Construction 4.0: Industry 4.0 at construction firms

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ABSTRACT,
Industry 4.0 and Smart Industry are two terms that refer to the so-called fourth revolution, which is currently being faced by many firms. This fourth industrial revolution requires a more automated and digitalized strategy. Examples of Smart Industry applications are the Internet of Things (IoT) and the usage of cloud storage. Scientists are claiming that the construction sector is lagging in adapting to Industry 4.0, even though it could help them towards a better competitive position within their market. That is why this paper examines the hurdles construction firms are facing and which elements they should add or eliminate in their strategy. This is studied by a maturity scan, which is in the form of a survey, which shows that the participated firms have a low maturity level of 2 (Starter). The main obstacles construction companies are facing are a rigid and conservative company culture, the nature of temporary and unique construction projects and the resistance against change. Nevertheless, there are some obstacles which are complex to overcome, because they are inherent to construction projects. A suggestion for construction firms could be to change their business strategy towards a more modular way of building, which requires and gives the firm an opportunity to adapt to a more automated and digitalized strategy. Furthermore, being more open and maintain a more progressive culture would be helpful to be more adaptive towards Industry 4.0.

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Industry 4.0, Smart Industry, Construction, Strategy, Innovation

1. INTRODUCTION

Construction 4.0 can be described as Industry 4.0 applications within the construction sector. Construction 4.0 could be the remedy to solve the housing shortage. This paper examines why the construction sector is lagging in terms of adapting to Industry 4.0. This paper will first start with a description of the current situation of how the construction sector is facing problems with implementing Industry 4.0 followed by a problem statement and a research question.

1.1 Situation and Complication

In 2018, the Dutch government started with the so-called "Smart Industry Implementatieagenda 2018", which outlines the guidelines and principles of applying to Smart Industry and Industry 4.0. Smart Industry and Industry 4.0 are two interchangeably used terms to describe the digital revolution, which many firms are currently undergoing. This guideline of the implementation of Smart Industry principles to Dutch firms is needed to foster digitalization among enterprises and ensure future-proof companies. Especially for small and medium-sized enterprises (SMEs), Industry 4.0 applications can provide opportunities to improve business performance (Smart Industry, 2018),

Industry 4.0 is considered as the fourth industrial revolution which initiates processes of digitalization, Smart Industry solutions, Internet of Things (IoT), and cyber-physical systems. This digital revolution complies with rapid changes in the business environment, reduced product lifecycles, and changing customer preferences. (Cugno & Castagnoli, 2021)

However, several studies show that firms that are actively operating in the construction sector are lagging behind in terms of adaptation to Industry 4.0. "Comparing the progressions between multiple industries, the construction industry is reluctant in incorporating these innovative technologies into its common practices despite the drastic developments demonstrated by the other industries." (Alaloul et al., 2020, p. 1) There are also other studies, which are claiming that adaptation to Industry 4.0 technologies is necessary, because of low productivity, the low amount of skilled workers, such as engineers, and the rise of complex projects. Industry 4.0 applications could solve these disadvantages and increase productivity. Moreover, Turner et al. (2021) is asserting that the construction sector is the main industry that has a low adaptation rate to Industry 4.0 in comparison to other industries. (Turner, Oyekan, Stergioulas, & Griffin, 2021).

This increased productivity could be a remedy for the housing shortage in the Netherlands, where the demand for houses exceeds the supply. ABN AMRO (2019) claimed that the labour productivity among construction firms is pretty low, due to a low degree of automation and standardisation. This could be solved by modular building, which will be explained in paragraph 4.1. By modular building, which is also called 'Prefab', could lead to a 40% increase in the delivery of houses. Moreover, besides the fact that the housing shortage must be solved, the Netherlands is aiming towards a minimum Energy Label C for at least 30 million square metres of office space by 2023. In short, there are some challenges for the construction sector.

1.2 Research Objective

Based on the previously mentioned reasoning, the aim of this research is the mapping and identifying of the challenges and barriers to overcome for the construction sector and which elements construction firms should add to their strategy in order to adapt to these technologies. In short, the main barriers are mapped first, and subsequently, the strategies to follow for construction firms are outlined.

1.3 Research Question

Thus, based on the research objective of this paper, the following research question is posed:

What are the main obstacles for construction firms to overcome to adapt to a strategy with industry 4.0 applications?

This research question is posed to identify and distinguishes the obstacles which construction firms must overcome to adapt to Industry 4.0 and which strategies to follow to adapt to Industry 4.0.

To answer this research question, two sub-questions can be posed:

1. What are the main obstacles to overcome to adapt to industry 4.0 in the construction sector according to existing literature?

2. How can these obstacles, faced by construction firms which adapt to Industry 4.0, assessed in practice?

These sub-questions are elaborated in the fourth paragraph: the theoretical framework.

2. ACADEMIC & PRACTICAL RELEVANCE

As already mentioned in section 1.1, this paper contributes to shed a light on the different obstacles construction firms face when implementing Industry 4.0. This paper also gives insights into how firms can overcome their strategy to be more agile towards Industry 4.0. The academic and practical relevance must be seen as interrelated elements, because construction firms can use these insights to improve their business, perhaps to solve the housing shortage in the Netherlands. Moreover, companies involved in this research will receive a consultancy report which identifies the main obstacles and strategies to overcome for themselves.

3. THEORETICAL FRAMEWORK

In the previous section, the research question and their sub-questions are formulated. To answer the research question, the sub-questions should first be answered by a thorough literature study. This theoretical framework starts with discussing the first sub-question when the second will follow at a later stage in this section.

3.1 Construction 4.0

The study from Turner et al. (2021) distinguished used Smart Industry technologies into seven different sections. The first few mentioned technologies are (1) data analytics and the use of (2) artificial intelligence. Examples of these two kinds of technologies are the so-called artificial neural networks, where historic data are used to gain insights into the past to develop better scenarios and a well-performing decision-making. Thus, these two interrelated technologies make decisions by artificial intelligence with the help of data analytics. The next kinds of used technologies are (3) robotics and (4) automation. These innovations offer great opportunities to improve productivity and viability, but encounter many barriers to implementation due to the degree of complexity among construction projects. The construction sector solved this by implementing modular building manufacturing, which means that parts are manufactured at the plant but must be assembled on-site. For instance, construction firms use digital fabrication and adaptive manufacturing, which mean manufacturing elements in a customized and digital way. 3D-printing by Computer-Aided Design (CAD) is also a form of automation and robotics, because of the help of computer-aided design. The third main component of a construction 4.0 technique is (4) Building Information Management (BIM). This technology enables firms to get access

easily to building plans and the current state of activity on the construction site. Within this technology, safety issues should be taken into account, because BIM detects safe work areas and potential hazards. Nevertheless, firms must ensure that IoT is connected towards BIM in order to receive on-site data. The next kinds of techniques are (5) smart wearable technologies, which make "use of a multitude of sensing technologies to detect the movement and psychological state of individuals, including the environmental conditions in which they work" (Turner, Oyekan, Stergioulas, & Griffin, 2021, p. 749). Examples of this are smartwatches which measure the performance and the health status of workers on-site, who can then be managed properly. The sixth major technologies are the (6) Digital Twins, which enable construction firms to display a construction site virtually and test hypotheses before implementing on-site, which helps predictive decision-making. BIM and Digital Twins are really interrelated to each other. And finally, the overarching technology which entails all the aforementioned techniques, is the (7) industry connectiveness, which ensures that the technology's stay in connection between on-site activities and the office, this also includes the overarching technique Internet of Things. So, these seven different technologies are the current state-of-art at construction firms. In the next section, the different obstacles which construction firms encounter to apply Industry 4.0 are discussed.

3.2 Obstacles to apply Industry 4.0

Other sectors beyond the construction sector are already perceiving benefits of adapting to Industry 4.0. However, the construction sector is lagging behind. First of all, construction operations are tied together by the involvement of different stakeholders as customers, subcontractors and municipalities. Besides this, construction projects involve complexity, on-site operations and individual ability to handle the project. And at least, the construction sector consists merely of SMEs which have low access to financial resources, which means that the construction sector does not have the means to invest in Industry 4.0 applications. (Oesterreich & Teuteberg, 2016)

Moreover, the study from Oesterreich & Teuteberg (2016) claims underinvestment in R&D among construction firms, which contradicts the economic impact of construction operations. The same study sums up different reasons for underinvestment in innovative ideas. The first reason is the degree of complexity related to construction projects, due to the high amount of involved stakeholders and processes. Secondly, the uncertainty, which means that since construction projects are on-site and unique, it consists of a lack of uniformity and a high degree of specification. Thirdly, the fragmented supply chains have many different forms, all involved in production of the end-product. For instance, there are so many individuals involved in the building process, for example plumbers, electricians, carpenters and bricklayers. Fourthly, the construction industry consists of many companies that are short-term thinking focused, because of loosely coupled systems with tight couplings in individual projects and loose couplings in the permanent network. By mentioning this, short-term thinking counteracts innovations. Fifthly, the firm's structure of many industrial enterprises is decentralized which causes problems of initiating innovations. Subsequently, the nature of temporary construction projects impedes innovations and finally the construction business culture; construction companies are well-known companies which are against changes and maintain a quite rigid culture. Summarizing the previous summation, there are 7 reasons that hamper innovations; complexity; uncertainty; fragmented supply chain; short-term thinking; decentralized company structure; nature of temporary construction projects; and the construction industry culture.

3.3 Maturity models & Industry 4.0

Since Industry 4.0 affects the business in such a way that repositioning and revision of the value proposition and maybe even the corporate strategy is needed. That is why maturity scans are developed to measure the level of maturity to implement Industry 4.0 technologies. Often times, the senior management of firms are uncertain about outcomes of implementing Industry 4.0 and have lack of knowledge about the techniques. On top of that, these technologies involve a high amount of investment, which brings some risks. Therefore, maturity scans and models come into play as they "provide large scale of knowledge about companies' current state and a path to pursue for implementation of Industry 4.0 strategies" (Akdil, Ustundag, & Cevikcan, 2017, pp. 61-62). Furthermore, the same study claimed that a certain maturity level refers to a pathway to prevent problems and reach a certain achievement. (Akdil, Ustundag, & Cevikcan, 2017).

The paper of Schumacher et al. (2016) developed a concept where maturity and readiness towards Industry 4.0 are measured. They claimed that strategy, leadership, customers, products, operations, culture, people, governance and technology are the dimensions to measure the maturity level. Of course, there are many other scientists who developed maturity models. Examples of these models can be seen in Table 1.

Ganzarain & Nekane (2016) asserted that a developed maturity scan helps firms guide to identify new opportunities to diversify by Industry 4.0 against their competitors. Their model identifies the obstacles which hinder the implementation and envision a strategy to adapt to Industry 4.0.

Altogether, this means that a maturity scan gives direction with a strategy to implement Industry 4.0.

Table 1 Comparison of dimension from different maturity models (Santos & Martinho, 2020)

Model 1 (Schuh et al., 2017)	Model 2 (Schumacher et al., (2016)	Model 3 (Lichtblau et al, 2015)
Organizational structure	Leadership	Strategy and organization
Organizational culture	Strategy	Employees
Resources	Culture	Smart Factory
Information Systems	People	Smart operations
	Technology	Smart products
	Operations	Data-driven services
	Products	
	Customers	
	Governance	

4. METHODOLOGY

In this section, the methodology will be discussed, where the relevance and importance of the maturity scan are discussed and how this will be applied to the sample of this research.

4.1 The SIMS Scan

This research can be seen as a descriptive and explorative research where the main obstacles and strategies to overcome and to follow are examined by the SIMS-scan developed by IXIA. The SIMS scan is a scan which measures the maturity level by the following components: strategy, business culture &

employees, products/services & customer contact, value chain and technology & IT management. To explore the different hurdles, a case study must be done with the collaboration of different construction firms. This case study will be done by the SIMS scan developed by IXIA and the University of Twente. This scan is a maturity scan which measures the level of maturity towards Industry 4.0, which is also described in section 2.3. The results of the scan will be displayed by radar plots. Ungerer (2018) validated his scan by an extensive workshop with experts. There are no academic articles which are referring to the SIMS Scan from IXIA.

According to IXIA Smart Insights (2021), this scan consists of seven aspects, which can be seen in Figure 1, that covers all the aspects of maturity to adapt to Industry 4.0.

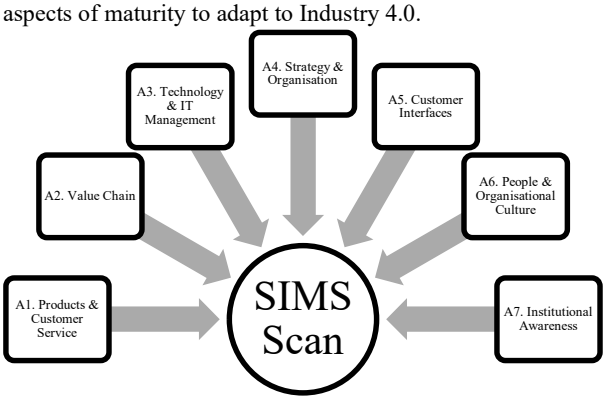

Figure 1 Consisting aspects of SIMS Scan (IXIA Smart Insights, 2021)

Ungerer himself, who developed this scan, asserted in his paper that his developed scan consists of seven aspects, 35 measurements questions and five maturity levels. The seven aspects consist of 5 measurement questions, which come to a total of 35 measurement questions. He claimed in his paper that all the measurement questions, which are asked on a Likert scale, are covering the seven different aspects, which increase the validity of the test. The answers reach from not at all (1) to fully (5). The results are displayed by radar plots and by a level of maturity. The distinguished maturity levels can be found in Figure 2. All the different aspects form a radar plot where the results can be seen. (Ungerer, 2018)

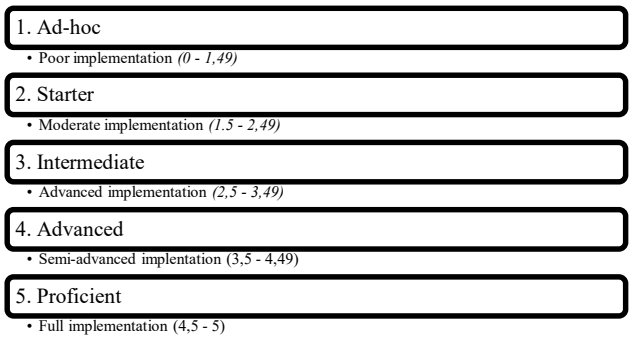

Figure 2 Level of maturity after performing the SIMS Scan (Ungerer, 2018)

These different maturity levels indicate a certain degree of how far ahead a company is in implementing Smart Industry applications. These levels are developed according to a certain quantitative score, which points out the level of maturity according to the different aspects. Based on the answer options that are given on a Likert scale, the maturity levels depict a certain qualitative score depending on the results from the scan. These qualitative scores can be seen in Figure 2. These scores are finally computing as an average score, by all the three cooperating firms in this research. Based on confidential matters, the list of questions cannot be published in this research.

4.1 Research Design

Three companies which are actively operating in the construction sector participate in filling the scan and will follow a workshop, which will be recorded, to discuss the results from the scan. This means that triangulation is used to combine quantitative data from the scan and qualitative data from the workshop to improve the validity of the research. “The triangulation made possible by multiple data collection methods provides stronger substantiation of constructs and hypotheses” (Eisenhardt, 1889, p. 534). This same study also claimed that combining both quantitative and qualitative data will offer a more synergistic view about the results and the study. “The qualitative data are useful for understanding the rationale or theory underlying relationships revealed in the quantitative data or may suggest directly theory which can then be strengthened by quantitative support” (Eisenhardt, 1889, p. 538). The participants from the different firms are members of the highest management of the organisation, because answering the scan needs internal insights from the firm. The results from the scan will be displayed by radar plots, which will also be used during the workshops, to discuss answers and gain insights. In the sixth paragraph, first the total average score is displayed and discussed, which will be followed by a summary of the workshop per aspect of the scan. The radar plots will be separately shown in Appendix A per dimension.

The three different firms are actively operating construction firms within the region Twente. Company X has less than 25 employees and is a metal-producing company which is mainly producing facades and other building components. The second company is Company Y which has between 25 and 50 employees and is active in demolishment to make sites ready for construction or rebuilding and is active in asbestos removal. Company Z is an installation engineering company with more than 250 employees. Finally, these participating companies will receive a consultancy report where they can read the main obstacles and strategies to overcome to adapt to industry 4.0.

First, a small company tour is given by the participants of this research to gain an insight into the firm. This workshop will be in the form of an informal group interview, where the results of the scan will be displayed to a group of people from the participating firms. According to Cooper & Schindler (2014), group interviews can consist of different amounts of people. For this research, mini-groups or maybe even dyads or triads suit the best for this study. The mini-groups, which will consist of from two to six people, will first be tried to achieve, but when the availability of participating person cannot be reached, dyads or triads will be used to perform the workshop.

The non-probability sampling method is used, because of the case study. This non-probability sampling method does not focus on generalizability but on convenient characteristics like the availability of time, having a network to reach the firms and the willingness to participate. “Works on quantitative research generally treat anything other than probability sampling as “convenience sampling,” and strongly discourage the latter. For qualitative research, this ignores the fact that most sampling in qualitative research is neither probability sampling nor convenience sampling, but falls into a third category: purposeful sampling (Patton, 1990, 169ff.). This is a strategy in which particular settings, persons, or events are deliberately selected for the important information they can provide that cannot be gotten as well from other choices” (Maxwell, 2013, p. 23). Maxwell asserted in his study that purposeful sampling could be a

possibility when there are some limitations connecting to the research. Again, this validates why only 3 participated companies are chosen within this case study.

5. RESULTS

In this section, the main results are discussed to answer the research questions. In Figure 3 below, the combined total average maturity level can be seen. The combined average score is 1,98. This radar plot shows that the average maturity level of companies X, Y and Z lies around the 'Starter level' (2). According to the scan, this means that all the three companies have an average score of a moderate implementation to Industry 4.0 applications. This confirms the statement about the low adaptation towards Industry 4.0 in the construction sector.

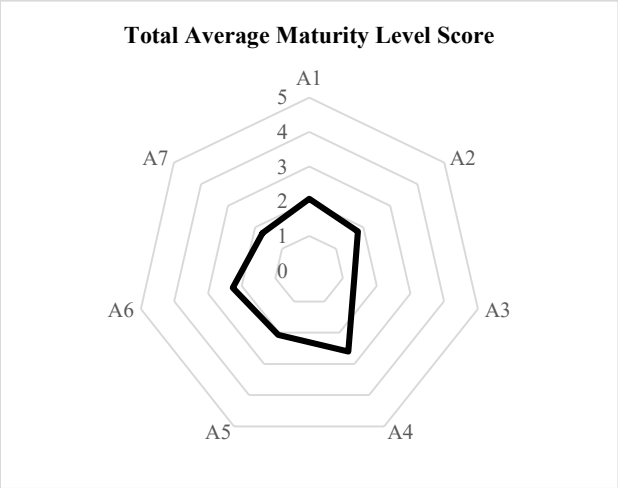

Figure 3 Combined Total Average Maturity Level Score Per Aspect

When looking at Figure 3, Aspect 4 is coming forward, because it has the highest score, compared to the other aspects. This is because Aspect 4 was about Customer Interfaces and asked questions about which channels firms use to reach their customers and suppliers. Most of the companies are using social media this time to get in contact with their main stakeholders, which belong to the digitalization of Industry 4.0, and that is why this aspect is standing out. In Table 2, the average score per aspect per company is shown. The majority of the scores show a low score of approximately below 2. Appendix B shows a specific radar plot about the total maturity score from the three different firms.

Table 2 Average score per aspect per company

	Company		
Aspect	**X**	**Y**	**Z**
A1.	1	1.8	3.4
A2.	1.6	1.2	2.6
A3.	1	1	2
A4.	3	2.4	2.4
A5.	2.2	1.6	2.4
A6.	1.8	2.6	2.4
A7.	1.4	1.8	2

In the next part of this section, the results of the workshop will be given by a detailed summary of every aspect.

5.1 Workshop

This paragraph will show the discussions of the workshop with the three different participating companies and why the companies scored certain scores.

5.1.1 General information

The three participating firms differ in many company features. One firm has a turnover of over 50 million euros and one has a turnover of less than 5 million euros. The same sounds for the number of employees. Company X employs less than 25 people and company Z has over 250 employees. Company Y is in the middle of both firms. Altogether, the three firms differ in company features, such as size. This is because it will give a better representative view of the construction sector.

5.1.2 Introduction questions

Appendix A shows the three different radar plots for the introduction questions. This plot shows that Company X and Y are around the same score (2), except Company Z. This company with the green line is jumping out with a high score.

These introduction questions are about the market a firm is competing in, for example, the stability, growth, dynamics and the pace of changes are features of certain competing markets, which are asked in the introduction questions. These questions also include how innovations are penetrating the market and by what pace.

First Company X and Y: these two companies are scattered around the same values. Both companies face a rigid company culture, in terms of employees who stick to traditional and the same job procedures. Furthermore, their jobs as unique typesetting work include traditional job procedures where hands are always needed to perform the jobs. Company X stated explicitly a distinction within the construction sector: the traditional construction firms and the prefab firms; where houses are produced at a factory. X stated that prefab firms are using more and more innovations, because their operations are much more focused on the use of machinery instead of human interruptions. X added to their reasoning that their employees would favorably divert to a more modular way of building. X thinks that they are not the only firm within the construction sector that thinks the same.

Then Company Z, which is claiming that their company is in a very flexible market and sees more innovations penetrating the market. During the workshop, Z nuanced that this person, who participated during the workshop, is stimulating and fostering innovations at the company and the market. However, Z concluded that their job procedures are quite rigid, because their job procedures require unique human interruptions, why it is difficult to implement certain innovations, such as digitalization. During the workshop, Z stated that when looking at the whole firm, Z would choose lower scoring options. As can be seen in the other plots, Z scores at every aspect higher compared to the other two firms, but that is because the interviewee is stimulating innovations within the market and the firm itself.

5.1.3 A1. Strategy and organization

This aspect measures to what extent the strategy contributes to the firm where Industry 4.0 can be applied to. Company X is scoring at every question a '1', which means that X is not observing any Industry 4.0 applications within their served strategy. X claimed that they are using some innovations at their firm, for example, new machinery that can produce components faster, but not innovations that change their job procedures. So, their innovations are only about job efficiency. Company Y scores a little bit higher (1.8) than Company X, but still low. Y stated that their strategy does not include any Industry 4.0 applications. However, Y scored a '3' for the extent to which the

progress of the implementation of Industry 4.0 is periodically updated. Y said that it is only updated, because the only digital or automated system they use is 'Office 365' and 'Sharepoint', which is automatically updated by their software providers. Altogether, Y thinks that Industry 4.0 does not belong to their strategy but more to their operational tactics at the office.

Again, Company Z is scoring much higher (3.4), than the other companies, but this is once more because Z is stimulating innovations. However, in contradiction to the other two companies, Z is using a digital time registration system and a digital inventory system. This means that Z is a little bit more focused on implementing Industry 4.0 in their strategy.

5.1.4 A2. People and organizational culture

This aspect is about testing to what extent the internal company culture and their employees are facilitating innovations. Company X scored an average of '1.6' and Y '1.2'. Company Z, conversely scored a '2.6' at this aspect. X and Y both claimed that their conservative business' culture is not facilitating innovations and digital solutions inside their firm. X and Y both see that the higher management and the employees on the site do not identify any benefits of the use of digital tools, such as digital infosystems or digital construction plans. Both firms observe that their job procedures are already a while doing well and their employees like the way of working, so they asked themselves; "why change it?". However, Company Z scored a little bit higher with a '2.6'. This company scored at every question a '2' or a '3', because the participant observed internally that the company is ready to implement Industry 4.0 applications, but due to their unique and complex jobs which require no digital solutions, it is nearly impossible to get used to such applications. So, X and Y are both claiming that their rigid business culture impedes innovations and Z is asserting that their unique jobs do not require Industry 4.0 applications.

5.1.5 A3. Products and customer services

This business aspect is measuring to what extent firms offer customer-related services and how smart technologies are implementing to the offered products. Company X and Y scored an average of 1 at this aspect. X said during the workshop that their score could be a little bit higher, because they use a digital visualization for the customer when offering their plan. For instance, a digital construction plan where the client can see which bricks the house gets and what the facade will look like. However, at their production process, they use machinery which is not linked to the office, because of the unique and mainly customized demand. Y, with an average score of '1' as well, observes that there is no openness towards new ideas in terms of innovations, so the customer does not see any smart technologies towards them. This is also because of the conservative and rigid industry culture. Z scored a '2', but is also claiming that their customer does not see anything like a smart technology, due to their customized way of working and the only work Z is doing as a customer service is maintenance, which does not include any smart technique. The only smart technologies which the customer can perceive are smart sensors or other technologies Z is offering to their customer. Since this aspect is measuring the customer services, Z is scoring a '2' as well.

5.1.6 A4. Customer interfaces

This aspect about customer interfaces is measuring to what extent the firm's customers can come into contact via digital channels. All three firms scored relatively high, compared to the other six aspects, at this aspect, due to the use of social media channels and their website. Company X scored a '3' with the reasons that they use many social media channels, their website and e-mail. Company Y and Z scored a '2.4', but they said as well that they use Facebook, e-mail and their website to give potential customers the opportunity to get in contact with the firm. Nevertheless, Company X and Y scored a '1' about the question whether the firms itself gather customer data to serve the market better. They both claimed that for themselves, it is not necessary to gather these data, because the data come to them, since the customer always tells their wishes how the result should look like.

5.1.7 A5. Value chain

This aspect measures the maturity of Industry 4.0 technologies and practices throughout the process from customer demand to product delivery. Company X scored at this aspect a '2.2' and stated that their organization is not that focused on the digitalization of their firm, because the sector does not requires a more digital workspace. Inside the value chain itself, there are some smart technologies, but these are not linked to the production process itself, for example to detect delay. Company Y scored a '1.6', which is quite low. Y observed that nothing is coupled internally in terms of smart technologies and systems. Their company is much more focused on the data input instead of the processing of data by digital solutions and smart coupled technologies. The only focus for them to digitalize their company is at the office where the main applications are running on Office365. Company Z scored a '2.4', which is the highest of all the three participants. Z claimed that their value chain is to a low extent coupled and linked between different systems and departments. They use for example a digital hour system, but there are not any smart technologies or digital systems that increase the value in the chain towards the customer, because of the, in their experience, little added value.

5.1.8 A6. Technology and IT management

This sixth aspect measures the extent to which smart technologies are implemented in the organisation and how these technologies are used to add features and services. Company X scored at this aspect a '1.8', which is the lowest of all the three participated firms. Company X and Y both do not have an IT department internally, they both outsource their IT management. Company X scored at every question a '1', except the question about how the firm is securing their ICT data and data exchange, where they scored a '4'. They claimed that for them, but it is ubiquitous, that IT data must be secured for the threat of hackers. Company Y scored a '2.6' at this aspect, which can be seen as relatively high. Company Y admitted that they could score a little lower afterward, because they do not use autonomous systems which are directly coupled between different departments. However, they claimed as well, that they are really serious about data security. Company Z scored a '2.4', but in contrast, they have an IT department internally. This IT department consists of a few people who are monitoring the systems. Yet they admitted that their task is only limited and it could be much more sophisticated. Z has an IT department due to their company size of more than 250 employees, which is expensive to outsource.

5.1.9 A7. Institutional awareness

In this section, we measure the extent to which the importance of data security and privacy are known and the corresponding measures are applied, which concern Industry 4.0. Company X scored a 1.4, since their IT and data privacy are outsourced towards an external IT department. Nevertheless, they emphasized the importance of data security and privacy. This counts the same for Company Y and Z, which scored respectively a '1.8' and a '2'. All the three participated firms admitted afterward that this aspect could score a little bit higher, but it is just ubiquitous that data security is present internally.

5.1.10 General remarks

Some results from the scan show deviating data from the workshop. This is proven by the fact that some respondents

during the workshop admitted that they could give some questions another score, which could affect the reliability of this study.

6. CONCLUSION

To answer the main research question, first the two sub-questions must be answered. The first sub-question is about which obstacles firms must overcome to adapt to Industry 4.0, according to existing literature. According to the theoretical framework; complexity, the high amount of stakeholder involvement, on-site operations and individual ability to handle the project are the main obstacles to adapt to Smart Industry applications. A fragmented supply chain, unique work activities and underinvestment in R&D are also not solving the problem. Moreover, the rigid business culture, short-term focusing firms, decentralized firm's structure and temporary construction projects impede Industry 4.0.

The second sub-question is about how these obstacles can be assessed in practice. The theoretical framework highlighted different maturity scans which cover different business aspects to measure the maturity towards Industry 4.0.

The research question is about which obstacles construction firms must overcome to adapt to a strategy with Industry 4.0 applications. These obstacles consist of the elements which are mentioned in paragraph 2.2, which are complexity, uncertainty, a fragmented supply chain, short-term thinking, decentralized company structure, nature of temporary construction projects, and the construction industry culture. These are the main elements which should be eliminated at the firm's strategy to overcome to adapt to Industry 4.0.

The second part of the research question is about what are the main strategies construction firms should follow to adapt to Industry 4.0 applications. Construction firms should first change their rigid and conservative business culture, which is mainly hampering the innovative strategy. Many companies resist change and do not see an opportunity as a necessity to change. Moreover, the outsourcing of IT and ICT services mean that the innovation will not come from the construction firms themselves. However, there are some factors that are inherent at construction firms which are impeding the adaptation to Industry 4.0. These are the unique work activities, which can be overcome by changing their strategy to a more 'Prefab' or modular way of working, where more machinery and automation are required. Other elements which are inherent in the construction sector are the fragmented supply chain and the high amount of stakeholder involvement, which cannot easily be overcome.

Nevertheless, all of these factors are confirmed by existing literature, but there is one factor which is impeding Industry 4.0 according to existing literature, but this will be discussed in the next section.

7. DISCUSSION

This section will describe the implementations and limitations of this research which will be followed by future research suggestions.

7.1 Theoretical & practical recommendations

This paper gives insights into the main hurdles construction firms are facing when implementing Industry 4.0. According to the results and conclusion of this paper, all of these factors are confirmed by existing literature, but there is one factor which is impeding Industry 4.0 according to existing literature, which is that construction firms have a shortage of liquidity, but this is rejected by all the participants during the workshop, because they confirmed that many construction firms, especially in the region Twente, possess sufficient liquid assets to make investments in Industry 4.0.

Due to the complicated sector features is it difficult to implement directly Industry 4.0 applications. Construction firms are mainly focused on unique work and not on, for instance, modular building, which requires a much more automated, standardized and digitalized job procedure. In addition, construction companies retain rigid and conservative cultures, which makes it in the first place difficult to adapt to Industry 4.0, but in the second place to change to modular building instead of the conventional way of working. There are some elements which construction firms can change internally: a more progressive company culture and long-term thinking. With this, a strategy is needed which directs the company towards a more digitalized and automated firm. Firms with a more progressive company culture where employees discuss internally about the strategy and their job will foster the competitive position in their market.

Finally, a 'technology manager' could be helpful in order to foster innovations and technologies into companies, since the participants admitted that there are a few coupled systems and this manager can discuss innovations internally with employees and facilitate to couple systems internally, for example by IoT or the use of cloud.

This paper will contribute to practical implications such as solving the housing shortage in the Netherlands since Smart Industry would foster productivity and the competitive position for construction firms.

Thus, the most important part which firms should add to their strategy is to be more open and progressive towards innovations in terms of digitalization and automation, which can be done by retaining a more progressive and open company culture. Internal meetings and discussions with the higher management and employees, with maybe even the help of a 'technology manager', could be helpful in order to foster (digital) innovations at construction firms.

A practical suggestion to be more adaptive to Industry 4.0 is modular building. Since the work of construction firms requires unique job procedures, it is difficult to make direct couplings between systems and departments, because every action is unique. That is why construction firms should think about modular building. However, the employees of the participated companies admitted that they are not willing to change their way of working towards a more standardized way, since they are already satisfied with their jobs.

7.2 Limitations & future research

This paragraph will be about the elements that limited the outcomes of this paper and future research suggestions will be given. The case study and the small sample size make it difficult to give general conclusions about the construction sector as a whole, which decreased the level of validity. Furthermore, the fact that all of the workshops were done in dyads or triads, decreases the validity as well. Besides this, COVID-19 made it difficult to reach firms that are willing to participate in this study.

Besides the set-up of this paper, the participants also influence the validity of this paper, because, at some aspects, they admitted during the workshop that they would give some questions another score after seeing the questions another time.

Suggestions for future research within this field are to use the survey from IXIA and send this to a larger sample which gives this paper the opportunity to make general and valid statements about the entire construction sector in the Netherlands. Moreover, a firm which has already adapted towards a more digitalized and automated strategy would maybe increase the validity, by comparing the results. Another suggestion would be

to examine what the costs and efforts are for construction firms to change towards modular building, and if it is possible for conventional construction firms to adapt to this way of working. Besides this, a study about the reasons why construction firms are conservative and rigid would be helpful in order to understand why they have a low adaption rate towards Industry 4.0. Finally, a quantitative study could be needed to examine the positive relationship between the adaptation of Industry 4.0 and the competitive position in the market of a construction firm.

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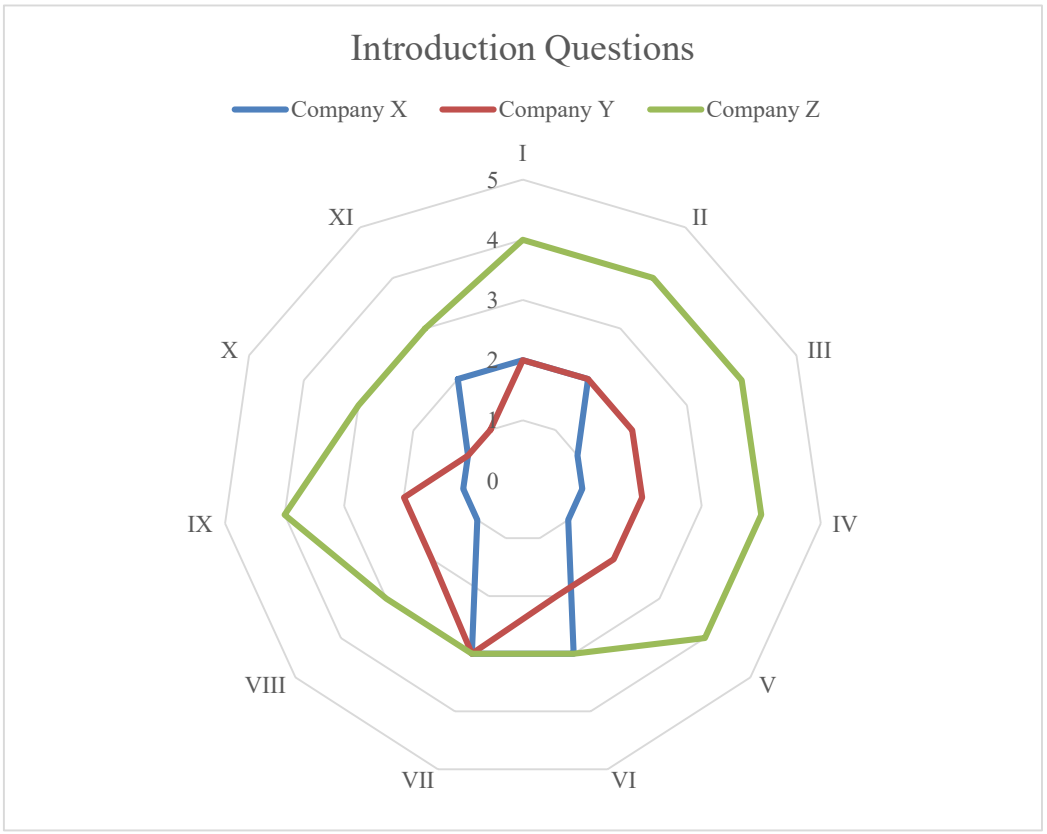
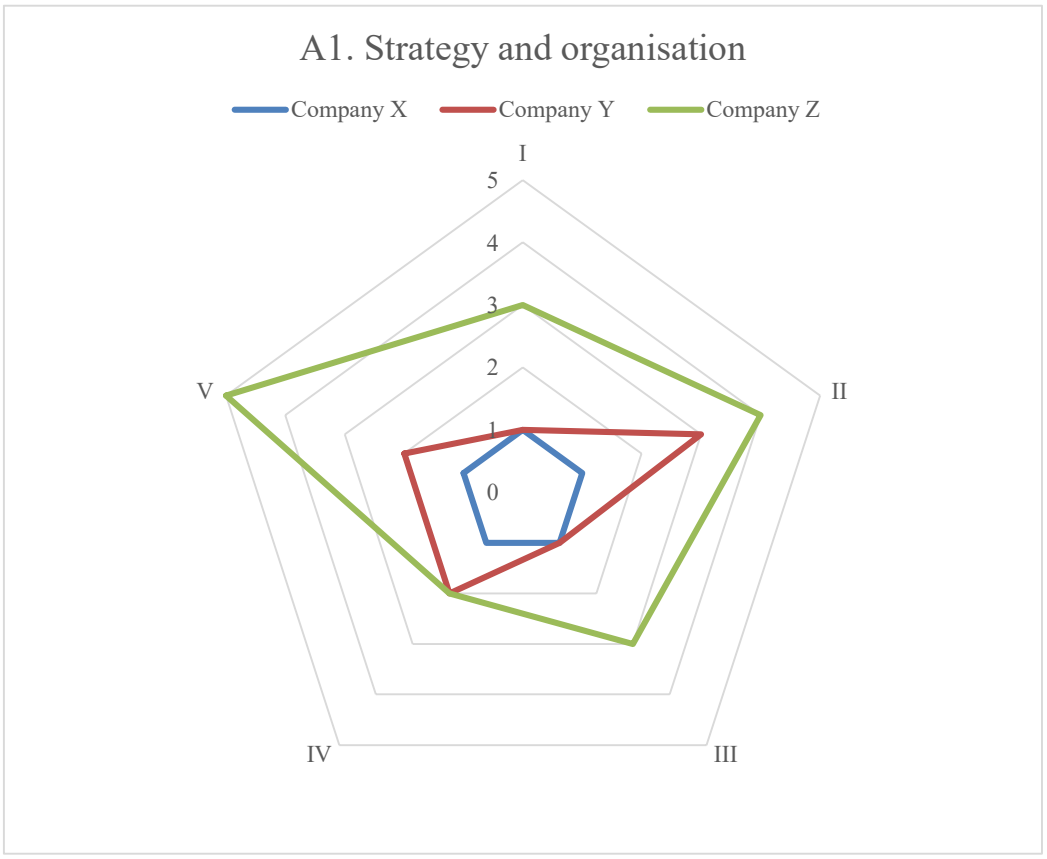
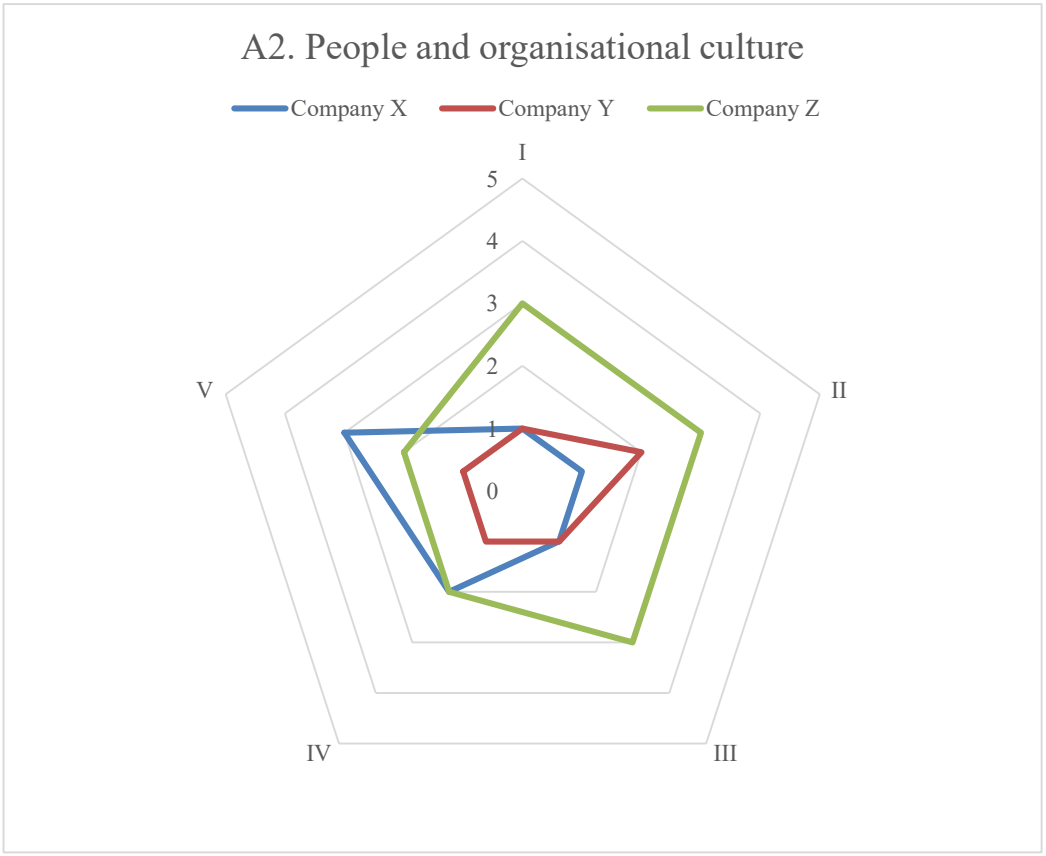
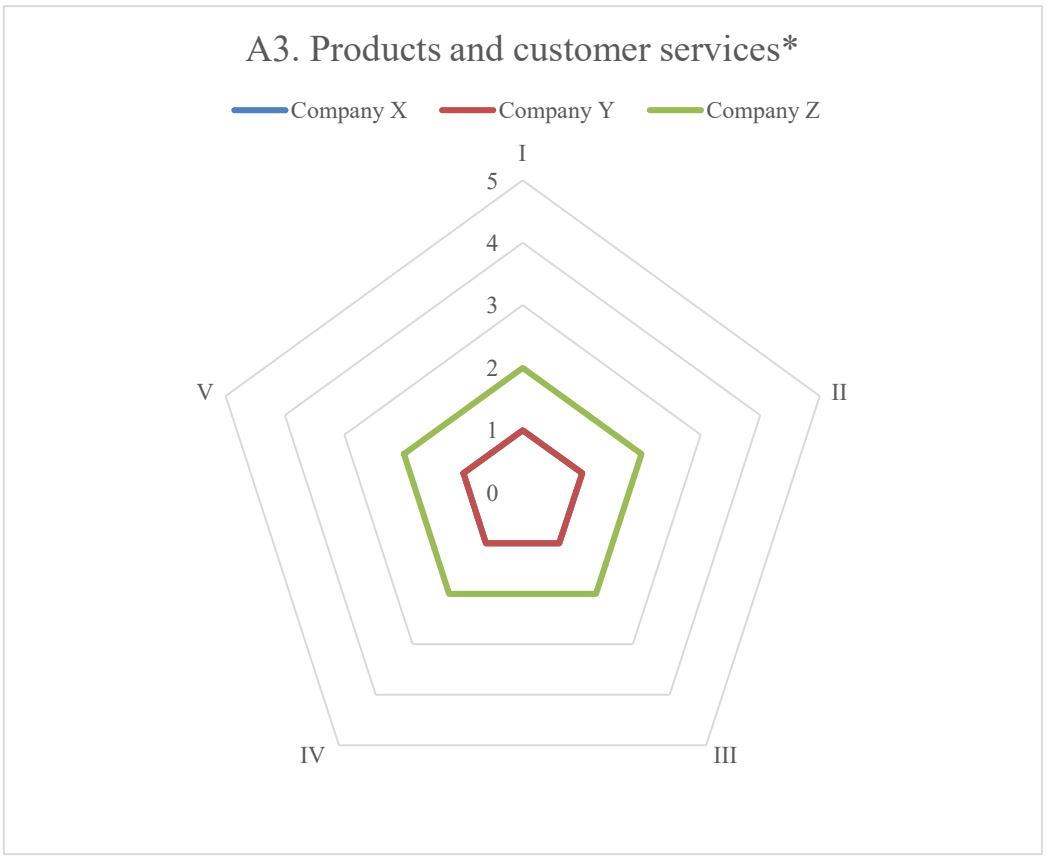
APPENDICES

Appendix A: Radar plots per aspect



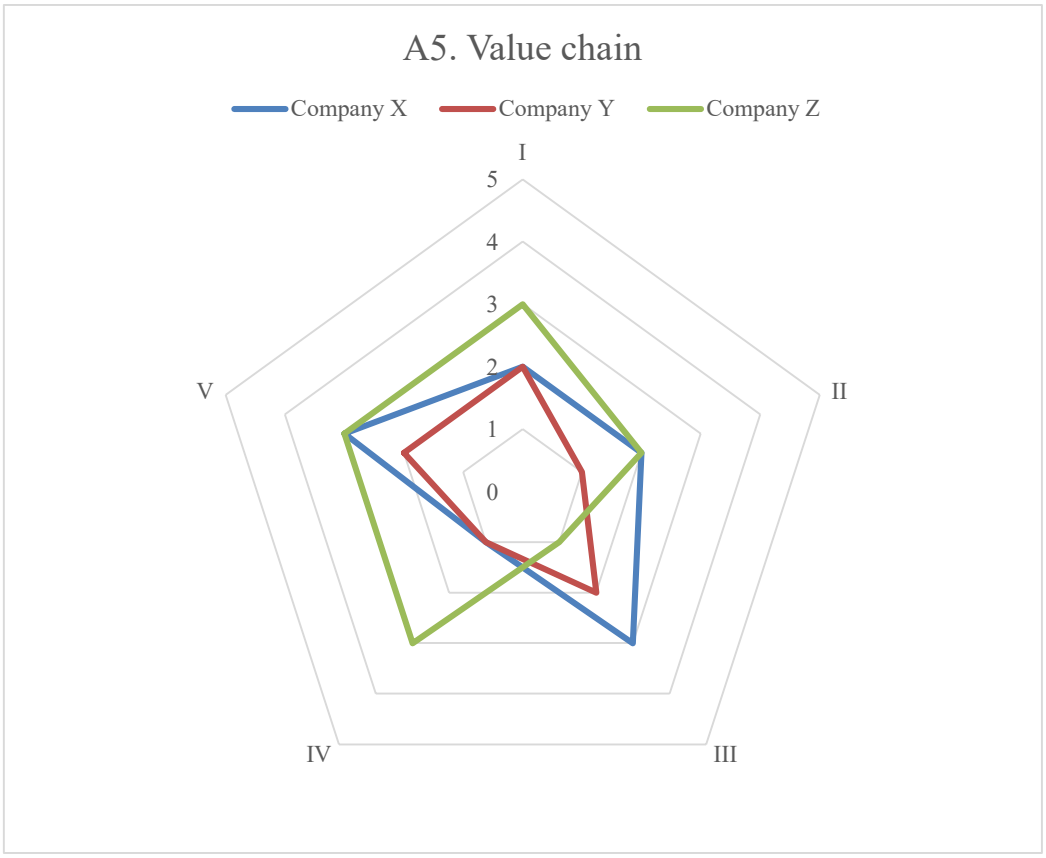


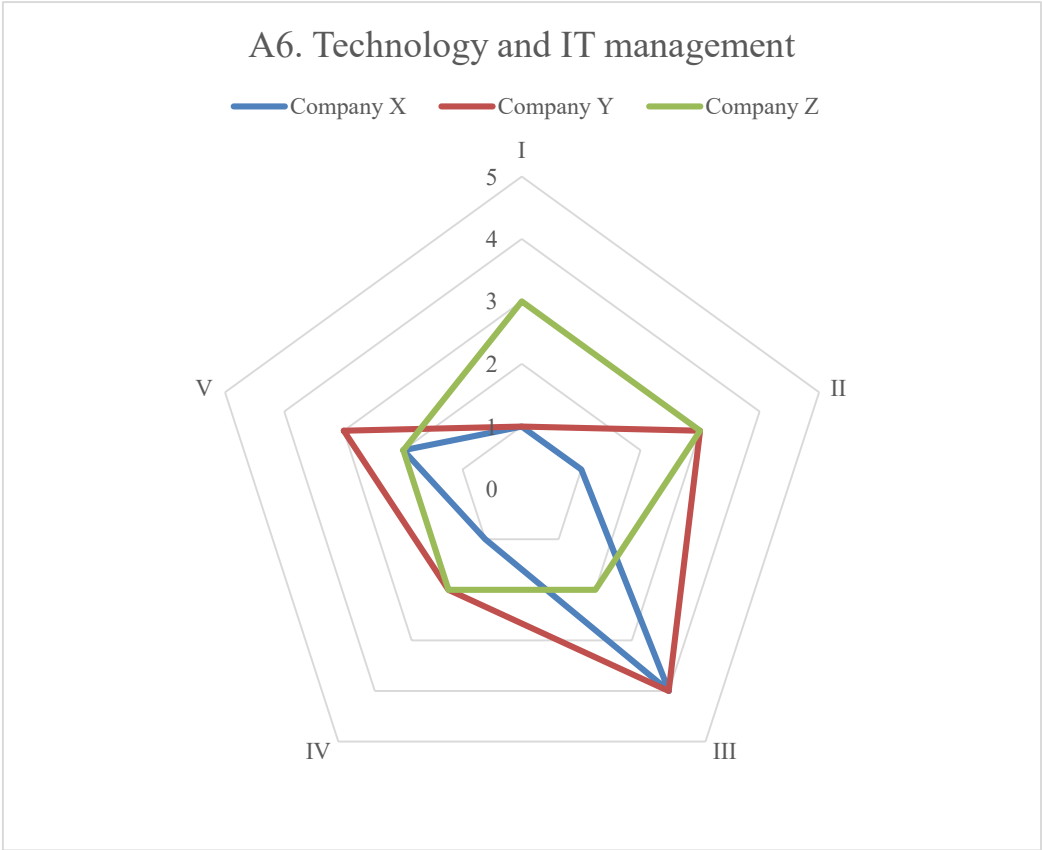


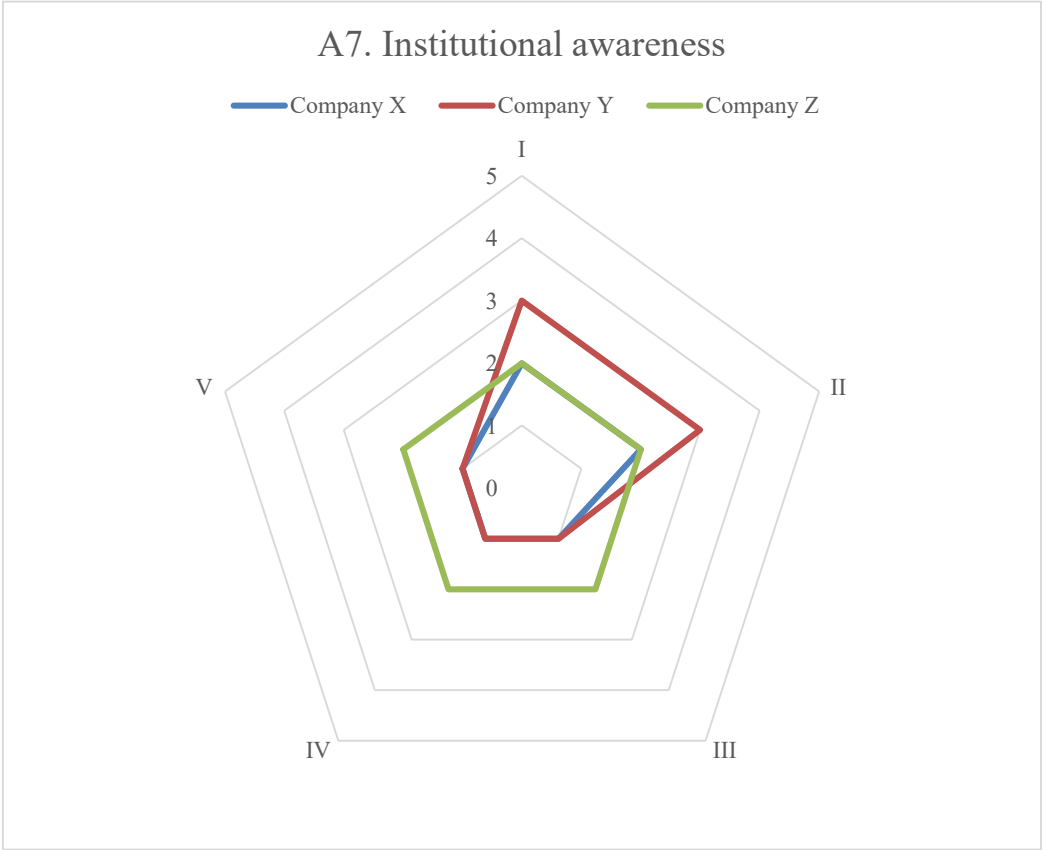


* Company X and Y have the same value, so red line represents blue line


A4. Customer interfaces
Company X
Company Y
Company Z
I
II
III
IV
V
5
4
3
2
1
0


A5. Value chain
Company X
Company Y
Company Z
I
II
III
IV
V
5
4
3
2
1
0


A6. Technology and IT management
Company X
Company Y
Company Z
I
II
III
IV
V
5
4
3
2
1
0


A7. Institutional awareness
Company X
Company Y
Company Z
I
II
III
IV
V
5
4
3
2
1
0

Appendix B: Radar plot total maturity score