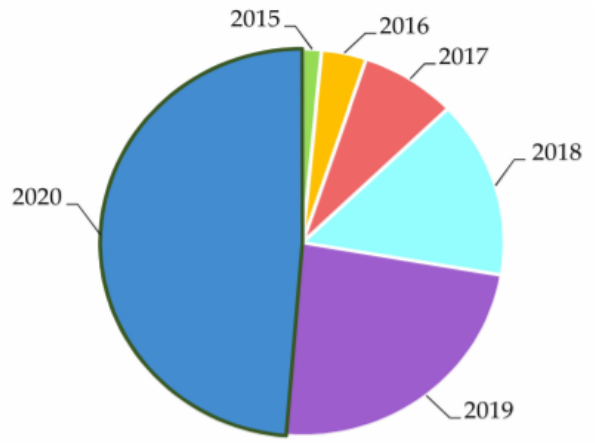

Figure 1.1: Publications of Industry 4.0 and Construction 4.0 (Kozlovska, 2021)

However, there is little to no research covering adopting I4.0 technologies in the Dutch C&DI. Besides, the focus is mainly on the barriers, not on what interventions could be taken to increase the adoption in practice.

Furthermore, the thesis will focus on the CDI Design & Engineering ($D\&E$) phase. As in literature, this specific development phase is almost not associated with I4.0. Therefore, this thesis aims to fill the knowledge gaps by supplying insight into the Netherlands' adoption and potentially overcoming the most significant barriers to adopting I4.0 technologies in the $D\&E$ phase.

2

Research questions & Methodology

2.1. Main research question

According to a step-by-step plan provided by Chan (2021), the main research question has been formulated. In step 1, it was essential to see what the issue was. Next, in step 2, one ought to look at what we know about this issue and in step 3, there will be a look at what is not known about this issue, what is new. These steps have been elaborated below, which ultimately formulated the main question.

Step 1, What is the issue?

Recently, there has been growing interest in I4.0 in the construction and development industry. However, it seems there is a mismatch with the adoption of I4.0 technologies.

Step 2, What do we know about the issue?

The literature describes what technologies there are, barriers that enable the (s)low adoption of I4.0 and the advantages of I4.0.

Step 3, What do we not know about the issue?

However, there is little to no research covering the adoption of the Dutch construction and development industry. Besides, the focus is mainly on the barriers, not on how to overcome the barriers in practice. Furthermore, almost no distinction is made between the phasing in the construction and development industry where the Design & Engineering ($D\&E$) phase is not often mentioned.

From these steps the following research question is addressed:

"Are barriers withholding adopting Industry 4.0 (I4.0) technologies (e.g. artificial intelligence (AI), internet of things (IoT) and Digital Twins (DT)) within the Dutch construction and development industry, and if so, can these barriers be overcome?"

Three terms of the aforementioned research question require further explanation prior to researching. This is done in chapter 4. The terms that are explained are the construction and development industry (C&DI), adoption and Industry 4.0.

2.2. Generic sub-questions

All sub questions below relate to the construction and development industry (C&DI) and will be answered based on the literature review. The findings in the literature will be the basis for the research questions:

(1) What are the main adopted I4.0 technologies?

(2) How is I4.0 adopted?

(3) How is the phasing in C&DI projects?

(4) What are the critical stakeholders in C&DI projects?

(5) What are the main drivers to adopting I4.0?

(6) What are the main advantages of adopting I4.0?

(7) What are the main barriers withholding adopting I4.0?

2.3. Research sub-questions

A series of sub-questions is adopted to help answer the main research question. Below an overview of each of the sub-questions is provided together with a short description of the question's objective. The methods, techniques, data collection, and data collection are discussed more in-depth in chapter 3. These sub-questions are prepared based on the literature review.

Sub-question 1, what are the main adopted I4.0 technologies in the Dutch C&DI?

Data collection: Literature review and survey

The objective of this question is to gain insight into which technologies are applied within the C&DI. Further research will be carried out based on the most advanced and adopted I4.0 technologies. Thus, the most advanced will be used for this research. The research will not include all technologies but will include the most well-known and, for now, most relevant. Because these technologies are most applied or have the most significant potential, the most literature can be found on this and several respondents are more familiar with these technologies. Therefore, this will lead to more data about the advantages and barriers that will eventually become important for its adoption.

Sub-question 2, is there a malfunctioning adoption of I4.0 in the Dutch C&DI?

Data collection: Literature review, survey and interviews

The objective of this sub-question is to determine if the Dutch I4.0 adoption is as (s)low as the literature describes for the adoption in general. Determining and understanding the Netherlands' adoption might give insight into the following steps to increase the adoption and optimize the potential advantages.

Sub-question 3, what are the barriers that are withholding Dutch organizations from adopting I4.0 in the C&DI?

Data collection: Literature review, survey, interviews and focus group

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This question aims to understand what barriers, and to what extent, are keeping Dutch C&DI stakeholders from obtaining I4.0. Knowing the barriers that are withholding Dutch urban developers contributes to gaining a clear understanding of the problem. When identifying the problems, the next step might be to see how urban developers can eventually overcome the barriers.

Sub-question 4, what are the main drivers of organizations to adopt I4.0 in the Dutch C&DI?

Data collection: Literature review, survey and interviews

This question aims to understand what drives Dutch C&DI stakeholders for adopting I4.0. Knowing the drivers and advantages gives insight into the extent to which it can be beneficial and why Dutch C&DI stakeholders should adopt I4.0. Moreover, getting the potentials straight might make it more eager to adopt.

Sub-question 5, what stakeholders work in the Design & Engineering phase with I4.0 in the Dutch C&DI?

Data collection: Literature review and survey

The objective of this sub-question is to specify the analysis further and see which stakeholders in the *D&E* phase work with I4.0 technologies. In addition, this question will also look at which C&DI stakeholders want to adopt I4.0 in the coming years. Finally, after analyzing the survey results, several C&DI stakeholders will be interviewed participating in the D&E phase to get more insights about the adoption and how to potentially overcome the barriers for adopting I4.0.

To give an answer to these different questions, a suitable research method is selected. This selected research method is discussed in chapter 3.

2.4. Dependencies between the research sub-questions

The research is structured first to understand the issue. Then provide more insight into how the problem might be solved. Due to this structure, the sub-questions have dependencies, as indicated in figure 2.1. From the I4.0 technologies (sub-questions 1), the barriers and drivers can be derived (sub-questions 3 & 4). The Dutch C&DI current adoption can be determined from the implementations of I4.0 and depends on the barriers and drivers (sub-questions 2). From the current adoption of the Dutch C&DI stakeholders, the research will focus on the Design & Engineering phase and will dive more in-depth into the adoption (sub-question 5). Ultimately, the 5 sub-questions will need to result in an answer to the main research question (SQ 6).

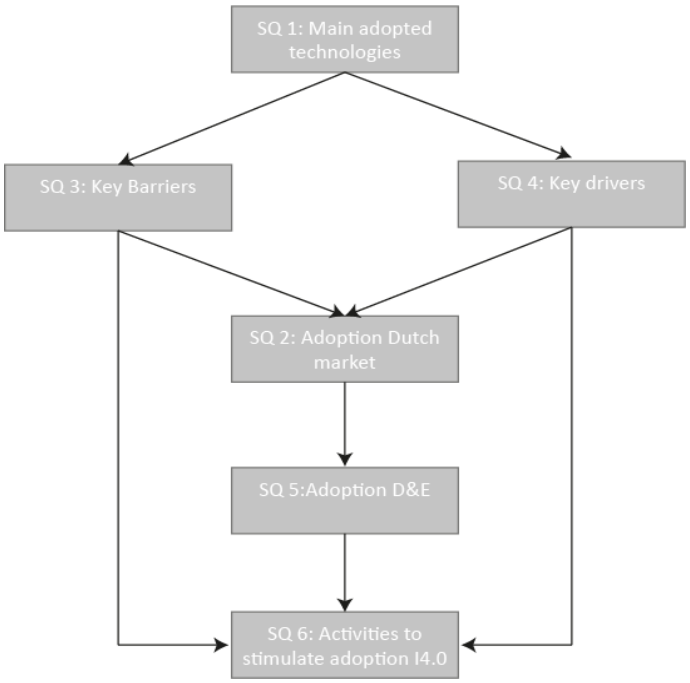


Figure 2.1: Dependencies between sub-questions (own stimulation)

2.5. Methodological approach

As indicated in each sub-question, this research uses primarily qualitative data with supportive quantitative data (surveys). The research is a mix of empirical and operational research, as is indicated in figure 2.2. The black arrows represent the switch between empirical and operational research.

The mix between empirical and operational research is due to first understanding the problem (empirical) thoroughly and then designing the activities to help solve the problem (operational). Due to the time this research is conducted, this report limits the research to preliminary new insights and interventions to overcome the most significant barriers.

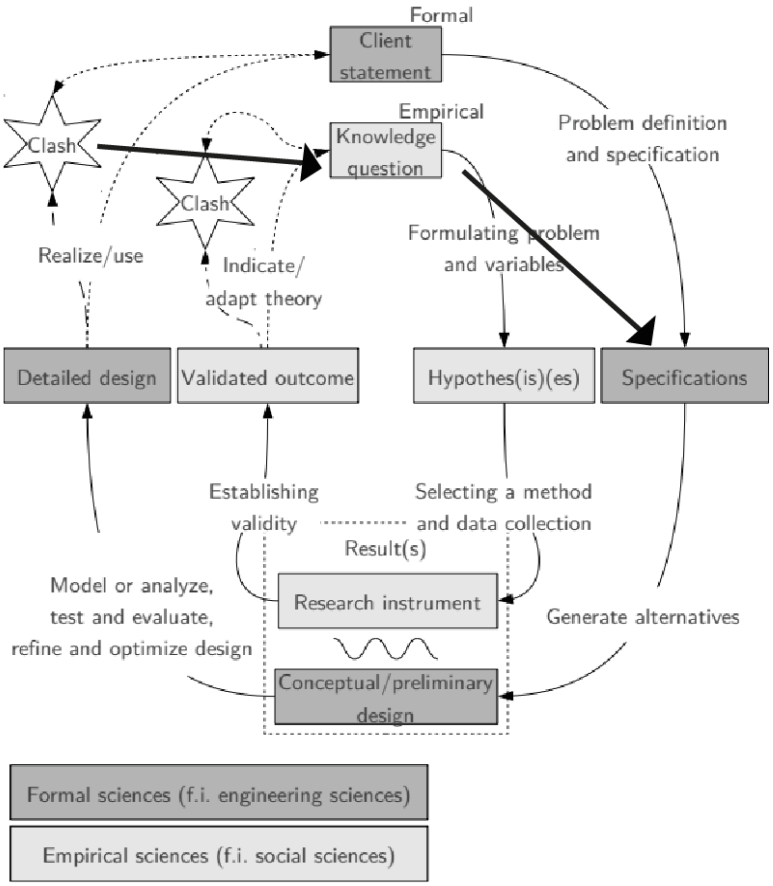


Figure 2.2: The formal and empirical cycle combined (Barendse et al., 2012, p. 6).

3

Research methods

This chapter describes the used research methods to gather the data needed to provide an answer to the proposed research question. In this section, the research strategy provides more insight into the data collection, methods and techniques, and data analysis for each sub-questions.

As discussed earlier, the research gaps are researched in a nascent phase. Therefore, according to the methodological fit for management field research, as introduced by Edmondson and McManus, a qualitative research method is more suitable for subjects in a more nascent phase (Edmondson & McManus, 2007). Furthermore, the research focuses on a new phenomenon whereby there are not many theories available yet. Therefore a qualitative research method is more suitable for answering the research question. However, the qualitative research methods (e.g. semi-structured interviews and focus group) will be supported by a quantitative research method (surveys).

3.1. Data collection, methods and techniques and data analysis

Literature review

In the first two phases, a literature review is conducted. The data collected in the literature study yielded standardised information about research topics. To do this effectively, a narrative literature review was conducted.

The literature review resulted in a better understanding of the different topics. As a result, a 'narrative review' of the literature is more suitable than a systematic review for this type of research (Bryman, 2016, p. 110). That is why a narrative literature review is conducted in this research. By this, a large amount of helpful information is found in a short period. However, the main flaw of this research method is that narrative reviews tend to be less focused and more wide-ranging in scope than systematic reviews (Bryman, 2016, p. 110). For the literature study, various internet sources were used, such as Google Scholar and Scopus. The selection of the literature was/is based on different search terms such as "Industry 4.0", "adoption" and "Construction 4.0", the quality of the source, the number of citations and the relevance of the research.

Survey

Survey research uses scientific sampling and questionnaire design to measure the characteristics of the population with statistical precision (Sukamolson, 2007). A survey provides estimates from a sample that can be related to the entire population with a degree of certainty (e.g., 57% of the population +/-

3% will answer the question this way 95% of the time). However, to meet this degree of certainty, a specific number of respondents need to fill out the survey that is too large for the amount of time of this research. This is further specified in section 3.2.1.

Multiple methods were used to reach C&DI stakeholders to fill out the survey as many respondents as possible. For example, an open call was done through www.gebiedsontwikkeling.nu. In addition, the survey was shared in the personal network and of others already working in the C&DI to increase the number of respondents. More about the survey is discussed in chapter 9. The data is displayed from several charts by Google Forms. The results are downloaded and further investigated and analyzed using own created tables and the working with the tool Power BI.

Semi-structured interview

The reason to conduct semi-structured interviews is to assess the different Industry 4.0 technologies that are integrated into the *D&E* apart from the other phases in teh C&DI. The advantage of choosing for semi-structured interviews is that there is more latitude to ask further questions in response to what is seen as significant replies (Bryman, 2012, p. 212). Also, the interviewer has a series of questions in the general protocol but can vary the sequence of the questions. The interviews will be held with multiple stakeholders within the *D&E* phase. The interviews will be recorded, a transcript will be made and analysed by the use of coding.

Focus group

The reason to conduct a focus group is to open discussions for further research. Ernest Dichter quoted in 1991; focus groups are meetings held with a limited group of participants (6-10) with the objective of discussion. The participants must know about the subject matter of the research but have not themselves participated in this research. The focus group will discuss the results through various propositions in which they choose aside. The propositions come from the survey and previous interviews. The purpose of the focus group is to see if the results can be questioned and if further discussion is needed for the research. In addition, it will also delve into what can be done to overcome the most significant barriers in a semi-structured interview style.

3.2. Respondents

For representative research, the research should meet specific requirements. This section describes how the respondents for the interviews and surveys are selected and if the research is statistically significant.

Survey respondents

Ensuring the data generated through the survey is statistically significant, the predefined number of respondents within a specific confidence interval must respond. The population that is being addressed in this research is Dutch C&DI stakeholders. According to CBS (2018), there are 97.000 employees within the C&DI. Therefore, with a confidence interval of 95% and a margin of error of 5%, the number

of respondents necessary to make the results statistically significant is 383. While within these 97.000 employees, it's not clear if all C&DI stakeholders are taken into account, such as the project managers from the municipalities, for example.

Due to the time limitations of this research, more than 383 respondents are too ambitious. Therefore, it is likely that the results are not statistically significant. However, the results can be used to conclude and give preliminary insights. Therefore, when the survey results are not statistically significant, a critical analysis is necessary.

Interview respondents

The interviewees are chosen based on the data and results of the survey. The focus after the survey will be more on stimulating the I4.0 and the stakeholders active in the *D&E* phase. Thus, the criteria for choosing the interviewees will consist of: (a) The respondent must be active in the *D&E* phase (b) there must be some content added by the respondent in how I4.0 can be stimulated.

Furthermore, it is suitable for the research to interview different stakeholders, i.e. companies with different job activities. In addition, it will be looked into to interview a public party at least also. In addition, at least one organization with 1-9 employees and one with more than 250 employees. Experts often avoid in qualitative research the "how many" interviews "are enough". As a result, there is variability in what is suggested as a minimum. However, many articles, book chapters, and books recommend guidance and suggest anywhere from 5 to 50 participants for an interview as adequate (Dworkin, 2012). Therefore, 5 interviews were conducted for this study as this is the minimum according to the literature.

Focus group respondents

Participants who had not participated in the survey or a previous interview were needed in the focus group. Based on the survey and interviews, suitable participants were approached. A variety of different backgrounds and sufficient knowledge about the subject were the requirements. It was also essential to include some public parties in the focus group as they had barely participated in the survey and had not been interviewed and therefore had the potential to open up the discussions. Like the interviews, the focus group was conducted with 5 participants.

3.3. Data plan

The data plan describes how raw and processed data are collected and used in this research project, how it is stored and who is responsible for it. The literature is mainly collected from the internet via Scopus and Google Scholar and the interviews are recorded and transcribed. All the data will be stored on the authors' computer, which is secured. For the data collection, the FAIR guiding principles are respected in order to enhance the reusability of data holdings (Wilkinson et al., 2016). According to these principles, data have to be:

- findable

- accessible
- interoperable
- reusable

The research will be published on a free access website (repository TU Delft), written in English, and according to the APA 2012 guidelines to meet these principles.

3.4. Ethical considerations

I4.0 is flying on a wave of modernism, which has led to many promises and, on the other hand, also introduced many new problems. New problems have arisen in the social, legal, environmental and personal meaning of life. Therefore, we must consider the social and ethical implications of technological vision and economic optimism because both are linked (KUČERA, 2018). Therefore this chapter introduces some ethical considerations about I4.0.

The ethical considerations are divided into two sub-dimensions. First, from an ethical perspective, the research subject will be discussed. Secondly, the research method will be considered. The ethical considerations are important as Industry 4.0 is designed with innovative technologies with good intentions. However, technologies are often susceptible to negative consequences on people.

Research subject

Industry 4.0 technologies are a sensitive topic when it comes to ethics. The question is whether this is even possible since we are talking about technologies that are all computer-controlled in the end. Can artificial intelligence-based machines respond to moral issues the way humans can? Can a robot make choices according to the cultural and moral system? Can consciousness be taught to a machine? We are also increasingly dealing with privacy rules. For example, the laws in the Netherlands have been tightened over the years. Hackers are increasingly active and appear more often in the news. For the time being, it seems critical to allow man and machine to work together. However, we must continue to be aware that we are now collecting more and more data from people, often without realizing it. The implementation of I4.0 in any sector raises ethical questions. During the research, ethical considerations will be taken into account in the development of the research.

The most important thing is that more awareness can be created about the possibilities of the technologies with this research and the results. That there should be room for innovations should become clear from this research and where the most significant problems lie concerning the adoption in the Dutch C&DI. In addition, the aspects above that computers take moral and social decisions will be difficult to accept.

Research method

Lack of informed consents All the interviews will start with an information sheet. This sheet should explain the research goal, the contact details and how the data will be processed.

Protection of participants In the research, semi-structured interviews will be conducted. In order to protect participants, their identities and recordings will be confidential. So if this research ever will be published, it needs care on the forehand. Therefore in the interviews, their permission will be asked for using their names and interviews. This is important not to harm the participants of the research. Invasion of privacy To make sure that the privacy of participants is not harmed, their privacy and anonymity are respected. Their personal information will be protected according to the Data Protection Act 2018. The information must be used:
- fairly, lawfully, and transparency
- used for explicit, specified purposes
- used in a way that is adequate, relevant and limited to only what is necessary
- accurate and, where necessary, kept up to date
- kept for no longer than is necessary
- handled in a way that ensures appropriate security
- including protection against unlawful or unauthorized processing, access, loss, destruction or damage (Government Digital Service, 2018).

Deception is involved The literature study is important that assumptions made are critically reflected and underpinned by reliable sources. This has been taken into account during the execution of this research.

3.5. Research phases

Before explaining the different phases taken in this research, it is essential to clarify the output of this research. The output of this research is an understanding of the adoption of I4.0 technologies in the Dutch C&DI. With extra focus on the $D\&E$ phase. Furthermore, it provides a stepping stone on what activities could be taken in the Dutch C&DI to overcome the most significant barriers to adopting I4.0. Resulting in how the Dutch C&DI could optimize the adoption and benefit from the I4.0 technologies.

To structure the research, four separate phases are identified throughout the report. The four phases are 'first impression and literature', 'Understanding I4.0 in the C&DI', 'I4.0 adoption Dutch C&DI', and 'Insights and potential interventions for adopting I4.0 in the Dutch C&DI'. In figure 3.1, an overview of the four phases is provided. Furthermore, each phase is formulated with a description.

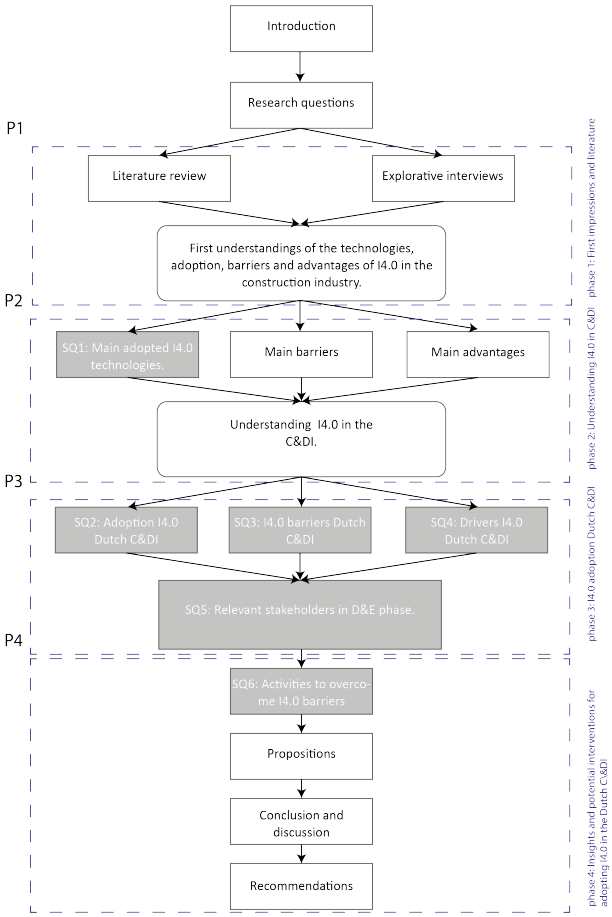


Figure 3.1: Flow chart phases research (own illustration)

First impressions and literature

In phase one, through literature review and exploratory interviews, the first impressions of the literature were drawn. These first interviews resulted in the first understanding of I4.0. In addition, the thoughts from others helped to formulate the first understandings of what barriers are withholding C&DI stakeholders from adopting I4.0, currently used I4.0 technologies and the advantages. Furthermore, tentative conclusions could be made about the adoption of I4.0. Finally, the literature could substantiate this.

Understanding I4.0 in C&DI

For understanding I4.0 in the C&DI more extensive literature is needed. So a good understanding of the advantages, barriers and main adopted I4.0 technologies. From these findings, a distinction is made of the most common barriers, advantages and technologies. These are used for the survey and to make the research more specific.

I4.0 adoption Dutch C&DI

After gaining the first impressions of the construction and development industry in general, this phase aims to obtain a deeper understanding of the Dutch construction and development industry concerning

the adoption of I4.0. The current 4.0 adoption in the Dutch market is analysed through surveys to parties involved in Dutch C&DI. Through this survey, a more in-depth analysis could be made about the barriers and drivers of I4.0. After analyzing the survey about the I4.0 adoption in general, the research focuses into the D&E phase by conducting several interviews.

Insights and potential interventions for adopting I4.0 in the Dutch C&DI

In phase four, several propositions were formulated based on the survey and the interviews conducted. First, the propositions are presented to stakeholders in the C&DI, especially from public bodies. These include the most significant barriers and are addressed within the focus group. Furthermore, there will focus on what to do to overcome these. Direct results are presented to see how the focus group responds. Then, based on this, final conclusions will be made and recommendations will be given.

Phase one: First impressions & literature

4

Explanation of terms

This section describes the three concepts formulated in the main research question. These concepts require further explanation, as mentioned before. The three concepts explained are Industry 4.0, construction and development industry and adoption. The explanation of these concepts comes from reviewing the literature.

4.1. Industry 4.0

As mentioned in the introduction, there are many similar terms for Industry 4.0 and also different meanings. This section will describe how I4.0 or the fourth industrial revolution developed and its impact on urban development.

The first industrial revolution was induced by water and steam-driven big central mechanical production units. This enabled the manufacturing of products in larger quantities and quicker than before. However, it took almost a century to their ubiquity in production processes at the start of the second industrial revolution. During this period, the new production technologies led to the urbanization of former rural settlements and contributed to urban growth.

Interestingly, the second industrial revolution was triggered by the opportunity to decentralize the electric power supply, allowing for inexpensive and much smaller drive units for conveyor belts. In addition, the assembly line concept split up many production steps into individual processes. As a result, employees could become more specialized and production costs significantly reduced. This resulted in several consequences for urban development in the industrializing world. First, production sites became larger and increasingly disturbing. Second, urban growth was accelerated, leading partially to the miserable living conditions of the working classes that impacted the development of new urban extension areas. Resulting in better sanitary and health conditions and improved urban hygiene. Third, mass production made automobiles more and more affordable for the growing middle classes (Müller, 2014).

After a century, the start of the third industrial revolution. The introduction of the first Programmable Logic Controllers (PLCs), electronics, and information technologies made individual production steps smarter. In the field of urban and regional development, new areas are being realized utilizing ICT. It was also documented that living in remote locations on the outskirts of cities in metropolitan areas would no longer be a disadvantage due to the long commute distances due to new telecommuting options at home. However, there were also tendencies to return to more compact city structures and the Ecocity

concept started to become more prominent. Later concepts of "intelligent cities", "ubiquitous cities" and "smart cities" arose, providing better services and starting the use of ICT in everyday life.

It took another 50 years until the dawn of a fourth industrial revolution, the development of miniature Cyber-Physical Production Systems (CPPS) and specialized Cyber-Physical Systems. These are tiny data processing units, including communication capabilities, and they use sensors as interfaces to the real world. Moreover, they are integrated into electronic and mechanical parts: mechatronics, software technology, and networking are the essential basic units of the Internet of Things (IoT) and Services (Müller, 2014). The ability to assign identities to the smallest batches of products and materials and precisely locate them enables the I4.0 functions: keeping track of the items of production processes at each level of the supply chain, inside the factory, and outside. In this way, the IoT is a digital representation of the actual production world. It enables smart planning, optimization, and control of the production steps and each supply chain section. The industrial revolutions and urban development over time are illustrated in figure 4.1.

Regarding urban development, the consequences of I4.0 are not yet clear. However, I4.0 is related to the further development of integrated and inclusive smart city concepts, and it has the potential to change urban development patterns.

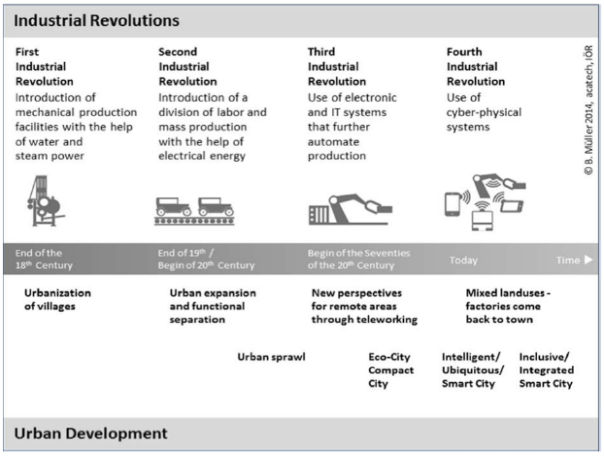


Figure 4.1: Industrial revolutions and urban development over time (Müller, 2014)

4.2. Construction and development industry

Phasing construction project

Traditional construction projects typically consist of six phases. These six phases are illustrated in figure 4.2. Not all projects go through these phases as there are sequence variations. However, most projects include planning, design, construction and operation phases (Halpin & Woodhead, 1998).

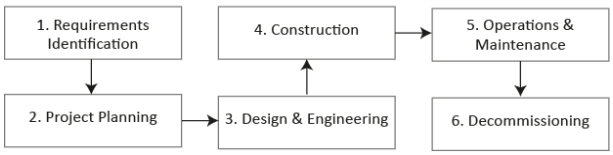


Figure 4.2: Halpin & Woodhead construction project phases, 1998 (own illustration)

Short description per phase:

1. When a need for a project arises.
2. Involves developing alternative project plans. These could meet the identified needs and evaluate each alternative for technological and economic feasibility.
3. Develops detailed engineering designs and specifications
4. The construction, from ground-breaking through to final inspection, takes place.
5. The project is occupied and commences operation.
6. Dismantle it once it becomes obsolete

Phasing urban design life cycle

VivaCity2020 identified a diagrammatic representation of the life of an urban development project. VivaCity refers to the life cycle to any scale from building to city level. The life cycle consists of four phases (Figure 4.3).

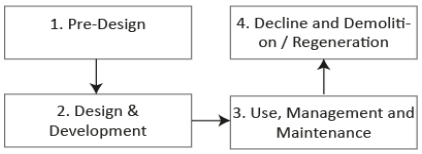


Figure 4.3: VivaCity project phases, 2020 (own illustration)

Short description per phase:

1. An individual, organisation or group identifying a need for an urban development project.
2. The focus of this phase is the project's urban design decision-making process and is where most of the urban design decisions are made in the urban design lifecycle. Concrete decisions on generic and detailed aspects of the designs of buildings and their environments are made. Also, decisions are taken on which stakeholders should be involved in the process, what tools decision-makers should use to make decisions, how best to consult stakeholders and when and how to integrate sustainability into every part of the project.
3. When people are using the buildings and spaces. To ensure that the buildings and spaces are used appropriately, that things do not break down and that people have a channel to discuss issues,

decisions need to be made about the beginning and continuing management and maintenance programmes.

4. At this stage of the urban design lifecycle, the urban development project has been used by people for some time and may have fallen into disrepair or is in a condition whereby intervention is needed. Depending on the external and internal drivers, the intervention could involve demolishing the urban development project or the decision to regenerate.

Phasing for research

For this research, the combined action of the above two urban development lifecycles is used. In the case of the VivaCity lifecycle, as far as this research is concerned, the Requirements identification and Project planning phases can be merged. Furthermore, compared to the urban lifecycle of Halpin & Woodhead, a distinction is made in the Design & Development phase. Figure 4.4 shows the phasing used for this research and presented during the survey. The survey also provides an option if the respondent feels that they are also functioning in another phase.

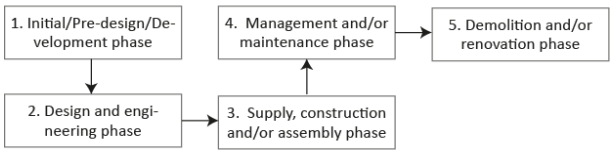


Figure 4.4: Phasing construction and development industry project (Own illustration)

Design & Engineering phase

It appears that the existing research on I4.0 technologies mainly focuses on the construction phase in the construction project's life cycle. For example, Son et al. (2010) showed that most of the work published in the International Symposium on Automation and Robotics in Construction during 1990-2008 focuses on technologies in the construction phase. The phase *D&E* consists of visualization, conceptualization, programming, cost planning, architectural, structural, systems design, analysis, detailing, coordination, and specification. In this phase, most of the project planning and execution information is provided. Therefore, this is an interesting phase to investigate for the research. Moreover, this is the first phase of a project where many stakeholders come together for the first time and depending on the project, this phase often takes quite some time and there is still a lot to gain, as mentioned in the literature review.

Stakeholders

The literature emphasises the importance of those affected by projects as key stakeholders on international development projects.According to the most common definition of stakeholders in development projects, stakeholders are affected by the outcome or those who can affect the outcome of a proposed development intervention (World Bank, 1996). Another common perspective on defining stakeholders defines stakeholders as those interested in a project/development activity (DfID, 2002).

To have effective research, all relevant stakeholders must be identified early in the process. Some stakeholders may be prominent in urban development projects, but others are excluded from the usual decision-making processes and are less important for this research. In figure 4.5, a distinction is made between different stakeholders in urban development. In figure 4.6, Jayasena et al., illustrate a review of the stakeholders of a smart city project in seven (7) key literature.

There is a lot of overlap in the tables about stakeholders within urban development and a Smart city. This research focuses on the stakeholders in the category "Those who affect the project". This category in table x will also immediately define which stakeholders are eligible for the survey and the interviews.

Broad category	*Sub-category*	*Types of Individuals/Groups*
Those who affect the project	Those involved in delivery of the project	Developer
		Client
		Owner
		Investor(s)
		Project manager/management team
		Banks
		Insurer(s)
		Contractor(s), sub-contractor(s) and suppliers
		Professional consultants (e.g. architectural, engineering and financial)
	Those who determine the context	Local Authority – Planning department etc.
		Regional government departments
		Central Government Departments
		Non-departmental public bodies such as Environment Agency, Housing Corporation etc.
Those who are affected by the project:	Directly affected	Users of the buildings, spaces, facilities etc.
	May be directly or indirectly affected depending upon the context	Local/surrounding community members
		General Public
		Local community groups such as resident associations, or other community-based groups
		Specific demographic groups such as those based on race, ethnicity, gender, age etc.
Others who may be interested		Environmental/social campaigning organisations
		Researchers/ Academics
		Media
		Potential users/clients for future projects

Figure 4.5: The generic stakeholder categories and types (Mathur et al., 2007)

Stakeholders of smart city
Academia and Research Institutions
local and regional administrations
Financial suppliers/Investors
Energy suppliers
ICT sector representatives
Citizens
Government
Property developers
Non-profit organisations
Planners
Policy makers
Experts and scientists
Political Institutions
Media

Figure 4.6: Main common stakeholders in review of seven smart city projects (Jayasena et al., 2019)

4.3. Adoption

Firstly, the distinction between innovation adoption and creation should be made. Innovation creation introduces a new product or service ahead of competitors (Kerin, Varadarajan, & Peterson, 1992). In contrast, innovation adoption is about adopting existing ideas (Naranjo-Valencia, Jiménez-Jiménez, &

Sanz-Valle, 2011).

This research will focus on the stakeholders adopting innovations as this is dominant in the construction industry. As a result, organizations feel more comfortable adopting existing tools that align with the current demand and not introducing new tools or ideas to surprise their client or the market as this is also not their field (Pérez-Luño et al.'s 2011). As mentioned in the problem statement, there is a gap between I4.0 and the construction industry. It will continue to grow as long as there is (s)low adoption of technology and a lack of innovative processes in construction (Zabidin et al., 2020).

On the other hand, there are applications/technologies specific to the construction industry, namely Building Information Modeling (BIM), 3D construction printing, or modular construction components. Thus, the construction sector has adopted the concept of I4.0 within the construction sector (Zabidin et al., 2020). These technologies are, therefore, on a certain level of maturity. Furthermore, central technologies like Building Information Modeling (BIM), mobile computing, cloud computing, or modularization have reached market maturity. Further analysis of the current adoption in the construction industry will be explained in the literature review.

5

Literature review

To understand the main topic, certain aspects must be analyzed more in-depth. Therefore, this chapter analyzes existing literature to understand the subject before executing the research and answering the research questions. This results in the first impressions and findings of the topic.

5.1. I4.0 technologies

Technology integrations

Integration and self-optimization are the two important mechanisms used in an industrial organization (Schuh et al., 2014). Three dimensions of integration essentially outline the paradigm of Industry 4.0 (Stock & Seliger, 2016):

- horizontal integration across the entire value creation network
- vertical integration and networked manufacturing systems
- end-to-end engineering across the entire product life cycle

Furthermore, the complete digital integration and automation of the processes in the vertical and horizontal dimensions imply automation of communication and cooperation, especially standardized processes (Erol et al., 2016).

Convergence and application of I4.0

Nine foundational technology advances power I4.0 of technological advancement. advanced robotics, additive manufacturing, augmented reality, simulation, horizontal/vertical integration, industrial Internet, the cloud, cybersecurity and big data and analytics (BCG, 2016).

The possibility of billions of people connected by mobile devices, with powerful processing and ample storage capacities as well as access to knowledge, is unlimited and will be enhanced by the advancement of technology in fields such as artificial intelligence, robotics, the Internet of things, autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing (World Economic Forum, 2020).

Those new technologies also bring new problems. For example, while automation will improve industry performance, it is understood that it may come at the cost of jobs. Cybersecurity issues will also emerge as people are increasingly connected to their devices and share more information

about themselves. There are also potential ethical issues in allowing machines or systems into critical decision-making processes.

In Chapter 6, different technologies will be discussed more specifically. Here, a selection of the most common technologies in the construction sector will also be made. These will then be included in the survey.

5.2. Potential advantages of I4.0 in the C&DI

The benefits of adopting I4.0 technologies are different for each stakeholder because they might deploy the tool differently. Furthermore, the advantages can be different per adopted technology and organizations could differently interpret the advantage. A BIM tool can enhance and improve the project process in the construction and development industry. BIM can transform how the project is being designed, constructed, analyzed and managed throughout the project lifecycle (Latiffi et al., 2013). This can lead to, for example, work reduction, optimization of the design and increased sustainability. The benefits considered in this study come from the scope of the technologies chosen and their application explained in chapter 6. In chapter 8, the benefits are explained based on the literature, which is taken into account for further research.

5.3. Barriers withholding adopting I4.0 in the C&DI

I4.0 technologies in the construction industry have increased in recent years. This is primarily due to the immense potential of I4.0 for improving the performance of construction projects and structuring their underlying management processes, as discussed in the previous section. It seems companies go through digital transformation to join with the constant evolution and react to the challenges imposed by society. However, as there are many benefits, these new technologies have many barriers before implementation and new challenges occur after implementation. Therefore, it is interesting to know what the main barriers are in Industry 4.0. Despite the benefits that the adoption of Industry 4.0 technologies brings, there is still a long way to go (Dalenogare et al., 2018, Frank et al., 2019).

Consulting firm Deloitte surveyed in nineteen countries chief executive officers (CEOs) if they were confident if their organization were prepared to incorporate the changes by I4.0. Only 14% of the CEOs revealed that their organization is prepared to incorporate I4.0. McKinsey revealed that four out of ten companies made good progress after implementing industry 4.0 (McKinsey Digital, 2016). This limited progress was made due to the various barriers withholding organizations to adopt I4.0. Researchers indicate that adopting I4.0 is a complex process. Many companies across different countries face issues due to different barriers (Luthra and Mangla, 2018, Dalenogare et al., 2018). Therefore, there is a need to identify the barriers in this research, leading to a smoother adoption (Kamble et al., 2018).

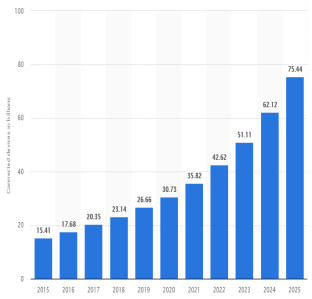
5.4. I4.0 adoption in the C&DI

The world is facing global challenges such as global warming, scarcity of natural resources, terrorism and economic divergence (Yoshihiro Shiroish, 2018). The connection between people and things and between the real and cyber worlds will enable the effective and efficient resolution of societal issues, create more quality of life for people and sustain healthy economic growth (Yoshihiro Shiroishi, 2018). Resulting in the growth of the construction industry that increased the demand for digital technologies. Advantages discussed in section 5.2 associated with I4.0 technologies are anticipated to drive the growth of the construction 4.0 industry. However, the barriers (section 5.3), such as lack of skilled staff and capital, is anticipated to hamper the growth of the construction 4.0 market.

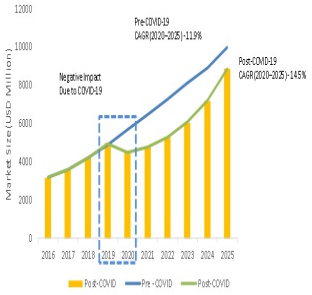
Indeed, most organizations are still in the early stages of preparations for I4.0. Businesses with comprehensive I4.0 strategies believe they are far more successful across multiple dimensions, including measures related to financial performance, societal impact, talent, and technology investment (Deloitte, 2020). Companies that already have the critical capabilities, such as manufacturing execution systems and data marts, may speed ahead, while other organizations lack these prerequisites. Small and medium enterprises (SMEs) and businesses in a more challenging financial or liquidity position may delay implementation until they can build the foundations or find the required financial muscle to invest. This can be seen as one of the main reasons that adoption in the construction industry is still (s)low.

The growing use and interest of innovative technologies have recently enabled the digitization, automation, and integration of the construction processes at all phases of the construction value chain (Oesterreich and Teuteberg, 2016). As a result, I4.0 has been impacting the construction sector since 2009. I4.0 makes it possible to integrate the workflows of advanced technologies into continuous improvement methodologies by incorporating factors such as IoT, AR and Big Data (Barreto et al., 2017; Li and Yang, 2017; Trompisch, 2017; Wagner et al., 2017). Briefly, these technologies enable the physical and digital worlds to be merged and bring significant enhancements to performance and productivity or as Yang and Gu (2021) describe as a network connection between systems, objects, and people.

One of the technologies of I4.0 is IoT (Chapter 6). Graph 1, shows the number of IoT connected devices worldwide from 2015 to 2025 (Statista, 2021). Another I4.0 technology is BIM (Chapter 6). Graph 2, shows the market size of the BIM market (Markets and markets, 2021). Same as the IoT graph, this graph shows a steep slope up as more and more companies are making use of this technology. In short, many new technologies have been developed within Industry 4.0 in recent years, two of which have been briefly highlighted, indicating that significant growth is expected. Thus, the literature confirms the growing interest and need for I4.0 in the construction industry, but still, many barriers make it hard to adopt I4.0 technologies.



(a) Connected devices with the internet per year (Statista, 2021)



(b) Pre- and Post-COVID-19 Scenario for Building Information Modeling Market (Markets and markets, 2021)

So in phase one, through literature review and exploratory interviews, the first impressions of the literature were drawn and the first interviews resulted in the first understanding of I4.0. In addition, the thoughts from others helped to formulate the first understandings of what barriers are withholding CDI stakeholders from adopting I4.0, currently used I4.0 technologies and the advantages.

Phase two: Understanding I4.0 in C&DI

6

Main adopted I4.0 technologies

In Chapter 6, different technologies will be discussed more specifically. Also, a selection of the most common I4.0 technologies in the C&DI is made. These are included in the survey. The literature review shows that there are many different technologies applied within the C&DI. Therefore, to delineate the research which is essential, several I4.0 technologies are selected that are now understood to be increasingly used. Below is a selection of nine technologies that will explain the characteristics and functionality. In addition, consideration was made whether the technologies in the *D&E* phase are applicable or can be applied. (See Appendix A). The following I4.0 technologies are included in the research:

Augmented reality (AR)

In general, AR-based systems support various services, such as selecting parts in a warehouse and sending repair instructions via mobile devices. In addition, the industry can use augmented reality to provide workers with real-time information to improve decision-making and work procedures. For example, workers can receive repair instructions on how to replace a particular part while looking at the existing system in need of repair (Eurostat, 2018).

Virtual reality (VR) and augmented reality (AR) technologies are already seen as game-changers for the construction industry. Virtual reality (VR) implies a total immersion experience that excludes the physical world. In comparison, AR adds digital elements to a live view. The possibilities of VR/AR technologies combined with BIM technology are endless. The first step would be to create a building model with BIM technology and then literally walk through and around it. AR has become one of the most exciting technologies to invest in because of the emerging concept of intelligent manufacturing.

An example of its application is real-time design feedback visualization of 3D projects and their environment. AR/VR technology supports fast and accurate simulation of architectural or structural changes, automatic measurements and enables design improvements. Another example is VR and AR for risk assessments (as a demanding and sensitive activity), enhanced with hazard simulations and clash detections, which have become a routine task encompassed by these innovative technologies. Moreover, VR/AR can support maintenance activities (Ceruti et al., 2019).

Blockchain

In 2008, was the introduction of cryptocurrency, a digital currency (e.g. Bitcoin and Ethereum). A blockchain is digital information stored in a transactional public database (block). It is peer-to-peer

verified or controlled by a network of computers (chain). The advantage of Blockchain over standard databases is that no intermediary is required as all data exchange takes place between end-users. In addition, no central authority is needed. Each node in the chain contains different information, such as contracts or proof of a tax transaction. The fact that each node controls the data and is responsible for safeguarding its piece of information through a digital signature makes it possible to exchange information quickly and securely and without the intervention of third parties.

For example, Blockchain can be used on contracts in the construction industry. Blockchain can act as the unique trusted administrator for all stakeholders involved in the execution of the contract. In addition, Blockchain can set up error-free processes for generating, monitoring and managing contracts. A smart contract is a kind of digital protocol that can be deployed in a Blockchain network to execute contract terms. Also, this can exclude intermediary parties and their services and improve the efficiency of contracts.

The Blockchain also provides transparency during the construction process, which can influence project workflow optimization. Moreover, it stimulates collaboration and ensures timely decision-making while minimizing risks. The Construction Blockchain Consortium confirms the increasing importance of Blockchain within the construction industry. Blockchain can become the catalyst for collaboration and encourage transparency in transactions during the realization of contracts, for example, through the "pay as you deliver" model. It enables digitally valid proof of realized contractual obligations that trigger payment (Construction Blockchain Consortium).

Geographic information system (GIS)

A geographic information system (GIS) creates, analyzes, manages, and maps all data types. GIS connects data to a map, integrating location data with all types of descriptive information. GIS helps users understand relationships, patterns and the geographic context. The integration of BIM (Building Information Modelling) and GIS have been applied in the construction industry for years now. BIM is an intelligent 3D modelling tool that supports engineering, architecture and construction professionals to effectively plan, design, modify and manage buildings and infrastructure. There are different integration methods between BIM and GIS, such as the extraction of GIS data on BIM platforms or the extraction of BIM data to the GIS context (Ma & Ren 2017).

Sharing information/data is considered helpful and leads to better performance and stimulating collaboration and cooperation (Kim & Chai, 2017). The benefits include improved communication and efficiency as well as better management and decision making. An example of the application of the integration of BIM and GIS in the construction industry are: to visualize and monitor the status of construction supply chains (Wang et al.,2017)

In the planning and design phases in C&DI projects, BIM-GIS integrations provide rich information for decision-makers. For example, they can evaluate the costs, scheduling, and sustainability early by showing a 3D virtual design with the environment(Cheung et al., 2012).

Besides, BIM-GIS integration can also perform complex building performance analysis to ensure an

optimized building design and its surrounding environment.

Artificial intelligence

In recent decades, there have been many definitions of AI. The definition for this research is the following: "It is the science and technique of creating intelligent machines, especially smart computer programs. It is akin to the similar task of using computers to understand human intelligence, but AI need not be limited to biologically observable methods." (John McCarthy, 2004) Through AI, the construction industry can benefit from increased efficiencies in cost and speed, for example. AI can provide predictive design to take into account many more factors than a human can. Through AI, different design alternatives can be created where, for example, electrical, mechanical and plumbing systems are taken into account in combination with routes for MEP systems and do not clash with the architecture. In addition, AI can provide better financial planning and increase productivity using historical data.

Sensors

Sensor technology has advanced in recent years as they grow smaller, more resilient and durable and better able to withstand various conditions in almost every industry (Nichols, 2020). According to Globe Newswire, the worldwide market for sensors is expected to reach $27 billion by 2022 as the value in 2016 was $7.5 billion (2018). Smart sensors communicate remotely, usually wirelessly, with a “home base” like a maintenance dashboard system. In addition, advanced smart sensors that use “system on a chip” (SoC) architecture provide smaller device footprints and relatively lower prices than previous-generation multi-chip packages.

Several construction industry sensors are embedded in concrete to indicate precisely when a new pour has finished curing. In addition, sensors can wirelessly provide real-time updates on project status, the location of vehicles, deliveries and assets or the condition of various components during construction or after.

Internet of things (IoT)

IoT is already an integral part of all industries, including the construction industry. Information collected via sensors can improve efficiency and also, for example, safety. For example, by using geolocation, hazard zones can be identified and then alerted to the construction site by other smart technologies. Through IoT, devices can be connected to each other and allows for Big Data, machine learning and AI to be connected. The information that can be gained from this can help in the planning of future projects. This allows the future perspective of finances and resources needed, among other things, to be worked out much better.

Benefits that can be achieved through adopting IoT are: up-to-date information for better decision making, improved project completion with minimal human effort, minimized project delay by drawing preventive measures, human resource management, environmental monitoring, economic benefits and much more (Dilakshan et al., 2021).

Simulation/Digital Twin (DT)

Simulations are used to mirror the physical world in a virtual model. A DT is an exact virtual copy of reality. Data from reality is implemented in the DT, making it different from a 3D drawing. Because real-time data is continuously fed into the DT, the model changes with real-time data. It can show the reality but also the predictions. For example, wear and tear can be included in a Digital Twin, taking it a step further than the BIM model discussed above. Digital Twins are primarily used to perform analyses for the management and maintenance of buildings and infrastructure. Based on the results of the analyses, the design can be optimized. A Digital Twin has the potential to increase the quality and speed of decision-making(Syam & Sharma, 2018).

Autonomous robots

An autonomous robot is also known as an auto robot or Autobot. It is a robot that performs behaviours or tasks with high autonomy (without any external influence). Autonomous robotics is considered to be a subfield of AI, robotics, and information engineering.

One of the least automated sectors is the construction industry, while manual labour still plays a significant role in productivity. Within the construction sector, the focus of robots is particularly, on the construction phase. For example, construction sites are becoming smarter so robots can be deployed and programmed smarter. However, the construction environment is cluttered, unstructured, and employs many people. Moreover, construction processes are usually labour-intensive and consider large margins of error in the built system (Saidi et al., 2016). Nevertheless, various robots are increasingly being used within the construction industry. Especially now that robots can become even smarter in collaboration with other technologies such as AI. By utilizing these robots in real-time constructions, the various parameters such as time, cost and quality can be improved (Kumar et al., 2016)

Big data & analytics

Big data is a term used to describe extensive data sets that may uncover hidden trends, patterns in behaviour and unknown correlations to make more informed business decisions. Big data is a term that refers to the large growing data sets that are collected using digital communication devices from satellites to smartphone applications, which are stored in computer databases and ‘mined’ by advanced computer algorithms (Surbakti et al., 2020). The gathered data can serve as the basis of AI and for the automation of systems. Big data is not a technology in itself but serves technologies such as BIM with data. For example, historical data from traffic, weather, community and business activity can be analyzed to search for patterns and probabilities. For example, these might help steer new projects and optimize the design in BIM and GIS or help optimal phasing for construction. The data can also schedule maintenance activities as required via BIM.

7

Main barriers to the adoption of I4.0

In section 5.3, it became clear that there are still many barriers to adopting I4.0 technologies in the construction industry. In addition, the adoption shows that the benefits do not often outweigh the barriers that need to be overcome for the time being. A more extensive literature review has led to the following twelve common barriers for adopting I4.0 in the construction and development industry. These barriers are explained and are included in the survey. Again, according to the respondent, there will be room in the survey to add other barriers if they miss out. From the survey and interviews, the extent to which a barrier is seen as a more significant obstacle than another will become clear.

Challenge in value-chain integration

This kind of challenge amplifies when multiple organizations in the value chain require integration. There is the need for close cooperation among value-chain partners and horizontal value-chain integration (Geissbauer et al., 2014).

Challenges in ensuring data quality

For fully realized big data, a large amount of data has to be generated. Moreover, this data is in the general complex of nature and heterogeneity, making it hard to measure if complete and accurate. Therefore this increases the risk of false discoveries and conclusions (Lohr, 2012). Moreover, data changes frequently, data integrity and consistency become a big challenge as they might be shared with multiple collaborators (Khan et al., 2014). As being interconnected between firms in Industry 4.0 is critical, this is a significant barrier.

Disruption to existing jobs

The displacement of humans instead of human resources might be a potential challenge in a social and organizational context. The advancements in Industry 4.0 could disrupt the labour market and potentially increase inequality (Swab, 2017).

High investment

According to Kache and Seuring (2017), high investment in people, processes, and technology is required at the corporate and supply chain levels to implement Industry 4.0. Firms, therefore, must re-engineer their existing strategies. In addition, companies have to commit to increasing their planned yearly capital investments by 50% for the next five years (Geissbauer et al., 2014).

Labour market inequality

As discussed, the disruption to existing jobs is a barrier as the labour market will be disrupted and inequality might increase. This social tension could be negative or positive, but the technologies will segregate the market into low skills/low pay and high skills/ high pay categories. The gap between those dependent on labour and capital increases inequality (Schwab, 2017).

Lack of digital strategy alongside resource scarcity

As Industry 4.0 requires a consistent flow and data availability vertically and horizontally within and across organizations, smaller firms might face challenges such as resource constraints (Schröder, 2016). Furthermore, it is a strategic decision to implement Industry 4.0 and reservations at the top management level, making it challenging to develop a digital strategy to implement Industry 4.0 initiatives (Ahlers, 2015).

Lack of clarity regarding economic benefit

The productivity paradox regarding technology implementation brings uncertainty about the precise assessment of the economic benefits of investing in technology and therefore, many firms seem reluctant.

Lack of digital skills

Hung (2016) cites that having employees with the required knowledge and skills is one of the biggest challenges. Firms admit that they do not have the expertise to realize the full potential of implemented technologies (Breunig et al., 2016). As more and more businesses become data-driven, the firms need a more qualified workforce which is one of the significant challenges (Geissbauer et al., 2014)

Lack of infrastructure

Industry 4.0 would require every channel member to be integrated. Therefore, digital infrastructure is a factor that cannot be ignored. As a result, the firms collaborate instead of competing as infrastructure development is needed for Industry 4.0 Buntz (2016) cites from Penton's survey.

Lack of internal digital culture and training

Breunig et al. (2016) state that to benefit from Industry 4.0, it is necessary to have a culture that fosters innovation and is open to change. Besides, it is essential to have internal capabilities. As these employees with these capabilities will be in higher demand, this might shift the employees needed within the organization.

Resistance to change

Implementing Industry 4.0 in organizations relates to employees who are unwilling to change the way they work. As a result, these employees resist using new technologies and practices (Haddud et al., 2017). Another dimension of resistance is the sensitive and personal data that is obtained. This deters firms, as well as individuals, from adopting Industry 4.0 for fear of privacy breaches.

Risk of security breaches

Breunig et al. (2016) talk about firms' cyber-security concerns and the fear of losing their data to third-party software and service providers in Industry 4.0. Hackers would pose severe threats to sensitive data (Lee and Lee, 2015).

8

Main advantages of I4.0

Industry 4.0 was initially aimed at boosting revenue growth, productivity and competitiveness. However, it is also increasingly being used for environmental and sustainable solutions (Bonilla et al., 2018). The technologies face essential requirements or barriers to adoption. These are discussed in the previous chapter. This chapter identifies several benefits that can be gained from the adoption of I4.0 technologies. These benefits are the result of the literature review and will be considered in further research. This is only a part of the potential benefits and results from the chosen scope of the technologies in chapter 6. Improved product quality think, for example, of an improved design of a building that better matches the current building and environment through BIM and GIS. This could lead to an increase in positive feedback from customers, the municipality or new residents, for example. Furthermore, improving vertical integration with I4.0 technologies such as IoT and AI, for example, enables the integration of departments and hierarchical levels of the organization, which can lead to increases in efficiency in decision making and improvements in production processes. The benefits considered for this research are:

- Improved product quality
- Production processes are improved
- Positive feedback from customers
- Energy efficiency
- Increase of company image
- Competitiveness
- Increased of efficiency
- Increase communication in the organization
- Increasing decision making

Many benefits are closely related and are still broad concepts and can be interpreted differently. For example, improved product quality may lead to more competitiveness, or an increase in the organisation's communication may increase decision-making. An increase of decision making can in itself also be explained that the increase leads to cost reduction or time for making choices

9
Conclusion phase 1 and 2

9.1. Generic questions

Below, the generic questions will be answered by means of the literature review. After the literature review, the research questions were formulated that are introduced here.

What are the main adopted I4.0 technologies?

The literature review shows that there are many different technologies applied within the construction industry. Therefore, the focus is I4.0 but is delineated to a scope of nine increasingly being used technologies in the construction industry. These nine technologies are explained in chapter 6 with also some examples of how they can be applied within the construction sector. It is important to notice that many more technologies are being used in the current market. However, a selection was made for the study and a study was conducted on the basis of these nine technologies. This does not say anything about the entire adoption of all technologies that are applied. The selection is made up of the most common technologies from the literature review. The nine technologies from I4.0 that are included in this research are AR, Blockchain, GIS, AI, Sensors, IoT, Simulation/Digital Twin, Autonomous Robots and Big data & Analytics.

How is I4.0 adopted?

The growth of the construction industry increased the demand for digital technologies. I4.0 technologies in the construction industry have increased in recent years. This is primarily due to theimmense potential of I4.0 for improving the performance of construction projects and structuring theirunderlying management processes. However, most organizations are still in the early stages of preparations for I4.0. Thus, while there is a growing interest, the barriers are still withholding organizations to adopt I4.0 technologies. Often small and medium enterprises (SMEs) are challenged financially or with liquidity which may delay adoption until they can build the foundations or find the required financial muscle to invest. Further research will have to show whether this is also one of the more significant barriers within the Dutch construction sector and what can be done about it. Conclusions will also have to be drawn as to whether the adoption in the construction industry is still (s)low in the Netherlands. However, the use and interest of innovative technologies is increasing and enables digitization, automation, and integration of the construction processes at all phases of the construction value chain(Oesterreich and Teuteberg, 2016). As a result, I4.0 technologies have impacted the construction sector since 2009 and

might change the construction industry with a significant impact (Barreto et al., 2017; Li and Yang, 2017; Trompisch, 2017; Wagner et al., 2017). It is essential to look at the adoption in the development phases as the D&E phase of the construction and development industry in the Netherlands, as there is still little attention for this in the literature.

Phasing in C&DI projects?

When a distinction is made later in the research between the different phases in the construction and development industry projects, a phasing must be maintained so that everyone adheres to the same phases. Different sources in the literature refer to different phases, but in general, they are very similar. Figure 9 illustrates the phasing used for this research.

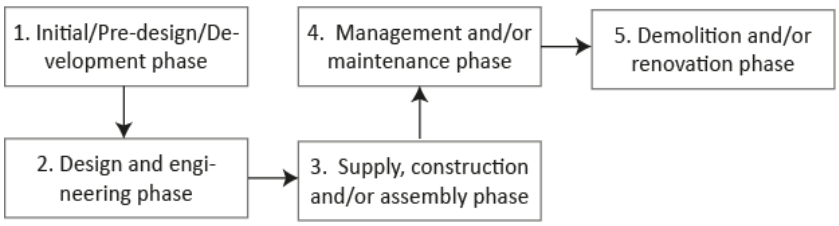


Figure 9.1: Urban development phases (Own illustration)

What are the critical stakeholders in C&DI projects?

For this research, a distinction has been made between stakeholders who affect the project and stakeholders affected. Stakeholders involved in the development and construction possibly use technologies during a project and are taken into account. The stakeholders involved in the research are project developers, investors, project managers, banks, (sub)contractors, consultants (e.g. architects, software as a service (SaaS) organizations and building physics), local authority and public bodies (e.g. regional or central government departments). Affected stakeholder as local communities, media or users of the city, buildings and facilities are not considered for the research.

What are the main drivers to adopting I4.0?

The drivers can be divided into three different categories: Strategic, operations and environment and people. The strategic drivers are a new business model for the entire organization or creating new value for greater competitiveness. Category operations include drivers such as increasing efficiency, cost savings, more quality and increasing turnaround time. Finally, work reduction and environmental impact (sustainability, circularity etc...) are included in the drivers' category environment and people (Muller et al., 2018).

What are the main advantages of adopting I4.0?

Despite the many different interpretations and benefits that can be achieved, the following nine benefits are taken into account for the survey: improved product quality, production processes are improved, positive feedback from customers, energy efficiency, an increase in company image, competitiveness, an increase of efficiency, increase communication in the organization and increasing decision making.

What are the main barriers withholding adopting I4.0?

Despite the drivers and potential benefits, adoption is still relatively (s)low due to the adoption of technologies still consisting of many barriers and new challenges that occur after adoption. In short, there is still a long way to go (Dalenogare et al., 2018, Frank et al., 2019). The twelve main barriers retrieved from the literature review are challenge in value-chain integration, challenges in ensuring data quality, disruption to existing jobs, high investment, labour market inequality, lack of digital strategy alongside resource scarcity, lack of clarity regarding the economic benefit, lack of digital skills, lack of infrastructure, lack of internal digital culture and training, resistance to change and risk of security breaches. It was decided to include many barriers in the research to find out more accurately what companies encounter and to look more specifically at how the barriers can potentially be overcome or removed.

9.2. Introduction research questions

Now that the generic sub-questions have been answered by means of the literature research, the research sub-questions have been formulated. These questions will be answered by means of own research. The sub questions that will be answered in the research are:

- What are the main adopted I4.0 technologies in the Dutch C&DI?
- Is there a malfunctioning adoption of I4.0 in the Dutch C&DI?
- What are the barriers that are withholding Dutch organizations from adopting I4.0 in the C&DI?
- What are the main drivers of organizations to adopt I4.0 in the Dutch C&DI?
- What stakeholders work in the Design & Engineering phase with I4.0 in the Dutch C&DI?

Phase three: I4.0 adoption Dutch C&DI

10

Survey

Chapter 5 presents the literature review done for this study. In chapters 6,7 and 8 a selection of common technologies, barriers and advantages is made. Their characteristics and how they are related or adopted to the construction industry is explained in the relevant chapters. The delineation was made to provide the survey with several relevant options for the survey questions. The options given to the respondents are derived from the literature review.

10.1. Answer options

The answer options have been kept closed as much as possible. However, the possibility of adding an extra technology, barrier or driver is also possible. This ensures that analyzes can be made short term and a bigger audience can be analysed. If everyone answered the questions openly, analysis would become much more complicated and would take much more time. Furthermore, an extensive 11-pt scale is used in the survey. Using 1-5 scales does not yield sufficient diversity in the data to enable optimal critical analysis. Using a 5-pt scale, scores tend to cluster around 3 and 4. While there is a considerable difference in most peoples' minds between a 3 and 4 on a 5-pt scale, making it not easy to discern the actual difference. In the respondents' minds, there's a difference between a rating of 6 and a rating of 7 that you can't capture on a 5-pt scale. So, on an 11-pt scale (i.e. 0 – 10), you will get a much broader spread of the results yielding better predictive analysis. The given answer options to the questions come from the researcher's literature review. For example, the most common Industry 4.0 technologies (chapter 6) in the literature review are listed as options in the survey as you can see here. The complete survey is included in appendix x.

What industry 4.0 technologies makes you company use of? (multiple answers possible)

- Augmented Reality (AR)
- Blockchain
- Geographic information system (GIS)
- Neural networks/ Artificial intelligence (AI)
- Sensors
- Internet of things (IoT)
- Simulation/Digital twin (DT)

- Autonomous robots
- Big data & Analytics
- No Industry 4.0 technologies yet
- I do not know
- Other:

To not exclude common I4.0 technologies used in the Dutch construction and development industry, the answer options also allow for other technologies to be added. Furthermore, the options no I4.0 technologies adopted and not knowing if I4.0 technologies are used are an option.

10.2. Subjectivity

This also immediately describes the subjectivity of a survey as the respondents all have different interpretations and different backgrounds. That is why the survey should be as clear as possible. In a survey with closed questions and questions with a scale, depth is difficult to fathom. That is why this survey is analyzed and used as a basis for interviews conducted afterwards. Keeping the questions simplistic by explaining the scale by the questions consisting of a 0-10 scale might help the respondents answer and interpret the question correctly. However, subjectivity will still have a significant impact on the data and analytics that are made. That is why it is essential to go into the questions in more detail to compare the answers better by interviews. However, with a survey, it is easier to reach a larger audience in a short time. Furthermore, the interviewees Furthermore, the interviewees are approached based on the survey. The survey results will decide which respondents are active in the D&E phase and have fully completed the survey. In addition, it will be considered whether a good alternation of stakeholders can be made and not 4-5 project developers will be interviewed.

10.3. Survey structure

The initial data will be collected by conducting surveys. The survey used in the research consists of seven parts. In the first part, personal and corporate information about the businesses is included. In particular, it consists of questions such as gender, company size, the experience of the respondent at the company, and the number of employees they are working with.

The second part will dive into the technologies used by the respondent company and to what extent it has been adopted. Part three investigates the adoption of Industry 4.0 technologies per life cycle phase of a construction and development project. The phases in the question are based on the literature review. Part four goes into depth about what the main drivers for the company are when adopting Industry 4.0 technologies. Part five focuses on the barriers/challenges experienced by the company when adopting the technologies. Part six mainly has the focus on how they look at Industry 4.0 in the next five years. Finally, part seven focuses on what barriers potentially can be reduced.

The questions have been formulated based on the main and sub-questions of this study. Thus, each

question must have a purpose and should refer back to the research questions in addition to some general questions. Appendix H provides an overview of the survey questions.

10.4. Target audience

In the first instance, the target audience will be published broadly. All respondents of whom the organization is a stakeholder or has to do with urban development in the construction industry will be included. This is to exclude as few parties as possible initially and to obtain as much data as possible. For example, there is the possibility that multiple respondents come from similar organizations. These can be similar organizations based on motivations, amount of employees or activities, for example. This broad set-up provides many data on which many analyzes can be made.

11

Survey results

The survey was online for three weeks through various social channels and ultimately resulted in x respondents. Unfortunately, through the social channels, there was little response and therefore, respondents had to be actively approached and often reminded. The entire survey can be found in appendix x.

The respondents filled out the survey via Google Forms. Since the analyses offered by Google forms are not extensive and cannot be easily modified, we opted to use a tool. By downloading the results in a CSV file and supplementing or improving the respondents' answers where necessary, the file could be implemented in Power BI. Microsoft Power BI is an interactive tool for visualizing data developed and published by Microsoft's American software company. In this tool, data can be linked as you wish and thus, multiple analyses can be made, which are interesting for this research.

Furthermore, the data analysis is analyzed in more detail in sections 11.4 (advantages), 11.5 (drivers) and 11.6 (barriers). The Average Index (AIn) evaluates the influencing factors and identifies the most critical factor (MZAbd, 1997). The AIn equation is as follows:

$$= \frac{(W \times n)}{N}$$

W: scale weight from 0 to 10, given to each factor by the respondents;
n: frequency of respondents;
N: total number of respondents.

In addition, the Relative Importance Index (RII) is calculated to determine the importance of the various factors relative to the cause. The RII value has a range of 0 to 1. The highest value indicates the most criticalness factor (Kometa et al., 1994). The equation is as follows:

$$\frac{(\sigma W)}{A \times N}$$

W: scale weight from 0 to 10, given to each factor by the respondents;
A: highest weight given;
N: total number of respondents.

Statistical Package for Social Science (SPSS) was used to analyze the collected data for reliability and validity. The reliability test checks the consistency of the collected data. Cronbach's Alpha coefficient is used where the coefficient value ranges from 0.00 to 1.00, where 1.00 indicates higher internal

consistency. The measurement process is reliable if the coefficient value obtained is greater than 0.6 (Toke et al., 2012). The value obtained by the square root of the reliability gives an upper limit for the correlation. Thus, for example, a reliability of 0.71 can never have a greater correlation than another reliability of 0.84 (Lester et al., 2014). The equation for the validity test is as follows.

$$S = \sqrt{Reliability}$$

S = validity

The value of the Reliability and Validity Test obtained from SPSS and the gathered data is illustrated in the appendices. The Cronbach's Alpha value can be checked in table 11.1 for the internal consistency to see if the conducted survey results are reliable.

Cronbach's Alpha	Internal Consistency	What to do?
< .50	Unacceptable	Devise other questions to measure the construct
.50 - .60	Poor	Devise other questions and/or add questions that measure the construct
.60 - .70	Doubtful	Add a question that also measures the construct
.70 - .80	Acceptable	Nothing
.80 - .90	Good	Nothing
.90 - 1.00	Excellent	Nothing

Table 11.1: Cronbach's Alpha consistency

11.1. Profile respondents

The vast majority of respondents are male in the study. The type of gender is not of great importance to this study but does indicate the respondents. Possibly there is also a big difference in, for example, the knowledge or interests in I4.0. However, we cannot analyze this as there is too large a proportion of male respondents.

The distribution by age group is about the same. As suggested, the latest smart technologies are from the last decades. Is there, therefore, a difference in the scoring of familiarity with I4.0 per age group? The average of all respondents is a score of 6.37 (Figure 11.1). Table 11.2 shows that the youngest and oldest generations seem to have the slightest knowledge and/or affinity with I4.0.

Variable	Category	Familiarity I4.0 average score
Age Group	20-29	4,83
	30-39	7,45
	40-49	7
	>49	4
	Total	6,37

Table 11.2: Cronbach's Alpha consistency

More than half of the respondents hold a CXO position and therefore have an influential position within their company. In addition, more than half have more than one year of experience within their current company and half within the construction industry. As a result, the knowledge within the company should be sufficient to answer the questions. More than half of the organizations focus on the private and public markets. Furthermore, the profile of the respondents that consists of a width distribution of companies with different activities. For example, most respondents are project developers. A number (9) of ICT providers differ in what they offer or develop. Some offer a tool, while others provide different services. More results from the profile of the respondents can be found in Appendix B.

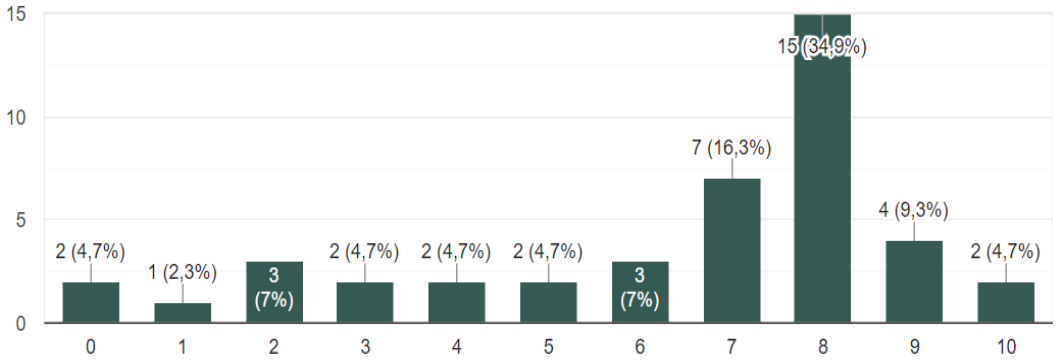


Figure 11.1: Familiarity with the term I4.0

11.2. I4.0 technologies

Adopted technologies in the construction and development industry

26 of the 43 respondents (over 60%) have already fully adopted an I4.0 technology within the company. However, respondents indicated that this varies by the technology they deploy. Furthermore, there is a clear distinction between the different technologies and it can be seen in figure 11.2 that GIS, Sensors, IoT, DT and Big data & Analytics are the most used by the respondent. More than half of the respondents use Sensors and Big Data & Analytics. It is also notable that only 3 out of 43 respondents (7%) do not know if they are using I4.0 technologies. In addition, more than 95% claim

that I4.0 technologies are applied within their company.

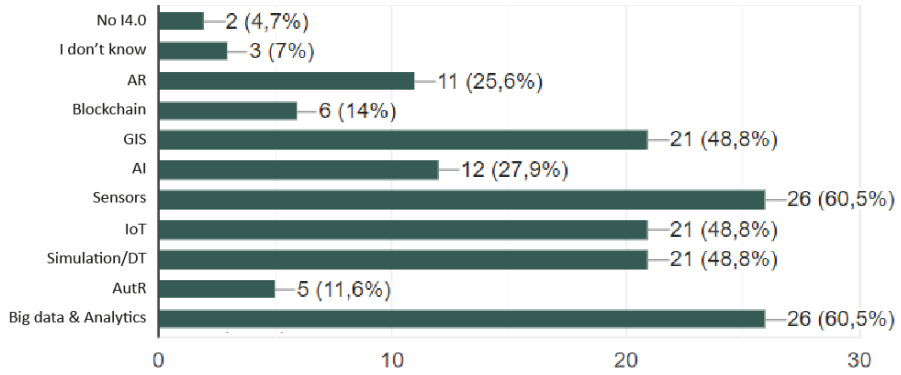


Figure 11.2: Adopted I4.0 technologies

Stakeholders active in *D&E* phase

Table 11.3 rounds up the results from figure 11.2. This is the percentage that applies the relevant I4.0 technology within the organization. Design and Engineering adopted technologies (*D&EAT*) are the technologies adopted by the stakeholders active in the *D&E* phase. The Growth Rate (GR) is to what extent the percentage of *D&EAT* has increased compared to the GAT. The GR illustrates if certain technologies are used less or more in the *D&E* phase compared to the entire urban development cycle.

Advantages experienced	GAT	Rank	*D&EAT*	Rank	GR
No I4.0	5%		0%		/
I don't know	7%		0%		/
AR	26%	4	39%	6	+ 53%
Blockchain	14%	5	13%	8	- 7%
GIS	49%	2	52%	5	+ 7%
AI	28%	3	39%	6	+ 40%
Sensors	61%	1	83%	1	+ 37%
IoT	49%	2	61%	4	+ 25%
Simulation/DT	49%	2	65%	3	+ 34%
AutR	12%	6	22%	7	+ 87%
Big data & Analytics	61%	1	70%	2	+ 15%

Table 11.3: Adopted I4.0 technologies

Conclusion

Figure 11.3 shows that only 5% of respondents do not use the I4.0 technologies within the organization who know about them—suggesting that in the Dutch market, most companies are already dealing with I4.0. Sensors and Big Data & Analytics are applied most often, followed by almost half of the respondents using GIS, AI or Simulation/DT. For the *D&EAT*, a distinction is made between the

respondents in the organizations active in the *D&E* phase or not. Incidentally, the percentage given here does not mean that these technologies are necessarily used within the *D&E* phase. The organizations also active in the *D&E* phase score higher for each technology adoption except Blockchain, as seen in the GR. The application of Blockchain in urban development seems to be applied in the phases after the *D&E* phase (Construction Blockchain Consortium).

It is striking that autonomous robots seem to almost double (83%) and thus seem to be applied mainly in the *D&E* phase. The literature showed that the focus of robots is mainly on the construction phase. However, the results show that most of them also play an active role in the *D&E* phase. So, where the AutR is applied is not clear. However, an organization can more easily adopt Autr in other phases if they already have AutRs in-house. It is noteworthy that more than 83% of the organizations using AutR are companies with more than 250 employees. This could be due to the costs involved.

In addition, the adoption of Sensors has increased among the active respondents in the *D&E* phase. However, the question is in which phase these technologies are applied. However, it can be concluded that at least the organizations that are also active in the *D&E* phase use sensors more often than the average across all phases.

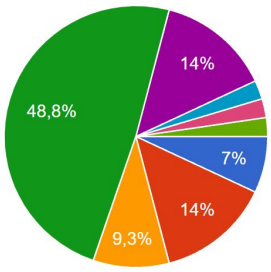


Figure 11.3: Graph 1, Usage Initial/Pre-design/Development phase

Whether the companies benefit from adopting the I4.0 technologies as outlined in the pie chart in Figure 11.3, only 14% (purple) indicate that the benefits are visible. Over 48% (dark green) say they are not yet taking full advantage, which makes sense since over half of the companies have not yet fully adopted the technologies within the company. Furthermore, it is striking that 21% of the respondents say they do not use I4.0 technologies or have no idea about I4.0 in their company. While the analysis in section 11.2.2 showed that 12% have no I4.0 technologies in use or have no idea. Herein seems to be some consistency missing in respondents' completion of the survey.

To what extent they experience benefits of the adopted I4.0 is shown in figure 11.4, in which they could give a score between 0 and 10. Herein similarities are seen with the pie chart. Indeed many respondents say they experience benefits but not yet optimally as only about 13% give a 10/10 as a rating.

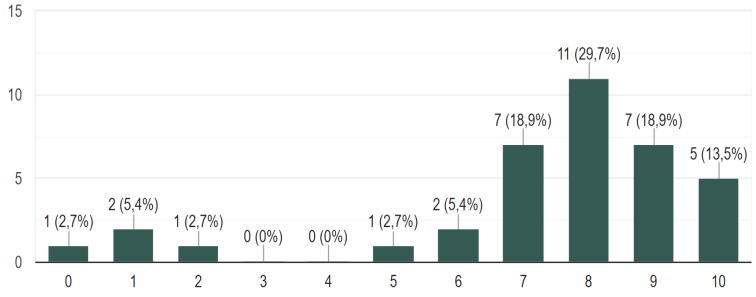


Figure 11.4: Seeing benefits of applying industry 4.0 technologies

11.3. Usage per phasing

The respondent profile of the survey shows the phases before the Supply, construction and/or assembly phase I4.0 technologies are adopted the most. The analysis compares the *D&E* phase to the rest of the urban development cycle. The respondents who indicated that they are using I4.0 in the *D&E* phase or have it in development are included. How the I4.0 usage of the 23 respondents is subdivided is shown in table G.2 (all phases are shown in appendix C). In the demolition and/or renovation phase, it is noticeable that 84% do not apply I4.0 or do not know if they do. For the Supply, construction and/or assembly phase, this is over 65%, while it is less than half in the phases before.

Variable	Category	Frequency	Percentage (%)
Usage	Don't know	8	19%
	Not	12	28%
	In development	4	9%
	Monthly	7	16%
	Weekly	6	14%
	Daily	6	14%

Table 11.4: Usage Design and Engineering phase

Table 11.5 illustrates what kind of companies remain in the *D&E* phase using I4.0. Here, the project developers and ICT providers dominate. Strangely enough, the architects who have a lot to do in this phase but seem not to use I4.0. However, it is almost impossible to imagine that the architects are not using, for example, BIM and GIS nowadays. Also notable, more than half of the investors are either not active in the *D&E* phase or do not adopt I4.0 in this phase.

Variable	Category	Frequency	Percentage (%)
Activity	Architect	0	
	Consultancy	3	13%
	ICT provider	8	35%
	Investor	4	17%
	Municipality	0	
	Project developer	8	35%

Table 11.5: I4.0 active organizations in *D&E* phase

11.4. Advantages experienced

The benefits experienced after adopting I4.0 are described here. The most significant benefits are probably related to the most widely used I4.0 technologies. The most used I4.0 technologies are again related to the profile of the respondents. For example, Blockchain in its current form of application will not quickly claim the advantage of product quality but rather be used to manage contracts and provide transparency throughout the process, leading to better collaboration and thus more efficient decision making. Therefore the most perceived benefits are related to the most used technologies.

The respondents were asked to score nine different benefits from the literature review between 0-10. When the question was left open, the respondent had no idea if they experienced the specific benefit. Scoring 0 meant that this benefit was not experienced and scoring a ten indicated that this advantage was fully experienced within the organization. The benefit, I4.0 increasing the positive feedback from their customers, was left open most often. The two highest scoring benefits were the increase of the organization's image and competitiveness with others. I4.0 technologies increase the energy efficiency within the company is the benefit that the respondents scored the least. However, the weighted average of the scores per benefit is not the lowest for energy efficiency. Because when all scores between 0-10 are taken into account, the benefits increase of product quality, improvement of production processes, communication within the organization and increase of efficiency score lower.

When comparing the respondents active in the D&E phase to all respondents, we see that the benefit product quality of the least allocated benefit among the D&E phase involved stakeholders is perceived a lot better. The weighted average rises from 6.08 to 6.81, making this benefit the most considerable increase. The advantage that sees the most significant decrease in the DE phase compared to all respondents is the more efficient decision making. However, looking at the RII, the more efficient decision making still scores second and the highest value indicates the most criticalness benefit.

The value of the Reliability and Validity Test obtained from SPSS and the gathered data is valid. The Cronbach's Alpha has a value of 0.833, which means that the internal consistency is good (Table 11.1). The validity test value of 91% illustrates that the survey findings are reliable. The results of the advantages can be found in Appendix D.

11.5. Drivers

The drivers results for adopting I4.0 described in this section. The most significant drivers are probably related to the profile of the respondent's organization. For example, will perhaps a more private party mainly want to cut costs and make more profit while a more public party may have the livability of the environment and thus more quality in mind. Or perhaps a smaller company will benefit more from creating new value for greater competitiveness. In comparison, a larger company could strive more to increase efficiency and therefore can reduce the work. Consequently, the most perceived drivers are related to the profile of the respondents and their organization.

The respondents were asked to score eight different benefits from the literature review between 0-10. When the question was left open, the respondent had no idea if this was a driver for their organization. Scoring 0 meant that this was not a driver and scoring a ten indicated that this is the primary driver of the organization. The driver, work reduction, was left open most often. The two highest-scoring drivers are creating new values for greater competitiveness and increasing the organization's efficiency. Turnaround or lead time is the driver that the respondents scored the highest on not being a driver. However, the weighted average of the driver cost savings scores lower than the turnaround time. Comparing the respondents active in the DE phase to all respondents, the ranking for the drivers does not change a lot. For example, the two highest scoring are still the same. Only they have been swapped from ranks 1 and 2. However, it is striking to see the scores increase significantly when all respondents are compared to the respondents in the DE phase. For example, among all respondents, the drivers' average scored 6.06 while the active DE respondents scored almost a point higher, namely a 6.95. Looking at the RII, indicating the most criticalness driver, no changes occur in the ranking.

The value of the Reliability and Validity Test obtained from SPSS and the gathered data is valid. The Cronbach's Alpha has a value of 0.896, which means that the internal consistency is good (Table 11.1). The validity test value of nearly 95% illustrates that the survey findings are reliable. The results of the advantages can be found in Appendix E.

11.6. Barriers

The barriers to adopting I4.0 are described here. The most significant barriers are related to the extent of adoption of I4.0. Furthermore, the adoption is related to the profile of the organizations and respondents. For instance, large established organizations such as companies with 250+ employees may find the resistance to change a significant barrier while having the capital for adopting I4.0. On the other hand, smaller organizations would perhaps like to change, with no resistance but no capital, to adopt I4.0.

The respondents were asked to score twelve different barriers retrieved from the literature review on a scale from 0 to 10. When the question was left open, the respondent had no idea if this was a barrier for their organization. Scoring 0 meant that this was not a barrier and scoring a ten indicated that this is the primary barrier of the organization. The barriers, lack of digital strategy alongside scarcity of resources and the challenge in the value chain integration, were left open most often. The two most

significant barriers are the lack of clarity on economic benefit and the challenge of I4.0 integration in the value chain. The disruption of existing jobs and the labour market inequality scored as the slightest barriers.

Comparing the respondents active in the D&E phase to all respondents, the ranking of the barriers does not change significantly. However, the most significant change from the DE respondents compared to all respondents is that the DE respondents see ensuring the data quality as an enormous barrier. Further, they see the lack of digital skills as a lesser barrier. Respondents had the opportunity to indicate any other barriers they experienced in adopting I4.0. Scalability emerged as a barrier that had not been mentioned before.

The value of the Reliability and Validity Test obtained from SPSS and the gathered data is valid. The Cronbach's Alpha has a value of 0.787, which means that the internal consistency is acceptable (Table 11.1). The validity test value of nearly 89% illustrates that the survey findings are reliable. The results of the advantages can be found in Appendix F.

11.7. Perspective

How do respondents see the future of I4.0? 80% of respondents claim that between 3 to 5 years I4.0 will significantly impact the construction and development industry (Table 11.6). Only 6% think that the transition of I4.0 will have an impact only after ten years. For respondents, the most significant impact can be made and therefore, the most to be gained for their organization is in the 'Initial/Pre-design/Development', DE and the 'Management and/or maintenance' phase (Table 11.7). The 'Demolition and/or renovation' and the 'Supply, construction and/or assembly' phase are much less attractive to the respondents, they think. The respondent profile of the survey shows the phases before the 'Supply, construction and/or assembly phase I4.0 technologies are adopted the most. Therefore, it is consistent that the respondents now use the most technologies and see the most significant potential for adopting I4.0 in those specific phases.

Variable	Category	Frequency	Percentage (%)
Perspective	<1 year	6	14%
	3 years	17	40%
	5 years	17	40%
	10 years or more	3	6%

Table 11.6: Perspective of the I4.0 impact

Variable	Category	Frequency	Percentage (%)
Phase	Initial/Pre-design/Development	24	58,5%
	Design and engineering	24	58,5%
	Supply, construction and/or assembly	8	19,5%
	Management and/or maintenance	22	53,7%
	Demolition and/or renovation	7	17,1%

Table 11.7: Phase to adopt I4.0 technologies

Respondents were asked to what extent they expect the adoption of I4.0 technologies to increase within their companies. Two pie charts illustrate this in Figure 11.5. The left pie is divided based on the increase in the next year. The right pie is divided by the extent to which adoption will increase within the company within the next five years. Yellow represents working toward the adoption of I4.0. So, in the left pie, it is visible that more than half of the respondents said they would start working on I4.0 next year if they did not already. The green areas are the respondents that say I4.0 is already fully adopted in their company. The left pie chart shows 7% whose company is fully operating I4.0. The right-hand pie then shows that in the next five years this has increased to 20%. Red are the respondents where I4.0 is not on the agenda. 21% do not see on the agenda the adoption of I4.0. This number drops below 10% with the prospect of the next five years. The dark blue colour is for the respondents having no idea if it is on their company's agenda. This percentage is the same in both pie charts.

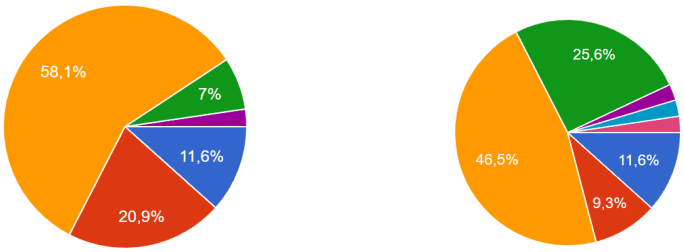


Figure 11.5: Pie charts of growth expectation adoption I4.0 within company

11.8. Stimulance

With the potential of I4.0 and the barriers to adoption, respondents were asked how they think their company could be encouraged to adopt I4.0 and which parties could remove or reduce the barriers. On whether external parties can contribute to the adoption of I4.0, many respondents said that it is key that the company itself organize the adoption of I4.0 within the corporate culture. I4.0 is not a one-time thing. External parties can support, help to set up or transfer specialized knowledge. The most frequently mentioned external parties that could help are the public governmental bodies. PropTech companies and science are also mentioned.

The respondents were asked which barriers could be reduced by more external attention and/or

stimulation from other parties and internal attention and/or stimulation within the company. The two barriers that can best be combated by external attention are the lack of digital skills and clarity on economic benefit. With internal attention, the two most manageable barriers to tackle are the resistance to change and the lack of digital skills. According to the survey, the barrier Disruption of existing jobs is almost not seen as a barrier. The results can be found in Appendix G.

11.9. Conclusion

Based on the results, conclusions can be drawn. So far in chapter 11, some results are discussed conducted from the survey. In this paragraph, the first conclusions are drawn based on the obtained data and results of the survey. Thus, the first conclusions will be outlined and in answering the sub-research questions, it will become clear where extra attention is needed in the interviews.

Sub-question 1, What are the main adopted I4.0 technologies in the Dutch C&DI?

From the survey results, it can be concluded that sensors and Big data & analytics are adopted the most among the proposed technologies. Autonomous robots and Blockchain are still the least adopted in the Dutch C&DI industry. Looking only at the respondents who are also active in the D&E phase, it appears that Sensors and Big data & analytics are still adopted the most. Autonomous robots and Blockchain are still the least adopted. However, the adoption of Autonomous robots of all respondents compared to the D&E phase active respondents is increased by 87%. Blockchain is less adopted in the D&E phase, dropping by 7%. The average adoption of all technologies is 39% among all respondents. Looking only at the respondents who are active in the D&E phase, the average adoption rises to 49%. The respondents added no technologies and concluded that no common used technologies are missing.

Sub-question 2, Is there a malfunctioning adoption of I4.0 in the Dutch C&DI?

All technologies are at least adopted by multiple respondents from different companies. What is evident from the results is that few companies are already actually seeing or utilizing the benefits when using the technologies. Several companies operate internationally. In the interviews, it might be interesting to see to what extent the Netherlands is ahead of other countries in adopting the technologies. It could be concluded that more than three quarters think that the mentioned I4.0 technologies will have a significant impact in the coming years on the C&DI industry and they have the adoption on the agenda for the coming years if not already there. So it seems that there is still considerable growth in the adoption of the technologies ahead. To speak of a malfunctioning adoption is not to say. From the interviews, the main focus will be to increase the adoption if the potential benefits are seen.

Sub-question 3, What are the barriers that are withholding Dutch organizations from adopting I4.0 in the C&DI?

The most significant barriers to adopting I4.0 technologies in the C&DI are the lack of clarity on economic benefit, the challenge in the value chain integration, lack of digital culture and training and

high investments. These are considered the most prominent barriers when analyzing all respondents and when analyzing the D&E active respondents. Therefore, the interviews will have to be clear and why these barriers are perceived as the most significant barriers to adopting I4.0 technologies. Subsequently, one can ask what can be done about this or not. Labour market inequality and the disruption of existing jobs do not seem to be barriers withholding companies to adopt I4.0 technologies.

Sub-question 4, What are the main drivers of organizations to adopt I4.0 in the Dutch C&DI?

The two main drivers for adopting I4.0 technologies in the Dutch C&DI are the increase of efficiency and creating new value for greater competitiveness. The increase in efficiency is very general and will be further explored during the interviews. These also emerge as the most prominent drivers when looking only at the D&E active respondents. However, the respondents active in the D&E phase score the drivers respectively higher.

Sub-question 5, What stakeholders work in the Design Engineering phase with I4.0 in the Dutch C&DI?

For this research, the stakeholders that participated in the survey and are active in the D&E phase with I4.0 technologies are the following consultancy, ICT providers, investors and project developers. One municipality, for example, is active in this phase but not yet active with I4.0 technologies. Therefore, for the interviews, we will look for respondents that are active in the DE phase, of which some are working with I4.0 technologies and some are not.

12

Interviews

The semi-structured interviews were conducted from respondents to the survey. Based on the results of the survey, a selection was made as to who should be interviewed. Some requirements were that the respondent should have a sufficient understanding of the different I4.0 technologies discussed in the survey, multiple I4.0 technologies were adopted within their company, and a clear understanding of the opportunities and barriers of adopting I4.0 technologies. For example, the four interviewed on average scored themselves with an 8.0 on the question, to what extent they are familiar with I4.0? While the average score of all respondents is 6.37. In addition, the interviewees see many perspectives in I4.0 technologies in the coming years and have all implemented several I4.0 technologies at their company. The interviews are converted into a SWOT model to overview the strengths, weaknesses, opportunities, and threads of adopting I4.0 technologies. The SWOT analyses of the interviews can be found in Appendix I. The SWOT models have been merged into a general SWOT model that shows overlap and compelling findings from the interviews. Based on this SWOT, conclusions are drawn about the most significant threads/barriers to adopting I4.0 technologies in the Dutch C&DI.

The four interviewees consist of two project developers and two ICT providers. The project developers both develop on a large scale meaning they develop subareas or several larger buildings within the cities and both are only active in the Netherlands. On the other hand, the ICT providers are active globally, one of which primarily provides services and the other ICT provider primarily offers a tool. All four interviewed are commercial organisations and thus have a profit motive, but all have interests and work together with government agencies.

12.1. Compelling findings from interviews

Below are the most notable findings compiled into a SWOT analysis. SWOT analysis is a technique for assessing a business's performance, competition, risk, and potential. However, this SWOT analysis consists of the compelling findings from the interviews and therefore is a SWOT about adopting I4.0 technologies by project developers and ICT providers in the Dutch CDI.

STRENGTHS	WEAKNESSES
1. Capabilities I4.0 and demand 2. Growing interest	1. Knowledge 2. Short-sightedness and money-drivenness
OPPORTUNITIES	**THREATS**
1. Proof of value 2. Entry level	1. Scalability 2. Municipal processes and policies 3. Full chain collaboration

Strengths

The capabilities of I4.0 technologies are endless these days. Technologies work; however, the application within the construction and development industry is now essential. In today's market, the range of smart technology providers and developers is vast. In 2018, ICT companies showed more substantial growth in gross value added than the Dutch economy as a whole compared to the previous year. The overall economy grew by 2.3%, while the gross value added in the ICT sector grew by more than 5%.

Furthermore, as reported by Statistics Netherlands, the number of ICT professionals and companies increased significantly (2020). End 2019, there were over 81 thousand companies in the Dutch ICT sector which is more than 50% more than in 2009.The growing ICT industry with more and more providers is making the competition in the sector grow and resulting in growth opportunities and an expanding ICT sector. It is evident from the interviews that there is growing interest in adopting I4.0 technologies. Although the barriers still withhold the adoption, the interviewees recognize they need to act to achieve the larger goals such as climate. The growing interest was already clear from the literature and the survey.

Also, the interviews show that the interest is growing and the perspective is positive, but the adoption is not yet very accessible. The I4.0 technology providers are there and the technologies are developing at a rapid pace offering many opportunities for the adoption of I4.0 technologies in the C&DI.

Opportunities/Weaknesses

The opportunities and weaknesses are merged here because different stakeholders were included in the SWOT analysis. For example, the project developer's knowledge of specific I4.0 technologies is substandard. This may be due to a lack of interest or education of the project developer. However, this provides an opportunity for the ICT provider to explain better the tools and/or services they offer. With different stakeholders in a SWOT, there is a close link between the opportunities and weaknesses. Under the opportunities is the 'proof of value' instead of 'proof of concept'. The ICT providers say that they have realized that they need to dive less into the underlying running I4.0 technologies at their customers. Expressing the economic value that the underlying technologies provide is important to the customer. AI, IoT and DT are terms that most project developers are not thoroughly familiar with, and they get bogged down by throwing these terms around. Producing more work with fewer people, more turnover, or earlier compliance with various sustainable certificates is more straightforward for a project developer. To do this, a simple approach at the board level is critical, as emphasized in the interviews. Giving insight into the economic benefit at the board level is now the main task claimed by the ICT providers.

Now sometimes, I4.0 as a hype seems bigger than the potential benefits achieved after I4.0 technology adoption. Expressing explicit values is important because the project developers are often short-sighted and only think 5-10 years ahead, as they say. In addition, in general, project developers have a profit motive that does not look far ahead. This also has to do with investors who are often behind a project. Perhaps there is a need to penetrate at those levels as well. On the other hand, there are claims that ICT providers' clients, such as a project developer or, eventually, an investor, may also have more knowledge in-house. Taking on new positions as data scientists, academics, and psychologists can help adopt, understand, and optimize I4.0 technologies.

The interviews also emphasized that high investments are often the problem for adopting I4.0 technologies, which became clear from the survey also. These high investments come together with the longer-term thinking on which more can be earned later on. Thus, the ball is in the court of both parties: the ICT provider will have to work harder on the proof of value, but the project developer will also have to be more open and start to shift gears before other project developers do, for example, start to reap the benefits of adopting I4.0 technologies.

Threads

Full chain collaboration within a construction and development project proved to be one of the biggest hurdles from the interviews. The C&DI appears to be a very conservative sector within which changes are complex. This has to do with the many stakeholders with different interests within the same project. Cooperation does not often seem optimal as not everyone speaks the same 'language', which means that not everyone works or can work in the same programs or has the same capabilities or knowledge. Transparency and trust are often hard to find and share files and data is often seen as 'scary'. Trust in other organisations is not yet optimal and undoubtedly due to privacy and complex data protection. Public parties, in particular, seem to be cautious.

In addition, it is pointed out in all interviews that the biggest problem in adopting I4.0 technologies lies with the municipal processes and policies. There is hardly multidisciplinary work within municipalities, which means that civil servants are often not well attuned to each other's work.

Furthermore, the interviews describe fear within the employees within the municipalities. Civil servants are reluctant to cooperate because they are afraid that the technologies will take over their jobs. The project developers and ICT providers say that the technologies will open new markets. However, the civil servants will have to be retrained and will have to learn a different quality.

Furthermore, the processes within municipalities can often not be accelerated. Whenever adjustments need to be made in developing an area, this must be done within the municipality's policy. It takes much time and if it is not implemented, the municipality will not deviate from it. The third major problem within the adoption of the I4.0 technologies is scalability. According to the ICT providers and project developers in the interviews, the Netherlands is very advanced compared to all other countries in Europe in adopting I4.0 technologies. However, it appears that the Netherlands is indeed open to innovations of adopting new I4.0 technologies on a small scale. However, when scaling up to further adopt different technologies, the Netherlands seems reluctant compared to other countries.

12.2. Conclusions

The data from the survey resulted in analyses that is used during the interviews. The most relevant barriers and I4.0 technologies are included in the interviews. The survey showed that the lack of clarity on economic benefit and the challenge in the value chain integration are the most significant barriers. During the interviews, these were also presented to see what could be done about them. Furthermore, other barriers were sought. In this way it was able to understand better the barriers that project developers and ICT providers in the Netherlands are facing that were not addressed in the survey. The most significant barriers that emerged from the interviews next to the survey results are the scaling-up problem in the Netherlands, the municipal processes and policies and the cooperation between stakeholders in the entire chain. Many fingers point towards the public parties that everyone within the CDI could benefit from this, including themselves, if they would approach some things differently.

The lack of economic benefit needs to be better elaborated and made transparent by the ICT providers to adopt I4.0 technologies faster. The ICT providers themselves also confirm this problem, that the proof of value needs to be worked out well. However, the ICT providers expect their customers, such as project developers, to develop more expertise and are more open to innovations. This still seems to be a big problem from the interviews, but it is being worked on.

That the Netherlands is progressive in adopting I4.0 technologies was also confirmed in all interviews, but the progressive is not continued when scaling up is needed. This often creates the impression that, for example, an alderman is working innovatively but does not experience the ultimate impact and potential benefits of the innovations. This problem occurs more often in the smaller municipalities than in the larger ones where more support, attention and money are spent.

Furthermore, the processes of the projects are complex because there are many stakeholders involved and they do not work together in a multidisciplinary way. Implementing something within the policy is not easy and fast because there are so many links between them that it takes a long time to change the policy. Where are the problems here and where are there opportunities to address this? Working together and transparently and building trust is also a barrier within current projects. Let alone when complex I4.0 technologies are involved, they are currently often too complex for many to see the economic benefit, let alone that they have to delve into the underlying technologies.

The interviews have given more depth to the barriers of the survey and eliminated the lesser barriers. These will be transformed into five different propositions that will be assigned to the focus group. What is their opinion and view of the proposition? When is a side was taken in the proposition, what can be done to overcome the barrier? Also, because fingers are pointed at public parties, these barriers should also be presented to them to see if they look at it the same way as the commercial parties in the interviews. This will be explained in the next chapter.

Phase four: Insights and potential interventions for adopting I4.0 in the Dutch C&DI

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Focus group interviews

Prior to the focus group, several propositions were drafted based on the survey and interviews. These propositions highlight the critical aspects that result from the conclusions of the survey and interviews. The purpose of the propositions is to see if the focus group agrees with the research results. In addition, examine whether there is room for discussion between different interpretations of different stakeholders and what is possible to overcome the most significant barriers. In the survey and interviews, there were hardly any public parties involved. The results show that there are often references to the policies and processes of the public parties withholding them to benefit from the adoption of I4.0 technologies. Because of this, there must be multiple representatives from a public party participating within the focus group. Unfortunately, due to COVID-19, the focus group could not meet and it was decided to ask the propositions separately to all participants. However, the views of the others were included to create interaction. Below are the main issues of the propositions with a conclusion.

13.1. Conclusions from the compelling findings from the focus group

Proposition 1

The survey shows that over 80% of respondents believe that I4.0 technologies will significantly impact the C&DI. However, adoption is still relatively low. Does this problem lie with the providers of the I4.0 technologies or with the traditional fragmented C&DI? What can be done about this?

The focus group confirmed that ICT providers are still often unable to make the direct economic benefit concrete. There is often too much attention to the underlying running I4.0 technologies and how they work. It is much more important to make clear why the underlying I4.0 technologies are running. When it does not provide immediate benefits, the customers of ICT providers are often sceptical. Social responsibility is not yet a primary motivation and therefore, aspects such as security or cost reduction should yield immediate benefits. On the other hand, the digital knowledge gap is high in the C&DI.

The C&DI is also not an easy industry as more strict restrictions are imposed on sustainability, safety and circularity. For developing I4.0 technologies, these strict rules often hold back developments, while these technologies can gain a lot after further developments in these areas. Furthermore, adopting I4.0 technologies is still complex, but the training and after-care of I4.0 technologies are experienced as

inadequate. However, the ICT providers think that this also has to do with the closed mindset against changing now and the little knowledge in the field of innovation. Besides the economic advantage, which is confirmed as a significant barrier, the government processes and policies are often cited.

Proposition 2

The research shows that the Netherlands are progressive in adopting innovations such as I4.0 technologies in the C&DI compared to other countries. However, when it comes to scaling up, the Netherlands appears to be very cautious. This is due to the slow policy processes and decision-making structures of the government.

It is suggested from the focus group that the Netherlands is not so progressive at all and that it just depends on whom you compare the Netherlands too. That the processes and changing policies in a municipality appears to be very slow is confirmed in the focus group. This has to do with the structure and responsibilities in the municipalities. It is said that the organization is too big and incoherent. At the same time, it is also said that the government should become more extensive and more commercial to make faster steps considering innovations. More employees at the municipalities also mean more knowledge which is essential to innovate. In the Netherlands, the adoption of I4.0 technologies by the municipality must first be put out to tender and then assessed by the Municipal Council. The Council will then have to approve it and release the budget. When these steps are completed, the I4.0 technology should be adopted and used optimally. This may take years with many uncertainties. There are democratic council elections at least every four years that can also lead to new aldermen with new plans and visions. Furthermore, the I4.0 technologies are innovating rapidly, so the Netherlands will only lag more by waiting. In addition, the fact that governments are full of people with no knowledge of technologies and are open for innovations makes it challenging to create support for complex technologies that, in the civil servant's eyes, will only result in them cutting their fingers. They also point to the municipalities as the client with the wrong mindset and attitude. Tenders are often won by the cheapest bidder, leaving the developers and builders to bear the risks. This also prevents parties from innovating. Innovating means investing.

Proposition 3

In the Netherlands, larger decisions and investments within a municipality must always be passed on to the Council. Giving municipalities more responsibility would speed up development projects and benefit innovations. Or should it be possible for innovations to be submitted directly to a higher authority, directly to the Council?

Within the C&DI in the Netherlands, there are many different officials from the municipality involved in a project. For example, many different specialists are involved (e.g. a water specialist, a green specialist and a safety specialist). All these specialists have their interests and do not work in a multi-disciplinary way, resulting in poor coordination and delays within the process. On the other hand, the project

developer only submits safety documents during the FD (final design). Because of this, civil servants sometimes have to make a final decision immediately while they see the document for the first time. Suppose project developers give the specialists insight at an earlier stage or submit various documents earlier, for example, in the PD (preliminary design). In that case, this could reduce the delays that the projects sometimes incur.

The focus group also revealed that innovation initiatives could not simply be submitted directly to The Council. This would mean that the entire structure within the organization would have to change and this is not possible in the short term. Scandinavia has mentioned as an example that municipalities are larger and more commercial organizations where lower bodies are allowed to make decisions and are offered more financial resources. This results in better adoption of I4.0 technologies and fewer delays during projects.

Proposition 4

A restructuring of the C&DI processes could speed up and improve projects. For example, when issuing a tender, the project developer is involved in an earlier phase with the civil servants (e.g. green, water, and public space specialists). Alternatively, involve the specialists from the municipality earlier in the design phases. The municipality should participate if we want to change in terms of innovation and assume more risk. Being at the same side of the table will improve projects significantly.

A simplified pathway during projects in the C&DI could undoubtedly contribute to growth in innovations. At the moment, everything is set up in a fixed trajectory in which many steps have to be gone through, such as a schematic design, preliminary design and a final design. All have to be approved before there is the possibility of a permit being granted. Only then can demolition or construction begin. Many documents during the design phases are not delivered until the final design, which means that civil servants have not seen the pieces before and must immediately give final approval. When there is a lack of clarity in the documents, they are often rejected. This often causes many delays.

Involving various parties earlier in the process could therefore eliminate delays such as these. However, involving parties at earlier stages can also cause delays because parties get involved and often do not speak the same 'language', which takes time. This has to do with different starting points or interests. For example, a project developer aims for maximum profit as his primary objective and a contractor aims for high-quality service. The difference in language also has to do with specializing in different fields. For example, a BIM model from an installation consultant is different from a BIM from an architect. Giving each other insight earlier and explaining how each other's work fit together could help a lot. There must also be the will to understand each other but also to innovate. Finally, there must be active participation to make a move to innovate more. It is referred to that the participation of governments is essential to innovate. Participation is innovation in a nutshell.

Proposition 5

What is the level of trust between the public and private parties (e.g. between the municipality and project developers)? Are files and data exchanged confidentially? This does not seem to be the case and has to do with mistrust in each other and not speaking the same "language".

As in the previous propositions, speaking the same language is a significant barrier. However, participation also has an important role. Trusting each other to exchange data does not seem to be the most significant task. Nevertheless, understanding each other's data and dealing with it correctly is not easy because there is little uniformity. Applying technological innovations, therefore, requires social innovation and system change. Because that is what is needed to get further than just the 'one pilot where innovation is applied as often happens in municipalities. Many changes will have to be made in order to get going.

13.2. Conclusion

Throughout the focus group, there is much overlap between participants' answers, experiences, and opinions, as seen in the compelling findings. Also, some contradictions cause discussions which will be explained later in chapter 15. In Appendix 11, each participant's most essential points are listed point by point during the focus group. The most critical barriers were discussed during the focus group and the possibilities to overcome them are discussed in answering the main question in chapter 14.

Conclusions and more

14

Conclusions

This research aimed to understand the adoption and main barriers of adopting I4.0 technologies in the Dutch construction and development industry. Therefore, the main research question in this report is stated as follows: "Are barriers withholding adopting Industry 4.0 (I4.0) technologies (e.g. artificial intelligence (AI), internet of things (IoT) and Digital Twins (DT)) within the Dutch construction and development industry, and if so, can these barriers be overcome?" To draw a comprehensive conclusion, the sub-questions are answered first to then answer the main research question.

14.1. Sub research questions

Sub-question 1, what are the main adopted I4.0 technologies in the Dutch C&DI?

Data collection: Literature review and survey

To investigate the adopted I4.0 technologies in the Netherlands, a selection of the most used and common I4.0 technologies was made from the literature review. This resulted in the following nine I4.0 technologies: AR, Blockchain, GIS, AI, Sensors, IoT, DT, Autonomous Robots and Big Data & Analytics. The survey indeed showed that all I4.0 technologies had been adopted among the respondents in the Dutch construction and development industry and no other I4.0 technologies were introduced by the respondents.

The survey results show that sensors and Big data & Analytics are most adopted among the proposed technologies. On the other hand, autonomous robots and Blockchain are the least adopted in the Dutch construction and development industry. When looking only at the D&E phase, the results remain the same. However, the adoption percentage per technology increases, and the adoption of autonomous robots increases the most. However, it still belongs to the two least adopted technologies from the nine selected I4.0 technologies. To distinguish between the different I4.0 technologies is complicated since they are often combined or integrated. For example, GIS and BIM could be integrated into a Digital Twin that generates IoT-connected sensors data. With this data, for example, the design can be optimized using AI.

According to the literature and interviews, the possibilities of the I4.0 technologies are endless and the technological developments are accelerating. As the literature review describes, the interest in adopting I4.0 technologies is growing, the capabilities are endless and the number of ICT providers is

growing significantly. However, for the time being, technologies such as Blockchain and autonomous robots are less adopted than Big Data & Analytics. This has also to do with the fact that Big Data & Analytics have been used for longer than Blockchain and the developments are still less advanced. Because of this, the acceptance is lower and the sensitivity higher, according to the interviews.

The difference between the most commonly used technologies between the phases starting from construction and everything before does not appear to be significantly different from each other. However, the technologies are more often further developed in the construction phases. The research shows that the most significant potential of the technologies in the D&E phase is with the Digital Twins. From the interviews, it also appears that the developments around the Digital Twins are going fast. A Digital Twin is the digital equivalent of a 'real' component and can be as large as a complete building or as small as a pipe. 3D models of physical objects can be considered Digital Twins when integrated into an IoT ecosystem that collects data. Sensors collect data on the status of physical objects and automatically update the digital simulation. As a result, the Digital Twin is always up-to-date, even when real-world conditions change. So the Digital Twin consists of IoT and often sensors. AI applications are also increasingly being implemented. So a Digital Twin uses different techniques and is capable of a lot.

BIM is already a hugely powerful tool used by architects, manufacturers, fabricators and installers to visualize building components and share project information. However, the interviews show that all BIM users still struggle with sharing the project information with BIM because they all use BIM differently. When an IoT framework supports BIM, BIM is taken to an entirely new level and the Digital Twin can excel.During the interviews, the project developers active in the D&E phase emphasised that if the Digital Twins are further developed and applied to many projects, the entire design phases could positively be influenced. For example, Digital Twins can gather historical data on the built and urban environment and feed-forward the data into the design and the need to break down disciplinary silos. In any case, the project developers confirm that they are in contact with developing Digital Twins.

The most significant barriers in the research have to do with the processes within the C&DI between the stakeholders (especially the processes of the public parties). The construction phases are very isolated, confirmed by all focus group participants. Divergent processes, separate objectives and significant differences in skills make project-wide collaboration difficult. Therefore, the Digital Twin would provide an excellent visual, common ground allowing the construction phases to communicate more effectively. The Digital Twins are now paying off mainly after the D&E phases. However, if the data can be taken from completed projects and during the following years in new projects, the Digital Twins can have a significant role in the D&E phase. The project developers confirmed in the interviews that Digital Twins would replace many stakeholder activities in the D&E phase. For example, a Digital Twin will eventually optimize design choices and the architect may have a different role. So because the Industry 4.0 technologies will have a more prominent role in the D&E phase, the activities of different stakeholders will be able to change. Digital Twins can help improve the Netherlands' processes, which is among the most significant barriers.

Sub-question 2, is there a malfunctioning adoption of I4.0 in the Dutch C&DI?

Data collection: Literature review, survey and semi-structered interviews

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The literature review concludes that the construction and development industry lags behind other industries in adopting I4.0 technologies. Since the C&DI is a complex industry with many different stakeholders with different interests and lengthy processes, adopting the technologies is not easy, not quick to realize and the constraints are often more complex. For example, one of the focus group participants explained the complex constraints using 3D printing. One of the technologies is slowly but surely being applied more and more, especially in the construction sector. 3D printing of chairs or coffee cups is of a completely different level than printing an entire house. This involves much stricter requirements such as durability, architectural and building physic requirements, making several prototypes also very expensive.

Five out of nine I4.0 technologies have been adopted by at least half of the respondents in the survey. Concluding, Dutch companies are already consciously innovating their businesses in the Dutch construction and development industry. However, what is evident from the results is that only a few companies are actually seeing or utilizing the benefits when using the I4.0 technologies. However, this appears to be a distorted picture from the Netherlands. The Netherlands appears to be very progressive, but it appears from the interviews and focus group that the public and private parties all confirm that steps are taken on a small scale but that the actual elaboration and scaling up of the innovations is lacking. The slow processes of this to be at fault. 100% of all public parties interviewed during the survey confirmed that they recognize many problems with their policies and processes. However, these are not easy to change due to the structure of the public parties and the ingrained culture in the Netherlands.

More than three quarters think that the mentioned I4.0 technologies will have a significant impact in the coming years on the C&DI. The respondents have the adoption on the agenda for the coming years, if not already there. So it seems that there is still considerable growth in the adoption of the technologies ahead. To speak of a malfunctioning adoption is not to say but that the adoption is not optimal and the companies do not yet get the direct benefits out of it or see them at all says something.

In terms of adopting I4.0 technologies in the Netherlands compared to other countries in Europe, the Netherlands seems to be ahead of the curve. From the interviews and focus group, international players confirm that the Netherlands is more open to innovations and adopting the various I4.0 technologies. However, the opposite voices are heard: the Netherlands is very reluctant to scale up the innovations after adoption. The high-hat attitude the Dutch people have in the C&DI with innovations like adopting I4.0 technologies turns out to be disappointing when the focus group also talks with participants who operate internationally. The Netherlands appears to be safe and conservative and therefore less enterprising and taking the initiative than previously thought. When it was said that there was indeed a problem with scaling up due to, for example, the entrenched processes and structures, the other participants also realized that the adoption of I4.0 technologies in the Dutch C&DI might be less than thought before.

More is discussed in the following sub research question.

Sub-question 3, what are the barriers that are withholding Dutch organizations from adopting I4.0 in the C&DI?

Data collection: Literature review, survey, semi-structured interviews and focus group

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Initially, a selection of the most significant barriers regarding the adoption of I4.0 technologies was made from the literature review. This led to a selection of twelve barriers that were included in the survey. This resulted in several barriers to withholding adopting I4.0 technologies. In the interviews, the most significant barriers were explored and the interviewees had the opportunity to come up with other barriers. Finally, these barriers from the survey and interviews were taken into the focus group to see if the barriers could be understood. This also led to new insights and some new significant barriers. Below briefly, the barriers are explained and where they were retrieved.

The 43 respondents were asked to score twelve different barriers retrieved from the literature review in the survey. The most significant barriers to adopting I4.0 technologies in the C&DI are the lack of clarity on economic benefit and the challenge in the value chain integration. These are considered the most prominent barriers when analyzing all respondents and the D&E active respondents in the survey. On the other hand, labour market inequality and the disruption of existing jobs do not seem to be barriers withholding companies to adopt I4.0 technologies in the Netherlands.

During the interviews, the two most significant barriers from the survey were highlighted and further substantiated by the interviewees as why these withhold the adoption of I4.0 technologies. Furthermore, three barriers came up that were mentioned independently in several interviews. First, full chain collaboration within a construction and development project proved to be one of the biggest hurdles from the interviews. The C&DI appears to be a very conservative sector within which changes are complex. This has to do with the many stakeholders with different interests within the same project. Cooperation does not often seem optimal as not everyone speaks the same 'language', which means that not everyone works or can work in the same programs or has the same capabilities or knowledge. Transparency and trust are often hard to find as sharing files and data is often seen as 'scary', especially between public and private parties. The second introduced barrier in the interviews is scalability. According to the ICT providers and project developers in the interviews, the Netherlands is very advanced compared to all other countries in Europe in adopting I4.0 technologies. However, it appears that the Netherlands is indeed open to innovations of adopting new I4.0 technologies but mainly on a small scale. When scaling up to further adopt different technologies to increase the benefits, the Netherlands seems reluctant compared to other countries.

All interviewees pointed out municipal processes and policies are withholding adopting I4.0 technologies. The employees within the municipality are all responsible and specialists in their relatively 'small' fields. As a result, there is no multidisciplinary collaboration which causes many delays internally. Also, changing a policy within the municipality takes so long that it delays all processes within the

construction and development industry, which negatively influences the adoption of I4.0 technologies.

In the focus group, five propositions were drafted that reflected the five barriers mentioned above. From the focus group, more significant barriers emerged. Aftercare is often not offered by the technology providers. When technologies are adopted, maintenance is not actively done to keep the technology up and running or the users are not well enough informed about how to use it, which reduces its use. In addition, democratic municipal elections are seen as a significant barrier. Changes within The Council from, for example, a left-wing majority to a right-wing majority or changes in aldermen can delay or jettison previously agreed plans.

Ultimately, the following are the most significant barriers in the Netherlands based on the literature, survey, interviews and focus group:

1. Lack of clarity on economic benefit
2. The challenge in the value chain integration and collaboration
3. Elections and municipal policies and processes
4. Scalability

Further substantive explanations of the most significant barriers are explained in the conclusions of the literature, survey, interviews, and focus group. It is striking that of the four most significant barriers mentioned above, barriers 3 and 4 are barely addressed in the literature. Thus, these barriers really stem from the interviews and focus group and thus actually relate to the Dutch context. So these are new insights compared to the literature and confirmed that different countries thus have different barriers.

Sub-question 4, what are the main drivers of organizations to adopt I4.0 in the Dutch C&DI?

Data collection: Literature review, survey and semi-structured interviews

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The two main drivers for adopting I4.0 technologies in the Dutch C&DI are increasing efficiency and creating new value for greater competitiveness. These also emerge as the most prominent drivers when looking only at the D&E active and I4.0 adopted respondents. However, the respondents active in the D&E phase score the drivers respectively higher.

Ultimately, the interviews and focus group show that the main drivers are different for each company or even differ between employees within the same company. Also, the drivers can be different between companies with the same activity. However, in the end, it turns out that in all private organizations, a financial driver stands out logically as well. The focus group deliberately included public parties as they did not participate before. It is clear that for a municipality, a public party, the main driver is to create a sustainable municipality with a pleasant living environment where all residents are happy. Ultimately I4.0 technologies can contribute to all drivers and it only depends on how and where you deploy them. The more significant C&DI or country level trends act as a driving force within the Dutch

C&DI. Nobody denies that the I4.0 technologies will change the Dutch C&DI. However, adoption is still (s)low while it has the potential to contribute positively to the companies adopting I4.0 technologies is also can contribute to the previously mentioned trends in the introduction. An increase in adopting I4.0 technologies in the D&E phase can contribute positively to the increase in urbanization to make this run more smoothly. Furthermore, the I4.0 technologies can reduce work during the entire life cycle of projects in the C&DI and accelerate the creation of designs in the D&E phases that consider future maintenance, sustainability, and circularity, which could contribute to the Dutch housing shortage.

Sub-question 5, what stakeholders work in the Design & Engineering phase with I4.0 in the Dutch C&DI?

Data collection: Literature review and survey

From this research, the stakeholders that adopted I4.0 technologies in phases before construction in the C&DI are the following consultancies, ICT providers, investors, architects and project developers. The only organizations not adopting I4.0 technologies yet from the research are the public parties. Often they are the commissioners of a project and there is not much need for them to adopt I4.0 technologies themselves. However, they could and perhaps should encourage the parties, their partners, to focus more on innovations using I4.0 technologies. Furthermore, internally, there would be much room to work more efficiently by adopting I4.0 technologies. However, implementing significant changes within government structures is very complex and often takes years. The other stakeholders mentioned in section 4.2, such as insurers, did not participate in the research. Therefore, it is not possible to say whether they are already working on the adoption or adopting I4.0 technologies in the Netherlands. During the focus group, the public parties confirmed that there should be more room for internal innovations. Also, there should be more room for Industry 4.0 technologies in communication and collaboration with the private parties. The biggest problems with implementing significant changes within public parties are that confirmation or approval is always needed from a higher body within the public party, making prolonged processes and decision making.

In short, it is essential to look primarily at the public parties because they do not adopt the I4.0 technologies themselves in the current Dutch C&DI. However, at the same time, they slow down other private parties for adopting I4.0 technologies. Therefore, what needs to change at the public parties is essential for the adoption, which could ultimately pay for itself on a larger scale.

14.2. Main research question

Are barriers withholding adopting Industry 4.0 (I4.0) technologies (e.g. AI, IoT and Digital Twins) within the Dutch construction and development industry, and can these barriers be overcome?

Based on answering the sub questions, the main research question can now be answered. Throughout the research, a distinction was made between different phases of projects in the C&DI. Additional emphasis was placed on the D&E phase. During the research, this phase changed in the whole development process before the start of construction. The interviews and participants in the focus group are all stakeholders in the development process before construction. In order to answer the main research question, it is divided into two parts. (1) Are barriers withholding adopting Industry 4.0 (I4.0) technologies (e.g. AI, IoT and Digital Twins) within the Dutch construction and development industry (2) and can these barriers be overcome?

(1) Are barriers withholding adopting Industry 4.0 (I4.0) technologies (e.g. AI, IoT and Digital Twins) within the Dutch construction

Whether barriers withhold adopting I4.0 technologies could already be determined to some extent from the literature review. The focus was really on what the specific barriers would be in the Dutch construction and development industry with the focus on the DE phase. In the research, many different barriers emerge. The barriers differ per stakeholder and the extent to which they experience the barrier or not. The literature review introduced several barriers to withholding adopting I4.0 technologies. These were included in the interviews. The interviews mainly confirmed the most striking barriers from the survey and added some significant ones. The propositions in the focus group result in the research consists of seven significant barriers that are considered withholding the Dutch construction and development industry. The first part of the main research question can be answered that this is indeed the case. That something needs to be done is shown by all respondents in the survey, the interviewees and participants of the focus group as they see the potential benefits of I4.0 technologies adopted in the C&DI. Almost nobody denies that the I4.0 technologies will change or is already changing the Dutch C&DI. However, adoption is still low and in the second part of the main research question, the most significant barriers will be discussed and what could be done about them using the results of this research. The challenge of value chain integration and the whole chain collaboration are combined as barrier because they consist of many overlaps. This also applies to the barrier of municipal/other democratic elections and municipal policies and processes.

(2) Can these barriers be overcome?

Below are the most significant barriers from this research, with brief explanations of the problem and what potentially could be done to these barriers by several activities to potentially overcome them. However, this is not evidenced that these activities will keep the barriers from withholding adopting I4.0 technologies in the Dutch construction and development industry but can certainly be taken into

consideration as the activities presented are based on different results from the study. Furthermore, the mentioned activities must be focused on the Dutch context. Thus, the activities relate to, for example, the Dutch government structures and these must be taken into account.

Lack of clarity on economic benefit

The productivity paradox regarding technology implementation brings uncertainty about the precise assessment of the economic benefits of investing in technology and therefore, many firms seem to remain reluctant.

- ICT (I4.0) providers should take a different approach when acquiring customers or when a customer starts adopting the I4.0 technologies. There is often an approach with proof of concept focusing on the underlying running I4.0 technologies. Often terms like AI and IoT are then overused, making it hard to follow for the users. Instead, there should be more focus on the proof of value in which the benefits for the customer are concretely expressed. In addition, it would help to address societal or social problems that public parties can remedy if they are the customer. For example, with private parties, social accountability is then much less of a primary motivation for adoption. In short, the sales could be done differently and ICT providers might take a different focus. In any case, almost all non-ICT providers confirm throughout the thesis that they do not see the primary purpose of adopting the relevant tool or service or that it is not part of their motivation.
- The ICT providers and the (potential) I4.0 customers themselves claim that their organizations are full of people with no knowledge or understanding of innovations, especially regarding I4.0 technologies. Therefore, as ICT providers should inform their customers differently about the economic benefits, more knowledge could be gained from the customer side. There are several possibilities for this. Taking on new positions by hiring data scientists, academics and psychologists can help adopt, understand, and optimize I4.0 technologies. This may not always be possible budget-wise, but it can certainly pay off in the long run. Another possibility is to retrain people within the organization. However, this will take more time. For example, larger organizations in the Netherlands, such as Ballast Nedam and BAM, now have an internal department focused on I4.0 technologies such as AI and IoT and are working on the transition to building more modern buildings, environments and cities. The investment is often still too significant for the smaller companies but also has to do with the economic benefits that may not be transparent to them. At the same time, this survey shows that more than 80% recognize that the I4.0 technologies can completely change the Dutch C&DI within five years. However, they do not yet see how and what is in for them.
- When the knowledge is not sufficient about the I4.0 technologies, the mindset is often not open to innovations such as I4.0 technologies. Also, employees are often afraid of losing their jobs while not necessarily being replaced, but other positions are needed and can be retrained. Therefore,

companies will have to be more open to innovations if they do not want to be left behind when the rest have adopted I4.0 technologies and can gain multiple benefits and grow. Especially in public parties, they do not seem to be open yet when there is no immediate benefit to be gained. They recognize that when they are open to I4.0 technologies, for example, many more barriers will arise, such as the challenge in the value chain integration

The challenge in the value chain integration and collaboration

This kind of challenge amplifies when multiple organizations in the value chain require integration. There is the need for close cooperation among value-chain partners and horizontal value-chain integration. Furthermore, aftercare is often not offered by the ICT (I4.0) providers. When technologies are adopted, maintenance is not actively done to keep the technology up and running or the users are not well enough informed about how to use it, which reduces its use.

Full chain collaboration within a construction and development project proved to be one of the biggest hurdles from the interviews. The C&DI appears to be a very conservative sector within which changes are complex. This has to do with the many stakeholders with different interests within the same project. Cooperation does not often seem optimal as not everyone speaks the same 'language', which means that not everyone works or can work in the same programs or has the same capabilities or knowledge. Transparency and trust are often hard to find and share files and data is often seen as 'scary'. Trust in other organisations is not yet optimal and undoubtedly due to privacy and complex data protection. Public parties, in particular, seem to be cautious.

- Firstly, this has to do with the digital inadequacy at companies that collaboration is sometimes tricky when documents are shared in which complex programs have been used. Again, better coordination and explanation between the stakeholders would help here. In addition, retraining or taking on new positions is another possibility to reduce the digital deficiency within the company. Some stakeholders are engaged in various workshops to understand their documents, files or programs internally and externally to other parties. For the providers of the I4.0 technologies, follow-up care must be provided because otherwise, in no time at all, it seems that the new technologies are no longer being used.
- In the C&DI, I4.0 technologies are not very easy to apply. For example, in 3D printing, we can print from coffee cups to chairs. However, we can now also print houses, although this involves much more complex and stringent requirements such as structural safety. It has to be very good very quickly. There is currently no framework for making a sample for each part and having it checked separately. This will improve and we will learn this over time. The standards framework is not there yet and that is currently slowing down developments. So aspects such as sustainability, safety and circularity are often still aggravating factors for innovations. So this mainly needs time or exceptions will have to be made for specific innovations.
- Often there is no unified language spoken by the digital deficiency. There should be more worked

with shared workspaces and, for example, integrated construction planning programs. Furthermore, it currently takes much time to find out what one person means in official and social terms and what another person means in business terms and that one is not more important than the other.

The Environment and Planning Act in the Netherlands, known as the "Omgevingswet", will hopefully make collaboration easier. The Act seeks to modernise, harmonise and simplify current rules on land use planning, environmental protection, nature conservation, construction of buildings, protection of cultural heritage, water management, urban and rural redevelopment, development of major public and private works and mining and earth removal and integrate these rules into one legal framework. Thus, the Act could address several barriers. However, many stakeholders in the Dutch C&DI are currently looking up to the new Act. This again confirms how conservative the C&DI is, also in the Netherlands. The Environment and Planning Act will have to be implemented by mid 2022. However, we will have to wait and see as it was already scheduled to come into force in 2017.

Elections and municipal policies and processes

In the Netherlands, the mentality is that everything must be investigated parliamentarily and everything must be discussed as in the House of Representatives in Dutch, better known as "De Tweede Kamer", with currently 17 political parties, making it difficult for the Netherlands itself to respond quickly and adequately. This broad subdivision continues down to the municipal level. This makes decision-making complex, especially when there are municipal elections at least once every four years. New aldermen can eliminate former plans with their utterly different vision. At the municipal level, it is also true that for more significant decisions or investments above a specific budget, it must first be discussed within the municipality in the College before it can go to the Council. Then it has to be approved here, which takes a long time.

- In the Netherlands, they could organize and structure municipalities like Scandinavia into larger organizations with more financial resources and more authority to make decisions. In Scandinavia, this helps to speed up the projects and the growth of technological innovations.
- The Dutch municipalities do not work in a multidisciplinary way. The employees within the municipality are all responsible and specialists in their relatively 'small' fields (e.g. green, water, public space and sport). As a result, there is no multidisciplinary collaboration which causes many delays internally. There would be the possibility of putting several officials on several fields, better aligning their interests with each other. Then only one of the civil servants can represent several fields within a project team.
- Involving the specialists of the relative 'small fields' earlier in the design might accelerate the process. For example, a project developer provides documents in current projects, often for the first time at the DO (final design). Then the municipality immediately has to approve or reject them officially. This is because the documents have not been seen before and when something is not clear,

it is straightforward to dismiss them immediately. On the other hand, suppose certain documents would be delivered earlier, for instance, in the SO (schematic design) or the VO (preliminary design). In that case, this could benefit the project. The municipality should also participate more if they want to change, for example, in the technological field.

Scalability

The Netherlands seems advanced compared to other countries in Europe in adopting I4.0 technologies. However, it appears that the Netherlands is indeed open to innovations of adopting new I4.0 technologies on a small scale. However, when scaling up to further adopt different technologies, the Netherlands seems reluctant compared to other countries. For example, this often has to do with aldermen who want to adopt innovations but cannot do so definitively. So at first, they are only open to a pilot or a trial period. When finally the pilot is introduced and used, there may already be a new alderman with other plans because of elections. Furthermore, developers and construction companies find that government agencies often squeeze them. In the opinion of the project developers from this research, one of the heavily weighted criteria is the highest price for the land with the least risk for the municipality. Then the project developers have to take the risks. Therefore the bidding parties get defensive and bid to the municipality, which does not necessarily benefit the developments within the municipality.

- The municipality should participate more often and take risks if they want to innovate. For this purpose, various public-private partnerships (PPP) are possible. A joint venture seems the most suitable for adopting innovations because the municipality co-invests and gets on the same side of the table as the private parties. In the Joint Venture model, the municipality and the private partners set up a joint Land Exploitation Company known in the Netherlands as 'GrondExploitatieMaatschappij' (GEM). Private Partner(s) invest capital in balance to their share in the GEM and participate in risk-bearing. In return, the private partner receives the right to develop a part of the area. In this way, the municipality can reduce its risk of land exploitation. The Environment and Planning Act (Omgevingswet) has emerged in several interviews and the focus group. This could bring about a lot within the Dutch C&DI positively judged by private and public parties. However, it remains to be seen when this will be introduced, as it has been postponed for years. Furthermore, despite the interviewees' advantages, most parties are still sceptical as processes may be simplified, but the entire system and working method will have to be adapted. The Environment and Planning Act could respond to several significant Dutch barriers mentioned above. The discussion will take a closer look at the Environment Act.

Takeaway conclusion of the research

The most critical takeaway from this research in the Dutch C&DI is that if the technologies were adopted more, they would also have more room to develop. When the developments get more advanced, it is possible to respond faster and more effectively to trends such as urbanization, sustainability, anticipate

unexpected circumstances like COVID-19 and, for example, the Dutch housing shortage. The research shows that the I4.0 technologies currently manifest themselves somewhat more in construction phases, but there are many opportunities, especially in the D&E phase. Especially data from completed projects in the Dutch C&DI can contribute to adopting I4.0 technologies in earlier phases. Therefore, almost half of the respondents confirm that the phasing within the C&DI will develop with less complex dividing lines and that phases will be much more closely interwoven. This would ultimately also help with the processes within the projects, which in turn can positively influence the collaboration of all involved stakeholders. There is work to be done to get Industry 4.0 up and running and to optimize the C&DI. Therefore, this research contributes to the current most significant barriers in the D&E phase within the Dutch C&DI. Furthermore is addresses what could be done about these barriers to stimulate adoption in the Netherlands.

General notes

Essential to add to the conclusions that adopting I4.0 technologies can also lead to new problems or barriers. When a Digital Twin is powered by AI in the Cloud and needs to be shared with another organisation, this is still a bridge too far for many organisations. Although the developments will increase and many positive benefits to be gained, there will always be dangers and new barriers lurking.

15
Discussion

The outcomes of this research are discussed in this section. The main topics that will be discussed are: (1) the relation between the outcomes and existing theories, (2) the relation between the outcomes and practice and (3) the limitations of this research.

15.1. Theoretical implications

The literature study's findings, which covered chapters 4 and 5, are discussed in this paragraph. This section is to identify the relation between the outcomes of the research and outcomes from literature.

Industry 4.0

There is still much confusion surrounding the term Industry 4.0. Because it is such a broad term, there is not a universal definition for 'Industry 4.0'. This created confusion regularly and it was seen as if every innovative technology or service was being crushed under Industry 4.0.

Adoption construction and development industry

Existing literature was focused mainly on adopting I4.0 technologies in different industries or the construction or maintenance phases of the C&DI. The insights gained by this research broaden the existing I4.0 adoption in the Dutch C&DI knowledge by focusing on a different industry and phasing in the Dutch C&DI. However, this made it difficult to determine what level I4.0 is adopted as there is no universal or well-known framework to score the adoption.

I4.0 technologies, Advantages and Barriers

The adoption was researched based on nine different I4.0 technologies, twelve barriers and nine advantages conducted from the research. It might be the case that based on the selection of certain I4.0 technologies, advantages or barriers are not included, resulting in a withheld of essential characteristics related to the adoption in the Dutch C&DI. However, during the empirical part of this research, several other technologies and barriers emerged. This also has to do with which country the research is done. Therefore depends, for example, on the government structures, culture, and prosperity of a country.

Cronbach's Alpha coefficient

Since the number of respondents for significantly reliable results was not achieved due to the lack of time, Cronbach's Alpha coefficient was used. Cronbach's alpha calculates the internal consistency of data.

This has been done with SPSS for this research. This showed that the respondents consistently filled in the data so that the results could not have deviated entirely and, therefore, are somehow reliable. The extent to which the answers are reliable in a survey is open to discussion since respondents often have different interpretations and measures.

15.2. Practical implications

The findings from different elements of the empirical part of this research are discussed in this paragraph.

Applicability of the activities

Activities that are mentioned in the conclusions are also actually applicable remains to be seen. Furthermore, it remains to be seen whether this will result in a growth of the adoption of I4.0 technologies. The activities have also not been coordinated with the stakeholders who should undertake action and therefore cannot be confirmed. The interventions discussed here are conclusions or recommendations to specific stakeholders in the Dutch C&DI. There are also several other emerging points for discussion retrieved during the research, which will be discussed below.

The Environment and Planning Act (Omgevingswet)

The Environment and Planning Act bundles 26 laws and regulations on spatial planning, housing, infrastructure, the environment, water and nature. The Environment Act must provide clarity and efficiency. A coherent approach should lead to a good and sustainable physical living environment. There are four improvement goals within the Environment and Planning Act. The first is that the ease of use of environmental law is increased by making the Environment and Planning Act more transparent, predictable and easier to use. All knowledge and rules will be merged under one law and there will be as many general rules as possible. However, this currently only creates confusion in all interviews and focus groups. This can be questioned because this is more often the case with something 'new'. The second improvement goal is that the Environment and Planning Act encourages an integrated approach between different sectors related to the physical living environment. This leads to better coordination between the various disciplines. Better integrated coordination leads to accelerated and more transparent processes. This could contribute to one of the more significant barriers in the Dutch C&DI, resulting in an increase in adopting I4.0 technologies. The third improvement objective is to give local authorities more scope under the Environment and Planning Act to consider the acceptable quality of the living environment. Under current legislation and regulations, it is centrally laid down which standards are permitted for, for example, noise and vibrations. Under the Environment and Planning Act, municipalities can provide tailor-made solutions for each sub-area. However, the question is to what extent they are allowed to move within their customization. In any case, the municipality will be given more responsibilities, which could positively contribute to the adoption of I4.0 technologies, according to this study. The fourth improvement goal is to shorten the decision-making times of governments. For example, the decision period for granting permits has been reduced from twenty-six to eight weeks. This is an improvement

goal that all parties within the research are eager for if it is actually implemented.

In short, The Environment and Planning Act has improvement goals that could become very interesting for the Dutch C&DI. When the improvement goals are achieved, this will also positively affect the adoption of the I4.0 technologies. However, it remains to be seen whether the Environment Act will finally be introduced by mid-2022 and whether the Environment Act will be adequately complied with and the improvement objectives will be achieved.

Digital Twins

Digital twins emerge in this research as the I4.0 technology that offers the most potential to achieve the most significant benefits for the entire Dutch C&DI in the short term. The DT, in particular, can also contribute a lot in the D&E phase and is becoming increasingly sophisticated in current developments, as confirmed by the interviews and the focus group. More than half of the interviewees and focus group participants would bet on DT if they had to choose an I4.0 technology. The extent to which the DT is already applicable in the D&E phase can still be discussed. Although quite a few experts from the C&DI were interviewed, it is possible that with a different composition of the focus group and other interviewees, a different I4.0 technology might emerge as the one with the most potential to improve or contribute to, for example, better processes or more efficient decision-making. Digital twins in the D&E phase seem to depend on the historical data needed to develop. This way, DT can eventually make more sustainable and efficient design choices with cost and maintenance reduction in the D&E phase based on historical data and AI. IT pros can run simulations before actual devices are built and deployed. They are also changing how IoT, AI and analytics are optimized. This technology can identify a problem or error before its occurrence while working with the machines or systems and it has the potential to predict the outcome for the future. When these DT make many design choices, the DT will probably take over some building physics and architects tasks. Who should invest in the DT is, therefore, a good question.

Barriers and activities

The study provides the most significant barriers of the Dutch CDI. Activities are identified which possibly can lower or overcome the barriers. However, it remains to be seen if the Netherlands adjusts its municipal structures, giving municipalities more financial resources at their disposal and more decision-making power. This may bring new barriers to light, resulting in more negative emerging complications than if the activities were adopted. Therefore, the discussion is about the actual adoption of the activities and whether they actually reduce or overcome the barriers and what new barriers are created. In addition, when the barriers are reduced or overcome and adopting I4.0 technologies increases, this can also lead to new barriers not yet been included in the current research.

Progressive Netherlands

From the survey results, it seems that many companies are already in the process of adopting I4.0 technologies but that the absolute benefits are not yet achieved or realized. There is much confirmation

that the Netherlands is enterprising in the field of innovative technology. On the other hand, we seem to be very cautious when it comes to scaling up. Moreover, it depends on which country the Netherlands is compared with when expressing that it is progressive. So this is still open to discussion.

Municipalities The municipal structures, collaborations, and responsibilities are among the main reasons the Netherlands appears to be very progressive; however, this is not the case. There is much reference to the municipality in this research, to be the ones who delay projects in D&E phase in particular. Examples are implementing or changing a policy or approving a permit, as mentioned in the barriers. Many involved specialists are not coordinated, which means that much time goes by. It is advised to look at how the municipalities in Scandinavia are organized as more commercial parties that participate in projects and are given much more financial resources and responsibilities in decision-making. However, it is questionable whether something like this would also fit in the Dutch C&DI for the municipalities and such changes are not readily applicable. The Environment and Planning Act will demonstrate to what extent changes can be implemented in the short term in the Dutch C&DI. However, again the question is whether this will automatically lead to an increase in I4.0 technologies?

D&E phase

The survey results show that there is little difference in the results between all respondents and the respondents active in the D&E phase who are in the process of adopting I4.0 technologies. This is mainly because most of the respondents are active in the DE phase and the respondents' adoption is high. So it is debatable to compare only the D&E phase with all the respondents. However, the results show that the percentage of companies adopting I4.0 technologies is higher than all respondents combined. Follow-up studies could even better distinguish the C&DI project phases. From the interviews and focus group, it appears that when we start working with I4.0 technologies in earlier phases, the sooner these will be included in the following phases.

15.3. Limitations of the research

The nature of this study is exploratory due to the lack of previous research on this topic, meaning that there is a limited qualitative body of knowledge. Therefore, a qualitative research method is used whereby interviews and a focus group are conducted. The survey is represented as a quantitative research method but is not statistically significant due to the number of respondents. It is essential to include some limitations in the research. Therefore, the research phases will be discussed separately, starting from the second phase to understand the limitations clearly. The first phase will be disregarded as only literature is used here.

In the second phase, the literature is reviewed in-depth and the most adopted technologies, the most significant barriers and benefits after adopting I4.0 technologies are identified. The chosen technologies, barriers, and benefits included in the survey and interviews were chosen based on the researcher's chosen literature. Possibly other barriers, benefits and I4.0 technologies could have been included in the study.

However, the respondents of the survey and the interviewees were given the freedom to fill in or name missing barriers, benefits and I4.0 technologies.

In the third phase, the survey results are limited because it is not clear how the respondent interpreted the question or the answers. The interviews were conducted in order still to achieve some depth in the results of the survey. However, it was impossible to interview all survey respondents. In addition, the survey included questions which the respondent had to answer by giving a score between zero and ten. Although a description was given for the zero and the ten, there is still much room for own interpretation, which influences the results. Furthermore, the survey had to be short and straightforward and thus, not every term was explained, assuming that the respondent knew, would look it up, or it was not necessary if the respondent was not familiar with it. This could also have influenced the results and relevant data could have been lost.

The number of respondents to make the survey statistically significant was not achieved due to the time constraint of this research. Therefore, the results of the survey cannot be generalized. For example, the most significant barriers and technologies are taken from the literature are automatically the most significant in the Dutch C&DI? Probably not as the results show some other barriers from the interviews. Through the interviews, several new barriers emerged that the interviewees had not initially included in the survey. This may be because they only came up with them through the interaction during the interview. This also indicates the limitations of the survey. Among the respondents of the survey, there was only one respondent who represented the public parties. Among those interviewed, there were no representatives of the public parties. However, all interviewees had to do and work with public parties and they also pointed out that many significant barriers had to do with the public parties. For this reason, some public parties were involved in the focus group. However, all results in the research for the focus group were obtained from private parties.

In the fourth phase, the number of focus group participants was unfortunately limited to four respondents due to absence caused by COVID-19. Also, the focus group was not conducted simultaneously, but the propositions were presented to the participants independently. Therefore the results of this phase only act as a stepping stone for further research. Due to the lack of interaction in this phase, the results cannot be considered definitive. For this, further research is required.

A general limitation of the research is time. Furthermore, the activities answering the main research question are not proven or evidenced as adopting these will stop the barriers from withholding the I4.0 technologies. Besides, it is also not a fact that the adoption of I4.0 technologies automatically results in benefits.

16

Recommendations

Throughout the report, certain recommendations have been identified for practice and further research. This section briefly addresses several recommendations for practice (Stakeholders C&DI) and future research (academics).

16.1. Recommendations for practice

The practice recommendations identify concrete interventions to potentially drive growth in adopting I4.0 technologies in the Dutch C&DI. These interventions have already been explained in answering the main research question. Therefore, they are reproduced below without explanation.

ICT (I4.0) providers

- Different approach to (potential) customers.
- Aftercare after the adoption of I4.0 technologies at customers.
- Giving workshops and training

Government/Municipality

- Take more risk and participate more often. Work in PPPs as a Joint Venture construction.
- Restructure municipality as in Scandinavia
- Restructure distribution of specialists and work more in a multidisciplinary way.
- Ensure continuity of adopted plans within a municipality. Also, after elections when there is a change of aldermen with different visions, for example.

Project Developer

- Deliver documents earlier than the DO (Final Deisgn) and involve or give insights earlier in the progress to municipal specialists.

All C&DI stakeholders from this research

- Take on new positions (e.g. academics, data scientists and psychologists).
- Retrain employees.
- Develop an internal department on innovations.
- Open the more than only the mindset for innovations

- Work on a unified language.
- Prepare for The Environmental and Planning Act

16.2. Recommendations for further research

Focus on processes

The research shows that many I4.0 technologies focus on improving sustainability, production or reducing costs. However, many of the barriers to the adoption of I4.0 technologies lie in the processes in the Netherlands. Therefore, it could be investigated how the I4.0 technologies could be used more on the processes within the C&DI projects.

Similar study with another country and compare

A similar study in another country or several can distinguish the specific barriers for the Netherlands and the more general ones. For example, the study refers to the organization and structure within the municipalities in Scandinavia. Here the lower level municipalities have much more decision power and more financial resources at their disposal. Furthermore, the public parties are said to be more commercially oriented. Because they are organized differently, they seem to move more decisively and quickly in the C&DI.

The Environmental Act (De Omgevingswet

After the Environment and Planning Act has been introduced, research to what extent it has complied in the Dutch C&DI. Subsequently, research can be conducted into what effect the Environment and Planning Act has had on adopting I4.0 technologies.

Toolbox

Develop an Industry 4.0 Readiness Assessment Toolbox. The toolbox should facilitate informed national and local decision-making. Industry 4.0 will not be a viable option for development everywhere globally or in the respective countries. Let alone that benefits can be achieved everywhere already in the short term. So far, little is known about the supporting framework conditions concerning economic development, the quality of growth, employment and possible integration into international value-creating networks and the impact of I4.0 technologies. The toolbox could serve as a guide for analyses that national and local governments can conduct.

The same study in a few years

From the research, over 80% confirmed that I4.0 technologies will have a significant impact on the C&DI. In addition, respondents confirmed that if they are not yet adopting I4.0 technologies, it is on the agenda for the next few years. Compare to what extent adoption has increased over time and what barriers are still experienced.

In case of a growth in the adoption of I4.0 technologies

A survey could be done to determine which stakeholders in the C&DI might see their roles change or disappear and which new players might enter. In addition, it is interesting to investigate when the adoption has increased significantly what new barriers might come up.

Comparing practice with the literature

Alaloul et al. conducted a comprehensive review to identify the main barriers withholding or delaying the implementation of I4.0 related technologies within the construction industry (2020). The review shows the criticalness of the factors where Social comes as the most influential. Economic and Technological factors fall as second and third. Political comes as the least argued factor. The results are derived using the PESTEL framework and security as an extra factor that makes it PESTELS. PESTELS stands for Political, Economical, Social, Technological Environmental, Legal and Security.

17
Reflection

In my research two study targets are set that I wanted to achieve. My first goal was to learn more about Industry 4.0 as I am interested in innovative technologies that might change the C&DI sector a lot in the near future. Giving me insights into what barriers are withholding adopting I4.0 technologies in C&DI projects.

Secondly, I wanted to gain practical experience in this research field. Therefore, I was looking forward to the interviews to speak with many experts in this research field, where a lot of practical knowledge will be shared.

In addition, writing an academic report is and was a challenge for me and I hope to be proud of the research and the report at the end. I see the progress I have developed in the past months and my thinking has changed too with the help of my mentors.

17.1. Research process

Towards P1

Based on my interests in innovative technologies in the Dutch construction and development industry, I decided to research Industry 4.0. However, at the beginning of the research process, I struggled with defining and understanding Industry 4.0 as I found it hard to read much literature. This resulted from not being well-read in the topic and not knowing what data was and what others had already written. Moreover, I had not had gained a lot of knowledge about this specific subject during the courses of my masters MBE. During my master's in MBE, much was delving into the construction and development industry processes. However, the study did not focus on making the processes smoother, more efficient or faster or improving the design of a project in terms of quality or sustainability using innovations such as Industry 4.0 technologies. This is also because this is a particular direction and this transition is in progress. What I also experienced as difficult while setting up the research proposal was finding a suitable research method. Finally, there was a start and more time had been taken for the literature and the proposal began to take shape.

Towards P2

After the P1, I had to specify my research method in more detail. I found it challenging to make decisions as my mentors challenged me and focused on thinking and working as an academic. During our meetings, I often came up with new concepts which were not cohesive and I wanted to combine too

many concepts in one research. This sometimes felt a bit frustrating, as my mentors asked me to keep going back to the core. What is your problem statement and look back at just your title? There are four directions of inquiry that you try to connect in this research. By always putting the focus back, I came to a specific research proposal and learned to stick to that and not switch. This made me struggle but helped and resulted finally in a detailed research proposal.

Towards P3

Towards P3, the research could begin and the basis of the research was in place. I also started to enjoy the research more from here, and the mentors also saw this in my work. When the survey was finalized, it was necessary to start getting as many respondents as possible. I noticed that in order to get respondents, I had to keep actively approaching people and keep reminding them. This took more time than expected. However, it led to a sufficient number of respondents. Based on the results and conclusions of the survey, the interviews could be prepared. Making the transition from the obtained data to the first conclusions took some time but gave good insight and a good introduction for the interviews conducted in the next phase.

Towards P4

During P4, the interviews were conducted, a focus group was conducted, and the conclusion, discussion and recommendations were drafted. In P4, everything had to coincide and occasionally, during P4, things had to be rearranged because of COVID-19 restrictions and appointments could not always take place as planned. For example, the focus group had to be conducted in a different format. In addition, almost all interviews and the focus group were conducted online. This saved time but at the cost of sometimes getting through to the other person and having good contact. However, it was still possible to get good depth during the online interviews and focus group with proper preparation. This led to good discussions and a lot of valuable data was collected. As the interviews and the focus group have been conducted, these were worked out appropriately and the final conclusions of the research answered the main research question.

Towards P5

In the final phase of the study, the focus was even more on the conclusions, discussion and recommendations. Reviewing whether the results align with the expectations during the research. The research process went well and many different methods were used in this research. Ultimately, the research provided new insights into the Dutch construction and development industry. In particular, there is an emphasis on the barriers preventing adopting I4.0 technologies in the D&E phase and the potential interventions to overcome them.

17.2. Research method

Qualitative and quantitative research methods are used. The quantitative data is obtained by surveying Dutch C&DI stakeholders to assess the literature review findings and provide handholding during

interviews. The qualitative data was obtained by conducting the interviews and focus group on going deeper into the research topic and results through interaction and discussion. This gave a good understanding of the topic and valuable insights. Unfortunately, due to COVID-19, the focus group was given a slightly different interpretation but did achieve the intended result of causing discussions and substantiating the propositions prepared in advance. I had to adapt my research design during my research because data was missing and getting in touch with preconceived case studies did not go as planned. However, I do not think this negatively influenced the research since I could answer the research question with the current research method. In addition, the choices were made deliberately to change to the research method with an eventual comprehensive research method.

17.3. Scientific and practical relevance

The research also has a significant societal and practical relevance. As mentioned before, the transition to a more innovative C&DI with the potential benefits the I4.0 technologies are offering cannot wait any longer. Companies are beginning to understand the massive impact of I4.0 and the role of technology in fundamentally transforming business models and processes. Furthermore, C&DI stakeholders recognize the importance of sustainability, building faster and people moving into the city. As the C&DI is one of the most significant users and emitters of all industries, the Netherlands is also looking at a housing shortage and urbanization. This, combined with the viscous processes in the conservative construction and development sector and many other barriers, does not allow the C&DI to see the full potential of adopting I4.0 technologies. Therefore, the practical relevance of this study consists of several parts.

First, the research provides insight into what potential I4.0 technologies have and the most significant barriers. This is important because every organization is unique and has its way of operating and therefore needs its own approach. By generating an overview of the I4.0 technologies, advantages and barriers, C&DI stakeholders can see what they are up against or identify excelling in specific aspects, while others might not.

Second, providing a clear overview of what can be done to overcome the barriers and benefit from the I4.0 technologies might help to choose how to innovate their organization. By supplying insight on the advantages and how to overcome several barriers can positively influence the mindset of a company and could result in a competitive advantage. The conservative C&DI towards technological innovations is seen as a costly investment rather than a profitable long-term investment, currently dominating most companies.

This research might resolve the aforementioned challenges by motivating the Dutch C&DI to adopt a more innovative strategy by adopting I4.0 technologies.

17.4. Initial motivation

Going back to the initial motivation of this study, some things have certainly changed in the perception. The complexity surrounding the concept of Industry 4.0 turned out to be more complicated than

anticipated. In addition, my confidence was high after reading up on the potential of the Industry 4.0 innovations. However, after the research, I became more sceptical about adopting Industry 4.0 technologies in the DE phase. Most technologies are adopted in the phases after initial construction and therefore, this research has focused more on the phases before construction. However, the application of these technologies is still in a much less developed phase. The barriers that emerged in the research still seem to function as too significant hurdles. The research gives new insights into where in the Dutch C&DI the most significant barriers are for adopting Industry 4.0 technologies. In the earlier motivations for the research, the focus was mainly on the more commercial parties because the most potential lies to increase adoption. However, the research shows that there is much focus on the public parties and that the most significant steps need to be made in the processes within the public parties or in which the commercial parties need to move with the public parties. Therefore, the motivation changed during the research. The first motivation was to quickly identify the most significant barriers and then determine what can be done to overcome the barriers and exploit the benefits. Getting a clear understanding of the most significant barriers took more time due to all stakeholders' different interpretations, motivations, and goals using Industry 4.0 technologies. Therefore, more work was needed to analyse the data obtained in the interviews and focus groups. The most significant change in the research motivation is that the initial focus was more on how to increase the adoption to obtain the potential benefits. Later, the focus was more on alleviating or overcoming the barriers to improve adoption in the Dutch C&DI. However during the research almost nobody denies that the I4.0 technologies will change the Dutch C&DI. As the adoption seems still (s)low while it has the potential to contribute positively to the companies adopting I4.0 technologies is also can contribute to the previously mentioned trends in the introduction. An increase in adopting I4.0 technologies in the D&E phase can contribute positively to the increase in urbanization to make this run more smoothly. Furthermore, the I4.0 technologies can contribute to a reduction in work and accelerate the creation of a design that considers future maintenance, sustainability, and circularity, which could contribute to the Dutch housing shortage.

17.5. Concluding remarks

The study targets were set during the research proposal a half year ago. With this report, I am confident that I achieved my targets as I gained practical experience in this research field with interviews and focus groups. I spoke to many experts in this research field, whereby much practical knowledge was shared. Also, I got many new valuable insights into the technological field I was interested in. This also had to do with the methodology chosen to be sufficient and providing the data needed to make educated conclusions.

It was a long journey and there will always be recommendations for improvement, but I am pleased to confirm that this report satisfies me. I hope that you enjoyed reading this report.

A

Technologies adopted in *D&E*

Industry 4.0 technologies	*D&E* phase
Augmented reality (AR)	x
Barcode	
Blockchain	x
Bluetooth/RFID	
Camera	x
Crabots	
Digital twin	x
Geographic information system (GIS)	x
Global positioning system (GPS)	
Global system for mobile communication (GSM)	
Holographic display	
Industry foundation classes (IFC)	x
Laser scanning/Laser Detection and Ranging (LaDAR)/LIght Detection and RAnging (LIDAR)	x
Machine learning	
Mixed reality/Virtual reality (MR/VR)	x
Mobile robotic units on site	
n-dimensional (nD) modeling	x
Neural networks/Artificial intelligence (AI)	x
Parametric design Photogrammetry/Stereo-photogrammetry	 x
Point cloud/3D scanner	x
Prefabrication	
Radio frequency identification (RFID)	
Sensors	x
Third/Fourth/Fifth generation (3G/4G/5G)	
Unmanned aerial vehicle (UAV)/Drone	x
Wireless sensor network (WSN)	x
3D printing	

B

Survey respondents profile

Variable	Category	Frequency	Percentage (%)
Gender	Female	1	2%
	Male	43	98%
Age Group	20-29	12	28%
	30-39	11	26%
	40-49	9	20%
	>49	11	26%
Position in Company	CXO	23	53%
	Partner	3	7%
	Senior	7	16%
	Junior	10	24%
Experience at the organisation	<1 year	12	28%
	1-5 year(s)	16	37%
	>5 years	15	35%
Experience in construction industry	<1 year	19	44%
	1-5 year(s)	17	40%
	>5 years	7	16%
Activity	Architect	3	7%
	Consultancy	6	14%
	ICT provider	9	21%
	Investor	10	23%
	Municipality	1	2%
	Project developer	14	33%
Focus	Private	17	40%
	Public	4	7%
	Both	23	53%
Organizations size	1-9	5	12%
	10-49	19	44%
	50-249	9	21%
	>250	10	23%
Focus market	The Netherlands	22	51%
	Also internationally	21	49%

Table B.1: Respondent profile

C

I4.0 usage per phase

Initial/Pre-design/Development phase

Variable	Category	Frequency	Percentage (%)
Usage	Don't know	5	12%
	Not	11	26%
	In development	9	20%
	Monthly	7	16%
	Weekly	3	7%
	Daily	8	19%

Table C.1: Usage Initial/Pre-design/Development phase

Design and engineering phase

Variable	Category	Frequency	Percentage (%)
Usage	Don't know	8	19%
	Not	12	28%
	In development	4	9%
	Monthly	7	16%
	Weekly	6	14%
	Daily	6	14%

Table C.2: Design and Engineering phase

Supply, construction and/or assembly phase

Variable	Category	Frequency	Percentage (%)
Usage	Don't know	10	23%
	Not	18	42%
	In development	3	7%
	Monthly	6	14%
	Weekly	2	5%
	Daily	4	9%

Table C.3: Supply, construction and/or assembly phase

Management and/or maintenance phase

Variable	Category	Frequency	Percentage (%)
Usage	Don't know	8	19%
	Not	13	30%
	In development	8	19%
	Monthly	4	9%
	Weekly	3	7%
	Daily	7	16%

Table C.4: Management and/or maintenance phase

Demolition and/or renovation phase

Variable	Category	Frequency	Percentage (%)
Usage	Don't know	8	26%
	Not	12	58%
	In development	1	2%
	Monthly	2	5%
	Weekly	0	0%
	Daily	4	9%

Table C.5: Demolition and/or renovation phase

D

Results advantages

Results AIn and RII all phases

Advantages experienced	AIn	*Rank**	RII
I4.0 technologies increased our product quality?	6,06	9	0,61
With the I4.0 technologies, production processes are improved?	6,31	8	0,70
I4.0 technologies increased positive feedback from our customers?	6,73	5	0,67
I4.0 technologies increase our energy efficiency?	6,74	4	0.67
I4.0 technologies increase the company's image in the market?	7,15	1	0,72
I4.0 technologies increase the competitiveness of our company?	6,94	2	0,69
I4.0 technologies increase the efficiency of the company?	6,56	6	0,73
I4.0 technologies increase communication within your organization?	6,39	7	0,71
I4.0 technologies provide efficiency in decision making?	6,84	3	0,76

Table D.1: Results AIn and RII all phases, advantages

Results AIn and RII active *D&E* phase

Advantages experienced	AIn	*Rank**	RII
I4.0 technologies increased our product quality?	6,81	4	0,68
With the I4.0 technologies, production processes are improved?	6,48	7	0,72
I4.0 technologies increased positive feedback from our customers?	6,85	3	0,69
I4.0 technologies increase our energy efficiency?	6,76	5	0.68
I4.0 technologies increase the company's image in the market?	7,50	1	0,75
I4.0 technologies increase the competitiveness of our company?	7,09	2	0,71
I4.0 technologies increase the efficiency of the company?	6,45	8	0,72
I4.0 technologies increase communication within your organization?	6,27	9	0,70
I4.0 technologies provide efficiency in decision making?	6,68	6	0,74

Table D.2: Results AIn and RII active *D&E* phase, advantages

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Product quality	50,41	163,558	,686	,866
Production processes are improved	50,78	175,179	,566	,876
Positive feedback from our customers	50,41	161,097	,684	,866
Energy efficiency	50,41	170,328	,454	,888
Company's image	50,00	163,769	,743	,861
Competitiveness	50,15	161,823	,657	,868
Efficiency	50,67	169,538	,629	,871
Communication	50,78	165,718	,642	,869
Decision making?	50,33	171,154	,686	,868

Table D.3: Reliability and Validity test, advantages

Reliability Statistics

Cronbach's Alpha	N of Items
,883	9

Table D.4: Advantages Cronbach's Alpha result

E

Results drivers

Results AIn and RII all phases

Drivers	AIn	*Rank**	RII
Cost Savings	5,35	8	0,59
Turnaround time	5,49	7	0,61
New business model	5,89	5	0,59
Create new value for greater competitiveness	6,65	2	0,67
Increase efficiency	6,72	1	0,67
More quality	6,38	3	0,64
Work reduction	5,74	6	0,57
Environmental impact (sustainability, circularity etc..)	6,25	4	0,63

Table E.1: Results AIn and RII all phases, drivers

AIn and RII active *D&E* phase

Drivers	AIn	*Rank**	RII
Cost Savings	6,14	7	0,68
Turnaround time	5,91	8	0,66
New business model	6,96	5	0,70
Create new value for greater competitiveness	7,61	1	0,76
Increase efficiency	7,45	2	0,75
More quality	7,27	4	0,73
Work reduction	6,81	6	0,68
Environmental impact (sustainability, circularity etc..)	7,41	3	0,74

Table E.2: AIn and RII active *D&E* phase, drivers

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Cost Savings	43,97	263,090	,784	,873
Turnaround time	43,85	256,372	,537	,895
New business model	43,32	249,862	,532	,897
Competitiveness	42,59	245,219	,638	,886
Increase efficiency	42,74	232,685	,810	,870
More quality	43,00	229,879	,833	,868
Work reduction	43,53	252,863	,541	,895
Environmental impact	43,09	224,447	,766	,874

Table E.3: Reliability and Validity test, drivers

Reliability Statistics

Cronbach's Alpha	N of Items
,896	8

Table E.4: Driver Cronbach's Alpha result

F

Results barriers

Results AIn and RII all phases

Barriers	AIn	*Rank**	RII
Challenge in value chain integration	5,40	2	0,54
Challenge in ensuring data quality	4,76	8	0,53
Disruption of existing jobs	3,13	11	0,39
High investment	5,27	4	0,59
Labour market inequality	2,42	12	0,35
Lack of digital strategy alongside scarcity of resources	4,54	10	0,45
Lack of clarity on economic benefit	5,42	1	0,54
Lack of digital skills	4.92	5	0,49
Lack of infrastructure	4,81	7	0,48
Lack of internal digital culture and training	5,30	3	0,53
Resistance to change	4,84	6	0,48
Risk of security breaches	4,72	9	0,47

Table F.1: Results AIn and RII all phases, barriers

AIn and RII active *D&E* phase

Barriers	AIn	*Rank**	RII
Challenge in value chain integration	5,90	1	0,66
Challenge in ensuring data quality	5,05	5	0,56
Disruption of existing jobs	2,86	11	0,36
High investment	5,18	3	0,58
Labour market inequality	2,09	12	0,30
Lack of digital strategy alongside scarcity of resources	4,45	7	0,56
Lack of clarity on economic benefit	5,55	2	0,62
Lack of digital skills	3,86	9	0,43
Lack of infrastructure	4,24	8	0,53
Lack of internal digital culture and training	4,68	6	0,52
Resistance to change	5,14	4	0,57
Risk of security breaches	3,53	10	0,39

Table F.2: AIn and RII active *D&E* phase, barriers

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Value chain integration	50,81	276,828	,418	,773
Ensuring data quality	51,19	301,895	,160	,796
Disruption of existing jobs	53,03	269,166	,500	,765
High investment	50,87	285,316	,317	,783
Labour market inequality	53,81	282,761	,480	,769
Lack of digital strategy	51,65	259,370	,612	,753
Economic benefit	50,90	268,690	,483	,766
Digital skills	51,29	249,946	,614	,750
Lack of infrastructure	51,42	284,185	,324	,782
Digital culture and training	51,00	264,467	,550	,759
Resistance to change	51,26	269,198	,477	,767
Risk of security breaches	51,26	293,531	,206	, 795

Table F.3: Reliability and Validity test, barriers

Reliability Statistics

Cronbach's Alpha	N of Items
,787	12

Table F.4: Barrier Cronbach's Alpha result

G

Results Stimulance

Results internal attention and/or encouragement

Barriers	Frequency	%	Rank
Challenge in value chain integration	12	29,3%	6
Challenge in ensuring data quality	8	19,5%	10
Disruption of existing jobs	2	4,9%	11
High investment	14	34,1%	5
Labour market inequality	0		
Lack of digital strategy alongside scarcity of resources	9	22%	8
Lack of clarity on economic benefit	16	39%	3
Lack of digital skills	19	46,3%	2
Lack of infrastructure	10	24,4%	7
Lack of internal digital culture and training	15	36,6%	4
Resistance to change	21	51,2%	1
Risk of security breaches	9	22%	9

Table G.1: Results internal attention and/or encouragement all phases, stimulance

Results external attention and/or encouragement

Barriers	Frequency	%	Rank
Challenge in value chain integration	10	25%	6
Challenge in ensuring data quality	12	30%	10
Disruption of existing jobs	2	5%	11
High investment	13	32,5%	5
Labour market inequality	1	2,5	12
Lack of digital strategy alongside scarcity of resources	9	22,5%	8
Lack of clarity on economic benefit	16	40%	3
Lack of digital skills	17	42,5%	2
Lack of infrastructure	12	30%	7
Lack of internal digital culture and training	11	27,5%	4
Resistance to change	13	32,5%	1
Risk of security breaches	11	27,5%	9

Table G.2: Results internal attention and/or encouragement *D&E* phase, stimulance

H

Survey

Introduction

Welcome to this survey.

First of all, I would like to thank you for participating in this survey. I really appreciate it! The survey will take approximately 10 minutes to complete.

I would like to introduce myself: My name is Douwe Schoemaker and I am currently working on my master thesis research at TU Delft (Management in the Built Environment). I am researching the adoption of Industry 4.0 (I4.0) technologies in the Design & Engineering phase within area development.

The research aims to gain insight into the adoption of I4.0 technologies in the Netherlands. I4.0 is defined in this survey as technologies that enable the physical and digital worlds to merge and bring significant improvements in performance and productivity.

Survey responses will be kept confidential and will not be provided to other parties. All responses will be presented anonymously in the final report. If you leave your email address, you will receive the survey results (in the form of a final report) in January.

Thank you very much for your cooperation and commitment.

Kind regards,

Douwe Schoemaker
For questions about the survey, you can reach me at: douweschoemaker@hotmail.com.

Personal

Name respondent

Gender (optional)

Your email address for the report results (optional)

Age

Company name

Function in current company

- less than one year
- 1-5 year(s)
- more than 5 years

How many years have you been working in your current company?

- less than one year
- 1-5 year(s)
- more than 5 years

How long have you been working in the building and construction industry?

- less than one year
- 1-5 year(s)
- more than 5 years

What is your business activity? (software developer, consulting engineering firm, project developer, municipality, bank etc...)

Where is your business focus?

- private sector
- public sector
- both
- other

How many employees does your company have?

- 1-9 employees
- 10-49 employees
- 50-249 employees
- more than 250 employees

Does your company focus only on the Dutch market or also internationally? If you also operate internationally, in which countries?

Industry 4.0 technologies

There are several definitions for the term I4.0.Industry 4.0. has many different synonyms and different definitions. In this survey, we use that I4.0 technologies fuse the physical and digital worlds and bring significant performance and productivity improvements. In the Netherlands, the term "Smart Industry" is also widely used. The image below shows the revolutions/industries.

image

Here, we dive into the technologies such as autonomous robots and Internet of Things (IoT), among others, that most emerged in the literature review.

To what extent are you familiar with I4.0? (scale 0-10)

Which I4.0 technologies does your company use? (multiple answers possible)

- Our company does not use I4.0 technologies yet
- No idea if our company uses I4.0 technologies
- Augmented reality (AR)
- Blockchain
- Geographic information system (GIS)
- Neural networks/Artificial intelligence (AI)
- Sensors
- Internet of things (IoT)
- Simulation/Digital twins (DT)
- Autonomous robots
- Big data analytics
- Other

What stage are the applied industry 4.0 technologies in your company? For example, IoT (we are in the development phase) and Big data analytics (we are making full use of it and has been implemented for years)

How are the I4.0 technologies being used? (multiple answers possible)

- Only for own use
- Provider of to other companies
- We as a customer of other companies
- Other

Current adoption by phase and advantages

The literature confirms the growing interest in I4.0 in the construction industry, but what about the adoption of I4.0? For the following questions, the following phasing is used for the construction and development industry:

1. Initial/Pre-design/Development phase
2. Design and engineering phase
3. Supply, construction and/or assembly phase
4. Management and/or maintenance phase
5.Demolition and/or renovation phase

How would you classify the current adoption of industry 4.0 technologies in your company? (Scale 0-10 and if you have no idea, you can leave the question blank).
How often per phase does your company use I4.0 technologies?

"Initial/Pre-design/Development phase"

- no idea
- not
- in development
- monthly
- weekly
- daily
- other

"Design and engineering phase"

- no idea
- not
- in development
- monthly

- weekly
- daily
- other

"Supply, construction and/or assembly phase"

- no idea
- not
- in development
- monthly
- weekly
- daily
- other

"Management and/or maintenance phase"

- no idea
- not
- in development
- monthly
- weekly
- daily
- other

"Demolition and/or renovation phase"

- no idea
- not
- in development
- monthly
- weekly
- daily
- other

Does your company benefit from the use of I4.0 technologies?

- no idea
- no, no I4.0 technologies in use
- no, not yet, but we do take advantage of I4.0 technologies
- yes, but we are not taking full advantage yet

- yes, benefits are visible
- other

To what extent does your company experience the following benefits after using the I4.0 technologies?
On a scale of 0-10, where a
0 = we do not experience this benefit
10 = yes, we experience this benefit completely
If you cannot answer the question, please leave it blank.

I4.0 technologies have increased our product quality?

I4.0 technologies improve production processes?

I4.0 technologies have increased positive feedback from our customers?

I4.0 technologies increase our energy efficiency?

I4.0 technologies increase the company's image in the market?

I4.0 technologies increase the competitiveness of our company?

I4.0 technologies increase the efficiency of the company?

I4.0 technologies increase communication within your organization?

I4.0 technologies provide efficiency in decision making?

Are there other benefits that you experience after using I4.0 technologies within your company?

Drivers
What are the main drivers for the use of technologies 4.0 in your company?
On a scale of 0-10, where a
0 = not our main driver
10 = yes, this is our main driver
If you cannot answer the question, leave it blank.

Cost Savings

Turnaround time

New business model

Create new value for greater competitiveness

Increase efficiency

More quality

Work reduction

Environmental impact (sustainability, circularity etc..

Other drivers for which we use industry 4.0 technologies within the company?

Barriers

In addition to the opportunities presented by I4.0 technologies, barriers also exist and many new challenges arise. The following questions provide an overview of the most common barriers/challenges from the literature review. To what extent does your company experience barriers/challenges in adopting I4.0 technologies.

On a scale of 0-10, where a

0 = no barrier

10 = this barrier currently makes it impossible to adopt certain technologies

If you cannot answer the question, please leave it blank.

Challenge in value chain integration

Challenge in ensuring data quality

Disruption of existing jobs

High investment

Labour market inequality

Lack of digital strategy alongside scarcity of resources

Lack of clarity on economic benefit

Lack of digital skills

Lack of infrastructure

Lack of internal digital culture and training

Resistance to change

Risk of security breaches

What are other key barriers/challenges to adopting I4.0 technologies for your company?

Perspective

What will the future of I4.0 within the construction industry look like in three, five and ten years in the construction and development industry?

In your perspective, will the I4.0 technologies have much impact on the construction industry/area development? And over how long (1,3,5 or 10 years?)

To what extent do you expect the adoption of I4.0 technologies to increase in your company in the coming year?

- *no idea*
- *not, it is not on our agenda yet*
- *we are working on the adoption and implementation of I4.0 technologies*
- *are fully integrated in our company*
- *other*

In the next five years, to what extent do you expect to adopt I4.0 technologies to increase your company?

- *no idea*
- *not, it is not on our agenda yet*

- *we are working on the adoption and implementation of I4.0 technologies*
- *are fully integrated in our company*
- *other*

In which phase(s) of area development is there the most to gain for your company in adopting I4.0 technologies? (multiple answers possible)

- *"Initial/Pre-design/Development phase"*
- *"Design and engineering phase"*
- *"Supply, construction and/or assembly phase"*
- *"Management and/or maintenance phase"*
- *"Demolition and/or renovation phase"*

As stated in the previous question, will the current phasing be maintained within area development as I4.0 technologies are increasingly adopted? (on a scale 0 - 10)(No opinion, leave the question open)

How will this change?

What are industry 4.0 technologies on the agenda to implement over the next five years within your company? (multiple answers possible)

- *Our company does not use I4.0 technologies yet*
- *No idea if its on the company agenda*
- *Augmented reality (AR)*
- *Blockchain*
- *Geographic information system (GIS)*
- *Neural networks/Artificial intelligence (AI)*
- *Sensors*
- *Internet of things (IoT)*
- *Simulation/Digital twins (DT)*
- *Autonomous robots*
- *Big data & analytics*
- *Other*

Stimulance

The literature shows that due to the many barriers, adoption is low while interest is high. Therefore, it is interesting to explore how the barriers could be reduced and by whom and how?

Do you think that external parties should contribute to stimulating the adoption of industry 4.0

technologies? If so, which parties should do so?

What barriers could be reduced by more internal attention and/or encouragement within the company?

- *Challenge in value chain integration*
- *Challenge in ensuring data quality*
- *Disruption of existing jobs*
- *High investment*
- *Labour market inequality*
- *Lack of digital strategy alongside scarcity of resources*
- *Lack of clarity on economic benefit*
- *Lack of digital skills*
- *Lack of infrastructure*
- *Lack of internal digital culture and training*
- *Resistance to change*
- *Risk of security breaches*
- *Other*

What barriers could be reduced by more external attention and/or encouragement from other parties?

- *Challenge in value chain integration*
- *Challenge in ensuring data quality*
- *Disruption of existing jobs*
- *High investment*
- *Labour market inequality*
- *Lack of digital strategy alongside scarcity of resources*
- *Lack of clarity on economic benefit*
- *Lack of digital skills*
- *Lack of infrastructure*
- *Lack of internal digital culture and training*
- *Resistance to change*
- *Risk of security breaches*
- *Other*

If you have any comments or questions about the survey, please leave them here:

Thank you very much for completing this survey!

Kind regards,

Douwe Schoemaker

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Interview results

Respondent 1, project developer

SWOT

STRENGTHS	WEAKNESSES
1. Capabilities I4.0 2. Demand technology providers	1. Entry level 2. Short-sightedness and money-drivenness 3. Dependent on partners 4. Very fragmented industry with lots of stakeholders 5. Knowledge customers 6. Tech-washing
OPPORTUNITIES	**THREATS**
1. Taking on new positions 2. Competition 3. Innovation policy processes (government agencies) 4. Cheaper, faster, more sustainable and circular development 5. Subsidies	1. Traditional construction and development industry 2. Stuck-up municipal processes and policies 3. Scalability

Strengths

1. Capabilities I4.0: Possibilities are endless these days, now the application within the construction and development industry.
2. Demand technology providers: In today's market, the range of smart technology providers and developers is vast.

Weaknesses

1. Entry level: Adopting technologies and testing them out is expensive when it has to be applied within a large development project. So the entry-level is expensive and therefore high. When the developer has done one project, this does not mean that it is a success or not a success for other projects. The optimization will also certainly perhaps need more than five projects.

2. Short-sightedness and money-drivenness: Project developers are now looking ahead 5-10 years. Whereas with the adoption of smart technologies, the returns can only be seen after 20 years. Project developers need to be even more open to smart developments. However, ultimately project developers are very much money-driven parties and therefore, longer-term thinking remains difficult.

3. Dependent on partners: As project developers, we do not develop the smart technologies ourselves, only adopt them within our developments. We choose our partners and thus depend on how our partners adopt smart technologies. However, project developers might encourage adopting I4.0 technologies to choose the most innovative, sustainable or circular partners. This party may use smart technologies and thus be chosen more often.

4. Very fragmented industry with lots of stakeholders

5. Knowledge customers: Potential new users of smart technologies often have little or no knowledge, which means that support is not readily forthcoming.

6. Tech-washing: Providers of smart technologies often hoodwink their customers with terms like IoT and AI. When asked what the real benefit of the application is, this is still sometimes hard to find. Sometimes I4.0 seems more hype than actually developed.

Opportunities

1. Taking on new positions: Hiring data scientists, scientists and pschychologists can help with the adoption, understanding and optimization of I4.0 technologies.

2. Competition: Digital Twin developers will compete with several tasks of traditional architects. The competition can lead to, for example, more quality of design.

3. Innovation policy processes (government agencies): Many technologies are being developed but perhaps there should be more focus on innovating the policy processes.

4. Cheaper, faster, more sustainable and circular development

5. Subsidies

Threats

1. Traditional construction and development industry
2. Stuck-up municipal processes and policies
3. Scalability

Respondent 2, ICT provider

SWOT

STRENGTHS	WEAKNESSES
1. Providing and supporting the digital transformation of companies 2. Proof of value 3. IT works 4. Workshops 5. NL cloud	1. Awareness customer 2. Developments of IT 3. Translating the strategic plan into a tactical and operational plan
OPPORTUNITIES	**THREATS**
1. DCM 2. RVO and other subsidies 3. Rijkswaterstaat and Rijksvastgoedbedrijf 4. BREAAM and WELL certificates 5. Climate Change Agreement	1. Full chain collaboration, processes 2. Board-level awareness 3. Cloud and government bodies 4. Economic benefit 5. Garbage in garbage out

Strengths

1. Providing and supporting the digital transformation of companies
2. Proof of value
3. IT works
4. Workshops
5. NL cloud

Weaknesses

1. Awareness customer
2. Developments of IT
3. Translating the strategic plan into a tactical and operational plan

Opportunities

1. DCM
2. RVO and other subsidies
3. Rijkswaterstaat and Rijksvastgoedbedrijf
4. BREAAM and WELL certificates
5. Climate Change Agreement

Threats

1. Full chain collaboration, processes
2. Board-level awareness
3. Cloud and government bodies
4. Economic benefit
5. Garbage in garbage out

Respondent 3, ICT provider

SWOT

STRENGTHS	WEAKNESSES
1. Value > Concept 2. Simple rapprochement 3. Future-proof/Flexible 4. Progressive Netherlands	1. Hype > Economic benefit 2. Smaller municipalities
OPPORTUNITIES	**THREATS**
1. Collaboration stakeholders 2. Subsidies for scale-up opportunities 3. New market 4. Omgevingswet (Dutch Environment Act)	1. Tech-washing 2. Municipal governments often not multi disciplinary 3. Scaling up living labs 4. Job insecurity

Strengths

1. Value > Concept
2. Simple rapprochement
3. Future-proof/Flexible
4. Progressive Netherlands

Weaknesses

1. Hype > Economic benefit
2. Smaller municipalities

Opportunities

1. Collaboration stakeholders
2. Subsidies for scale-up opportunities

3. New market
4. Omgevingswet (Dutch Environment Act)

Threats

1. Tech-washing
2. Municipal governments often not multi disciplinary
3. Scaling up living labs
4. Job insecurity

Respondent 4, project developer

SWOT

STRENGTHS	WEAKNESSES
1. Capabilities I4.0 2. Demand technology providers	1. Clash between the development and techtask 2. Short-sightedness and money-drivenness 3. Dependent on partners 4. Knowledge customers 5. Tech-washing
OPPORTUNITIES	**THREATS**
1. Cooperation and trust between stakeholders 2. Acceleration in construction time 3. Innovation processes 4. Cheaper, faster, more sustainable and circular development 5. Subsidies	1. Traditional construction and development industry 2. Stroppy process 3. Sharing files and data

Strengths

1. Capabilities I4.0: Possibilities are endless these days, now the application within the construction and development industry.
2. Demand technology providers: In today's market, the range of smart technology providers and developers is vast.

Weaknesses

1. Entry level: Adopting technologies and testing them out is expensive when it has to be applied within a large development project. So the entry-level is expensive and therefore high. When the developer has done one project, this does not mean that it is a success or not a success for other projects. The optimization will also certainly perhaps need more than five projects.
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3. Innovation policy processes (government agencies): Many technologies are being developed but perhaps there should be more focus on innovating the policy processes.
4. Cheaper, faster, more sustainable and circular development
5. Subsidies

Threats

1. Traditional construction and development industry
2. Stuck-up municipal processes and policies
3. Scalability

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Focus group results

The survey shows that over 80% of respondents believe that I4.0 technologies will significantly impact the C&DI. However, adoption is still relatively low. Does this problem lie with the providers of the I4.0 technologies or with the traditional fragmented C&DI? What can be done about this?

Respondent 1, Project Secretary Area Development of municipality (100,000+ inhabitants)

- Explanation from the ICT provider, also too complex and sometimes still too innovative. So the actual benefit that we can get out of it is either not well explained or not achieved.
- Experience shows that the aftercare of innovation could be better by the ICT provider; otherwise, it simply appears that the use is quickly diluted and then nobody uses it and then we will get rid of it right away.
- Furthermore, it is challenging to innovate the C&DI because changing a policy within a municipality can sometimes take a very long time. So I would not just put the ball specifically in the providers' court, but the direct and real potential benefit that we can gain from adopting I4.0 is not often clear from the ICT providers. Unfortunately, however, the knowledge of innovation on our floor is not excellent either.

Respondent 2, Financial services provider (top 3 largest banks in the Netherlands)

- Too much emphasis is placed on the underlying revolving technologies. With AI, for example, we can obtain this data. Then, in explaining it, what can be achieved with that data is also essential. This may give rise to new insights that can reduce the construction time by two months. That is a concrete benefit that everyone can then understand.
- When the economic benefit is not clear, clients on the commercial side, for example, may feel abused and have the idea that they are only contributing to the R&D of the ICT provider.
- Digital deficiency is undoubtedly there in the CDI.
- Natural aversion to new technology (The why digitization and digital tools should be adopted is much more critical before training and workshops are offered on how the innovations work). Sure we train our people, but that is often about skills and not competencies.
- 80-20 rule where the 80% is the standardization and the 20% is the customization. The 80% could be digitized, automated and then robotized maybe. This is not in the standard DNA of the CDI

sector, with, of course, some positive exceptions. So much traditional thinking, saying I do not have time for this now.

- The larger contractors often spend over 70% or more on co-makers or other under suppliers. The main contractor has a day job managing that. So he only accepts innovation as proof of concept if it brings immediate benefits, such as going home an hour earlier the same day.
- Innovation starts with the design.
- In the C&DI, I4.0 technologies are not very easy to apply. For example, in 3D printing, we can print from coffee cups to chairs. However, we can now also print houses, although this involves much more complex and stringent requirements such as structural safety. It has to be very good very quickly. There is currently no framework for making a sample for each part and having it checked separately. This will improve and we will learn this over time. The standards framework is not there yet and that is currently slowing down developments. So aspects such as sustainability, safety and circularity are often still aggravating factors for innovations.

Respondent 3, CEO ICT provider (annual revenue + €700 million and active in 150 countries)

- This is true; the development and construction industry is, after the agriculture industry, the least innovative and digitized industry I remember from a recent Mckinsey study. So much is possible for a long time concerning the I4.0 technologies. Forty years ago, I was already doing innovations like Digital Twins. We pretend it does not exist or is entirely new, but you just have not started yet. Those who have not started will soon be the laggards. The bigger parties like Ballast Nedam and BAM in the Netherlands have an internal department on Digital Twins and IoT over the modern building, so they are working on it.
- Renewal happens mainly in the industry and it is straightforward if it brings benefit, we do it and otherwise, we do not do it, the human being mindset. You do not do it because it is socially responsible. That is not the primary motivation which specifically and mainly is safety and risk.
- As an ICT supplier, you make a mistake if you first have a conversation about your problems and what needs to be solved. Therefore, it is essential to offer an economic benefit straight away. Otherwise, you are not heard.

The research shows that the Netherlands are progressive in adopting innovations such as I4.0 technologies in the C&DI compared to other countries. However, when it comes to scaling up, the Netherlands appears to be very cautious. This is due to the slow policy processes and decision-making structures of the government.

Respondent 1, Project Secretary Area Development of municipality (100,000+ inhabitants)

- Implementing innovations within a municipality takes a long time, with the size and number of departments within the organization. About a presented innovation, first, a document has to be drawn up. Then it will be tested and evaluated by the Municipal Council. If the Municipal

Council agrees, the document will be referred to the Council (this can take up to a year). After this, the innovation can be introduced, adopted and used.

- A minor introduction of an innovation or a pilot can be applied on a small scale and not too significant an investment. However, new technologies and innovations often become costly, so The Council will often have to be included in the process.
- Furthermore, with the more significant decisions of significant investments, The Council is always in charge. It is democratically re-elected every few years. Implementing an innovation with one alderman does not mean that the re-elected alderman will also have this on his agenda after a new election. Furthermore, in the larger municipalities, the 'left' and 'right' parties seem to be growing further apart, widening the gap between the two and not making it any easier to implement policy.

Respondent 2, Financial services provider (top 3 largest banks in the Netherlands)

- Standards framework for new technologies
- Elections have been held, resulting in a new alderman bringing potential problems.
- Developers and builders may need to market more.
- Marketing or making clear why innovating with I4.0 technologies should be focused more on the social problems. So not necessarily the ICT provider needs to market, but this can also lie with the project developer or even the municipality. For example, there is a housing shortage problem. We have the solution with 3D printing, which allows us to produce more modular, affordable and better homes in a shorter time. A lot of people who do not come from the bèta world generally are not going to run faster if something can be done better with specific techniques. There is much more support when the social problem is put first, especially with municipal parties.

Respondent 3, CEO ICT provider (annual revenue + €700 million and active in 150 countries)

- The Netherlands thinks they are ahead and that we are modern and progressive, yes maybe if we compare ourselves to Nepal.
- It takes two main things to innovate faster: 1. Vision and the need why you need to innovate needs to become more clear for many. 2. Asset owner/infrastructure owner who is specialized in what it does and has the mandate to make decisions.
- On the government side, their are two massive mistakes. First, the government is bursting with people with no knowledge. Secondly, every four years, there are new elections with a new alderman. The previous alderman was on sports and the next one is on public works. The new alderman has never built and lacks that knowledge. There are many civil servants under it, working 35 hours a week. Secondly, suppose we have a housing shortage and 1000 homes need to be built, look at how long it takes before budgets, decisions and money are made available to put a shovel in the ground.
- We will not be able to solve the whole political side in the short term, at least not me with my background. An increase in the scale of the municipalities would be a good thing. Then you get

some more knowledge and mass. This advantage can be seen in the Netherlands, where the cities go faster than the smaller villages.

- Operational management should be separated from political management within the municipality.
- There is a lot to be gained from avoiding mistakes. Do it right the first time.
- The government is not focused on objectives, quality and results, but is focused on the cheapest provider. With the cheapest provider, you get the cheapest quality. Unfortunately, cheap and innovation often do not go together. Everything you do cheaply during construction or before will be encountered in the maintenance for which the municipality is often responsible.
- Two years ago, larger companies in the Netherlands said they would no longer build with the government because you are squeezing us out (Ballast Nedam, BAM, Arcadis etc...). It's all about the lowest price and then we have to take all the risks. So the bigger parties are going to bid defensively to the municipality. They should from both sides take the risk.

In the Netherlands, larger decisions and investments within a municipality must always be passed on to the Council. Giving municipalities more responsibility would speed up development projects and benefit innovations. Or should it be possible for innovations to be submitted directly to a higher authority, directly to the Council?

Respondent 1, function

- Currently, it is a big problem within the municipality that within C&DI everyone has a particular responsibility. Moreover, each specialist (e.g. safety specialist, an outdoor specialist, a green specialist, a water specialist) wants to bring his interests into the project. Therefore, the coordination between the specialists of the municipality is not always consistent.
- Referring all innovations to The Council seems impossible at the moment because too much work would then be passed on.

Respondent 2, Financial services provider (top 3 largest banks in the Netherlands)

- It is mainly in stakeholder management going wrong.
- The Council must be included differently.
- The Environment law must come soon.
- Innovative mechanisms or reaffirm commitment without The Council feeling they have to decide with the idea they have a knife at their throat.
- There needs to be participation to participation.

Respondent 3, CEO ICT provider (annual revenue + €700 million and active in 150 countries)

- In the Netherlands, the mentality is that everything has to become a parliamentary investigation and everything has to be discussed with 17 political parties, making it difficult to respond quickly and adequately. So decision-making in the Netherlands is not just we do it or do not do it, but do not do it for a while, procrastination.

- We are not going to solve the political side, and on the technical side, unfortunately, the business will stay ahead.
- At the board level, you then talk to a Council member who does not know anything about it and cannot decide anything independently because he is dependent on the opinions of the rest of The Council. So you are talking to a body whose decision-making process is prolonged and therefore, it is better for us as IT companies to be on the private side than on the public side.
- In Scandinavia, for example, the municipalities are much larger organizations and therefore more decisive, have more financial resources and are allowed to decide for themselves. Therefore, the processes are faster, adopting innovations are increasing and (all) parties make financial progress.

A restructuring of the C&DI processes could speed up and improve projects. For example, when issuing a tender, the project developer is involved in an earlier phase with the civil servants (e.g. green, water, and public space specialists). Alternatively, involve the specialists from the municipality earlier in the design phases. The municipality should participate if the Netherlands want to change in terms of innovation and assume more risk. Being at the same side of the table will improve projects significantly.
Respondent 1, Project Secretary Area Development of municipality (100,000+ inhabitants)

- Currently, SO, VO, DO, permit, and start building is lengthy process. However, everything is aligned in this traditional process in the C&DI.
- Involve specialists earlier in the process. Often a project developer delivers various pieces for the first time to the DO (final design). The municipality then immediately has to approve or reject them officially. The documents have not been seen before and when something is not clear, it is easy to dismiss them immediately. The project could benefit if certain documents were delivered or given insight earlier, such as in the SO (schematic design) or in the VO (preliminary design).

Respondent 2, Financial services provider (top 3 largest banks in the Netherlands)

- Involve civil servants and people from The Council earlier in the process so in a draft study. Instead of giving them in a later phase insufficient time to make a decision. No need to make it compulsory to involve interested parties at an earlier stage, but it can help ensure that several parties sniff around in earlier phases. However, this can also have its downside.
- The involved parties do not speak each other's language. Plus the fact that there are different interests. For example, a project developer may have the investor's breath on his neck and make a profit. At the same time, another party may be mainly concerned with the company's continuity and keeping a certain quality to its services. Mainly public and private parties often have very different interests.
- The BIM model of an installation consultant and the BIM model of an architect is entirely different.

Respondent 3, CEO ICT provider (annual revenue + €700 million and active in 150 countries)

- Innovate = Participate. Innovating is not telling someone how to change and that is what we are doing now. You need to participate if you want to innovate.

What is the level of trust between the public and private parties (e.g. between the municipality and project developers)? Are files and data exchanged confidentially? This does not seem to be the case and has to do with mistrust in each other and not speaking the same "language".

Respondent 1, Project Secretary Area Development of municipality (100,000+ inhabitants)

- As a secretary project developer, you represent the municipality within a project team. Within the municipality, you represent and defend the project developer. Trust is good between the municipality and commercial parties within a project team, but it seems to be less outside. It differs per project and municipality.
- There is also no unity in the 'language' that we speak to each other. No unity in files and drawings now causes miscommunication. A structural engineer and an architect, for example, use BIM for entirely different purposes. Never mind that the municipality can easily read this.
- Shared workspace and integrated construction planning with the entire project team will hopefully be stimulated by the Omgevingswet, which should be introduced in mid-2022.

Respondent 2, Financial services provider (top 3 largest banks in the Netherlands)

- Trust is fundamentally there, it's just that people often do not speak the same language (although at first glance, they think they do). It just takes time to figure out what one means in official and social terms and the other means in business terms and that one is not more important than the other.
- Sharing data confidentially is not automatic. Between the final project partners, it is, of course. However, in general, working together to accelerate innovation is a challenge. The Bouwcampus pays a great deal of attention to this. This is where clients (government), contractors (market) and science/knowledge come together and are forced to work together programmatically. Because that is what is needed to get further than just the 'one' pilot where an innovation is applied. Applying technological innovations, therefore, requires social innovation and system change.

Respondent 3, CEO ICT provider (annual revenue + €700 million and active in 150 countries)

- Work should be done in a PPP (Public-private partnership). However, the municipality is still the client and the engineer and contractor are still the participants.
- Joint ventures collaborations are becoming more common, but the government often remains on the sidelines. The government should say that in a joint venture, we take 25% of the shares and we take 25% of the risk. Get all stakeholders to sit on the same side of the table and you solve the problem together. If the municipality wants to become more decisive, then they have to take more risks.

- Municipality in the Netherlands is open to a pilot project, but the Netherlands is very reticent and cautious about upscaling, which is not conducive to innovation.

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