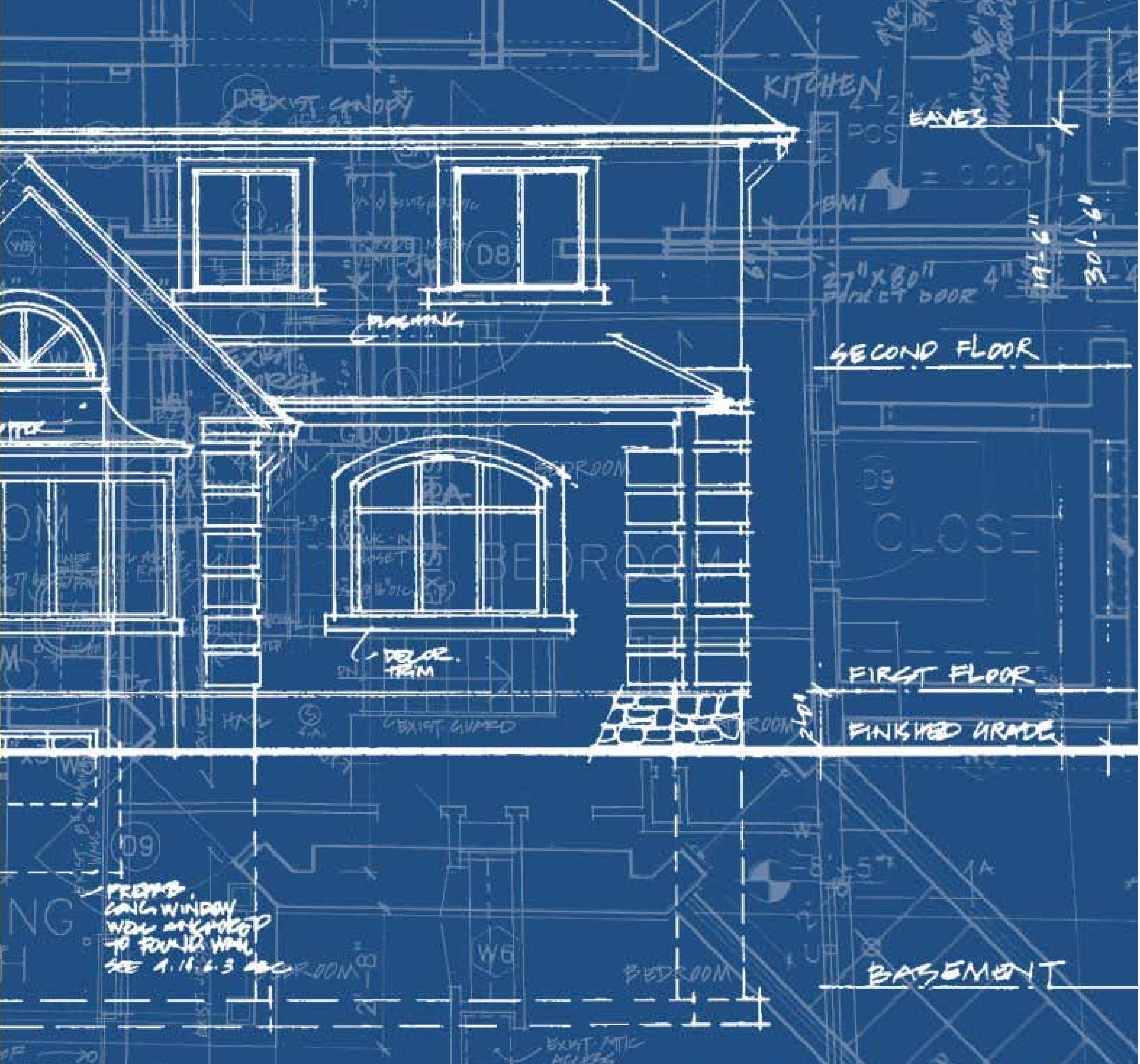
DATA PROVISION ON THE CONSTRUCTION SITE

A research into the preference and acceptance of construction workers for different innovations in data provision.



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Master thesis

Eindhoven University of Technology

Construction Management and Engineering

Data provision on the construction site

A research into the preference and acceptance of construction workers for different innovations in data provision.

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Preface

Dear reader,

With this thesis, I will complete my years as a student. I am very grateful to have had the opportunity to formulate my research within the field of my interest. I hope this research can contribute to the general knowledge on data provision towards construction workers, but most of all denounce part of the stigma of the conservatism of this group.

Throughout this process, I could rely on the support and guidance of many people. For this, I would like to thank Dr. Dujuan, Prof.dr.ir. Bauke and Dr. Raymond from the Eindhoven University of Technology. I also want to express my appreciation towards the company TBI and more specifically Ing. Jeroen and Drs. Neriman who offered great assistance and practical knowledge. Furthermore, I would like to thank my family and friends for being there through all the good and lesser moments.

Best,

Laurens van der Schaft
Eindhoven, December 2018

Abstract

The Architecture, engineering- and construction industry needs to keep up with current developments. Data provision is an important aspect of this. One specific sector is identified to require more attention, namely the construction site. Until now construction workers get information mostly in a paper-based format, which is an obstacle for BIM implementation on site. Moreover, alternatives which offer information through a digital interface will reduce the risk of outdated or wrong information. In addition, they offer more insights into the building process. The digital interface has the potential to reduce waste and flaws in this sector. This research aims to identify how new communication technologies can aid to innovation on the construction site. By means of literature review and expert interviews, a stated choice experiment has been set up which evaluates the preference and acceptance of construction workers regarding data provision. Both interfaces and data formats have been taken into consideration. The data is retrieved by a web-based questionnaire with 159 valid respondents from construction workers. Both Multinomial and Mixed logit model have been applied to analyse the data. Main conclusions from these estimations were that construction workers are less reluctant towards innovation as expected and are more likely to prefer digital interfaces. This would imply that the frequently observed prejudice that this group would be reluctant to accept innovation is unjustified. However, despite there is also a group who is less willing to adopt innovations. Therefore a phased implementation of a medium such as a tablet is advised. On this interface, a combination of both 2D and 3D data formats could be provided.

Executive Summary

The architect, engineering and construction industry is experiencing growth in the number of stakeholders and building concepts become more complicated. A large part of the industry responded on this by adapting their way of working. This adaptation was done by replacing the traditional way of working which relied on paper for change management. The replacement of paper is an information model stored on a central server, also called Building Information Model (BIM). BIM should not be mistaken solely as an ICT-tool, it also stands for a change in processes. The reported benefits of this innovation include a reduction in errors, pollution, waste and costs. If all stakeholders would adopt this innovation within the sector, the greatest benefit could be gained for all stakeholders. However, this is not the case; the construction sector falls behind in adoption, especially the processes on the construction site. The low rate of adoption is partly claimed to be due to the conservatism in the sector. Another reason is that the business case for BIM is not stated well enough. Literature research and case studies have been conducted on this topic, but these focus mostly on comparing new interfaces or innovations with the traditional situation. The comparisons lack an analysis of several innovations, which are mostly performed from a managerial viewpoint and do not consider the acceptance of the end-users. This research will fill a part of this gap in the field of literature and attempts to strengthen the business case of innovating the way of working on the construction site.

The specific aim is formulated by the main research question: How can new communication technologies aid to innovation on the construction site? The research consists of four main parts: First a literature research, in which a deep understanding of the topic and its context was gained. Secondly, interviews and questionnaires with different professionals were held within the sector to elaborate and validate the literature part. The third step is based on the outcomes of the initial research the main questionnaire was set up, involving two stated choice experiments. One investigated the preference of construction workers on the type and aspects of data provision, while the other focused more specifically on digitalization and whether workers accepted innovations. The fourth step was to collect and analyze the gathered data. The analysis was performed by estimating the relation with the Multinomial and Mixed logit models (MNL/ML).

From the literature, an overview was obtained of the interfaces, data formats and their properties, which are currently or in the near future available. This overview was complemented by conducting expert interviews and an initial questionnaire. In comparing the various interfaces and data formats, the most important aspects for construction workers were identified and later used as attributes. In addition, the initial questionnaires obtained information about relevant socio-demographics, awareness about interfaces and data formats, general understanding and motivation to respond in different settings.

All this information was used to design the main web-based questionnaire. The two stated choice experiments focused on data provision, in which interfaces and data formats were the two main aspects to be evaluated. This questionnaire consists of an introductory presentation which addresses the motivation, definitions and instructions to answer the questions. This part is followed by questions about the respondent’s socio-demographics and the stated

choice experiments. The first stated choice experiment had three alternatives which were paper, digital and none of both. The respondents were asked to choose the alternative which matches their preference the best. The second experiment went one step further to explore the acceptance of digital innovations using an unlabeled design. Last part of the questionnaire, the respondents were asked how innovative they were by use of the Technology Readiness Index.

It was preferred to be present for the introduction and where necessary assist with technical issues or unclarities. But also email, intranets and WhatsApp have been used to spread the questionnaires. A total of 178 respondents filled out the questionnaire of which 156 correctly and without any technical issues. Both MNL and ML models have been applied for the estimations of both designs. Overall, the ML model performed better than the MNL model which indicates there is heterogeneity in respondent's preference of data format and interface. This difference in goodness of fit can be explained by the heterogeneity of the respondent's choices. From the estimation of the first stated choice experiment, it can be concluded that construction workers are more likely to prefer a digital interface over paper. Important attributes which increase this likelihood of digital to be chosen are a tablet sized interface and a normal level of integration. The second stated choice experiment indicates that construction workers are willing to accept innovations. To be more specific, the workers are more likely to accept a BIM-model compared to Augmented Reality, and a tablet over a helmet with a visor as an interface. It also indicates that guidance during implementation increases the probability of accepting an innovation. Construction workers prefer on-site guidance. Social network (such as used by colleagues) has a positive impact on their preference to adopt. From these results, we can conclude that construction workers are in general willing to adopt more innovative data formats such as BIM-model and Augmented reality. Therefore, current prejudges in the industry might be unjustified.

The study found there is socio-demographic heterogeneity in the adaptation of the new communication technologies aid (especially the data format and interface) on the construction site. The estimations indicate the probability for construction workers with certain socio-demographics to prefer or accept an alternative. This is relevant as there is a larger preference for the digital alternative, but this does not hold up for all respondents. Not all construction workers are currently willing to adopt new technologies. The group who is the most likely to adopt this can be identified and they can be used as ambassadors. Ambassadors who are available for guidance can increase the acceptance of others to innovate. In this way, a phased transition period might increase acceptance and preference of the early and late majority of workers. Initially, this transition should focus on digitalization by use of tablets as interface and a combination of 2D and 3D information. Future research should indicate if the view of construction workers changes after this first adoption of innovation.

Executive Summary in Dutch

De bouwsector ervaart momenteel een grote groei in betrokken partijen en bouwconcepten worden gecompliceerder. Een groot deel van deze industrie heeft hierop gereageerd door hun manier van werken aan te passen. Deze aanpassing is verwezenlijkt door de traditionele manier van versie management en communicatie met behulp van papier te vervangen. De vervanging van papier is een informatiemodel wat op een centrale server staat, ook wel Bouw Informatie Model (BIM) genoemd. Waarin BIM niet alleen als ICT-oplossing moet worden gezien, maar ook voor een verandering in processen. Het grootste voordeel van deze innovatie wordt behaald als alle partijen binnen de sector hiermee werken. Echter dit is niet het geval; de aannemers liggen achter in aanpassing ten opzichte van hun sector, met name de processen op de bouwplaats. De lage mate van adoptie is gedeeltelijk te wijten aan de conservatieve houding binnen de sector. Een andere reden is dat de zakelijke argumenten niet duidelijk genoeg zijn. Literatuuronderzoek en casestudies zijn aan dit onderwerp gewijd, maar hierbij ligt de focus voornamelijk op het vergelijken van nieuwe gebruikersomgevingen of innovaties met de traditionele situatie. De vergelijking tussen verschillende innovaties ontbreekt en zijn van een leidinggevend oogpunt opgezet. Hierin wordt de mate van acceptatie van de eindgebruiker niet belicht. Dit onderzoek zal een deel van het gat in literatuuronderzoek vullen en probeert de argumenten voor innovatie op de bouwplaats te versterken.

Het doel van dit onderzoek wordt geformuleerd door de hoofdvraag: Hoe kunnen nieuwe communicatietechnieken bijdragen aan de innovatie op de bouwplaats? Het onderzoek bestaat uit vier delen: Als eerste een literatuuronderzoek, waarin het onderwerp en de context uitvoerig wordt belicht. Ten tweede, interviews en enquêtes met verscheidene vakmensen in de sector om de literatuur te bevestigen en aan te vullen. De derde stap is de hoofdenquête welke aan de hand van de resultaten van het initiële onderzoek opgesteld, bestaande uit twee verklaard keuze experimenten (stated choice experiment). Een richt zich op de voorkeur van bouwvakkers naar het type en de aspecten van datavoorziening, de andere richt zich specifiek op digitalisatie en de acceptatie van innovaties. De laatste stap is de dataverzameling en de analyse van de verzamelde data. De analyse is uitgevoerd door een schatting met het multinomiaal en gemengd logit model (MNL/ML).

Vanuit de literatuur is een overzicht verkregen van de gebruikersomgevingen, dataformaten en hun eigenschappen die momenteel of in de nabije toekomst beschikbaar zijn. Dit overzicht werd aangevuld door middel van expertinterviews en een initiële enquête. In het vergelijken van de verschillende gebruikersomgevingen en dataformaten werden de belangrijkste aspecten voor bouwvakkers geïdentificeerd. Daarnaast is de initiële enquête gebruikt om informatie te krijgen over de sociaal demografische gegevens, bewustzijn van gebruikersomgevingen en dataformaten, algemeen begrip en motivatie van de respondenten in verschillende configuraties.

Al deze informatie is gebruik om de web gebaseerde hoofd enquête op te zetten. De twee verklaarde keuze experimenten waren gericht op datavoorziening, waarin de gebruikersomgeving en de dataformaten de hoofdaspecten waren. Deze enquête bestaat uit een inleidende presentatie met als doel te motiveren, definities te verklaren en instructies te

geven. Dit deel wordt gevolgd door vragen over de sociaal demografische gegevens van de respondenten en de keuze experimenten. Het eerste keuze experiment had drie alternatieven; papier, digitaal of geen van beide. De respondenten werden gevraagd naar het alternatief dat het beste bij hun voorkeur past. Het twee keuze experiment ging verder in op de acceptatie van digitale innovaties. In het laatste deel van de enquête werden de respondenten gevraagd naar hoe innovatief ze waren aan de hand van de technologie gereedheid index.

De voorkeur was om aanwezig te zijn voor de introductie en waar nodig om te helpen met technische problemen of onduidelijkheden. Maar de vragenlijst is ook verspreid doormiddel van email, intranet en WhatsApp. Een totaal van 178 respondenten heeft de vragenlijst ingevuld waarvan 156 volledig en zonder technische problemen. Zowel het MNL- en ML-model zijn toegepast voor de schattingen van beide keuze experimenten. Het ML had een betere interpretatie van de data dan het MNL-model, wat aangeeft dat er heterogeniteit is in de antwoorden van de respondenten. Van de schattingen van het eerste verklaard keuze experiment kan geconcludeerd worden dat bouwvakkers eerder geneigd zijn om een digitale gebruikersomgeving te verkiezen boven papier. Belangrijke eigenschappen die de waarschijnlijkheid verhogen dat het digitale alternatief gekozen wordt zijn een gebruiksomgeving in een tabletformaat en een normaal niveau van integratie van informatie. Het tweede keuze experiment geeft aan dat bouwvakkers bereid zijn om innovatie te accepteren. Hierin zijn de respondenten meer geneigd om een BIM-model te verkiezen boven Augmented Reality en een tablet boven een helm met vizier. Ook wordt duidelijk dat begeleiding tijdens de invoering de waarschijnlijkheid van acceptatie verhoogd. Bouwvakkers prefereren begeleiding op de bouwplaats. Een sociaal netwerk waarin anderen de technologie al gebruiken draagt positief bij aan hun voorkeur voor de innovatie. Van deze resultaten kunnen we concluderen dat bouwvakkers in het algemeen bereid zijn om te werken met innovatieve dataformaten en digitale omgevingen. Dat betekent dat huidige vooroordelen jegens bouwvakkers onterecht zouden kunnen zijn.

Deze studie geeft aan dat er heterogeniteit is in de adaptatie van nieuwe communicatietechnologieën (vooral voor gebruikersomgeving en dataformaten) op de bouwplaats. De schattingen geven de waarschijnlijkheid aan waarvoor bepaalde sociaal demografische groepen een alternatief verkiezen. Dit is relevant om te identificeren omdat de voorkeur voor digitaal groter is, maar dit niet voor iedereen geldt. Niet alle bouwvakkers zijn momenteel bereid om te werken met nieuwe technologieën. De groep waarin bouwvakkers dit juist wel zijn kunnen gebruikt worden als ambassadeurs. Ambassadeurs die beschikbaar zijn voor begeleiding verhogen de kans op acceptatie door anderen. Op deze manier kan een gefaseerde implementatie de acceptatie en voorkeur verhogen voor adoptie van innovaties. In het begin kan deze transitie zich focussen op digitalisatie door middel van tablets en een combinatie van 2D en 3D informatie. Toekomstig onderzoek moet aangeven of de mening van bouwvakkers veranderd nadat ze hiermee geruime tijd hebben gewerkt.

Content

List of Abbreviations/Glossary

AEC	Architecture, Engineering and Construction
AR	Augmented reality
BIM	Building Information Model
BPR	Business Process Re-engineering
ICT	Information and Communication Technologies
IT	Information Technology
MEP	Mechanical, Electrical and Plumbing
ML	Mixed Logit
MNL	Multinomial Logit
TRI	Technology Readiness Index
VR	Virtual reality
RFI	Request For Information
2D	2 Dimensional
3D	3 Dimensional

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1.0 INTRODUCTION

The Architecture, Engineering, and Construction (AEC) industry is an industry which identifies itself by being conservative and has seen only minor innovations during the last decades (Styhre, 2010). In contrast with most other industries which have shown to be more progressive and have managed to increase their efficiency (Davies & Harty, 2013). These other (non-farm) industries have increased their productivity by more than 100% in the period from 1964 to 2008 (Teicholz, 2004; Vestergaard, 2017). In contrast to the construction industry where the productivity has remained the same over this period. Some actors in this industry see potential in closing the gap in progress with other markets and to obtain a great competitive advantage in the AEC-industry. The difference in increase of productivity is partly due to the demand of customer requirements for unique products within the construction industry. These demands lead to more costly and time-consuming products compared to batch production. This is not the only problem which can be identified within the industry. There is, for example, no tradition of cost- and profit statistics, there is a low level of mechanization and benchmarking is hardly used within the sector (Vestergaard, 2017).

In the last decades, this industry slowly started to adopt new ways of working and several ICT-tools. One of the most promising innovation which emerged is called Building Information Modeling (BIM). BIM can be seen as both a technology and a way of working (Eastman, Teicholz, Sacks, & Listion, 2011). It gives the opportunity to collaborate more efficiently and in an earlier phase of the design with multiple stakeholders. The collaboration is done through a server-based exchange of (3D based) information models. The models from the different stakeholders are combined in the server to get one integrated overview of the project. This process is realized by using uniform file formats and regulations about drawing and naming techniques, which increase clarity, reduce flaws (clashes between several disciplines) and improves the manageability and the preciseness of the design (Mäki & Kerosuo, 2015).

This innovation has made a strong entry in the construction sector with the support of an increasing level of IT facilities and the transition from 2D to 3D working in the industry (Nourbakhsh, Zin, Irizarry, Zolfagharian, & Gheisari, 2012). The promising potential lies in removing errors in a building design before it is built, as this could reduce a significant amount of the risks, costs and delays of a project. Another potential is in optimizing a building design, which could reduce energy consumption, facility management costs and increase the efficiency of the building (Liu, Xie, Tivendal, & Liu, 2015).

The potential of BIM is spread over many disciplines within the AEC-industry and in other related consultancy branches (BIR, 2015). The added value of the innovation is therefore divided over many stakeholders. Important in reaching the full benefit of BIM is that all stakeholders in the AEC-industry will adopt BIM in their working process. Currently, BIM has been mostly adopted by designers and only recently by other sectors such as; engineering departments, constructors and facility management. Initially, BIM was setup for designers, but it also presents a great potential for the construction sector (Svalestuen, Knotten, Laedre, Drevland, & Lohne, 2017). However, despite the promises made by many researchers about the benefits of BIM in this phase, only a few companies fully adopted BIM or realized the promised potential. BIM has in these companies mostly been adopted in the construction site offices and not yet on-site. There is still a gap between site offices and construction site workers (Chen & Kamara, 2008). The small rate of adoption of BIM is not due to a lack of the required technology or research in this field. There has been a substantial amount of research conducted on this subject, studying the benefits, technology, and ways of implementation of BIM. However, this body of research focusses mostly on possible applications of BIM tools, methods, and workflows, not on the readiness and extent to which this can be implemented (Eastman et al., 2011; Hardin, 2009). Only a few case studies have currently been conducted, in which specific implementations have been monitored (Moum, Koch, & Haugen, 2009; Ruwanpura, Hewage, & Silva, 2012). These case studies evaluate one specific way of adopting BIM on the construction site. However, do not make a comparison between several new methods of working but only relate to the traditional method. There is a lack of comparison between the different proposed methods to provide information (Mäki & Kerosuo, 2015).

1.1 Problem statement

In a time where BIM is widely implemented, and the AEC-industry starts to show a growing level of innovation, the on-site activities in the construction sector fall behind. Less attention has been paid to the way of working on-site. However new studies and initiatives show great potential for innovation in this area (Davies & Harty, 2013). The studies argue that by bringing BIM onto the construction site, data provision can become more efficient and can contribute to the prevention of errors. The currently performed research attempts to find new ways of providing data to construction workers. The motive to do so is because “the traditional form” of data provision is not effective in handling the increasingly more demanding building concepts and the number of actors (Berlo & Natrop, 2014; Bryde, Broquetas, & Volm, 2013). Previously two-dimensional drawings of floor plans, sections and details containing all the information were sufficient. However, with the growing amount of information other possibilities are considered. There have been several solutions proposed to either reduce the amount of information or to enrich it by introducing new forms. These solutions have not only been introduced because they might be more convenient to interpret, but also because they are less prone to human error and avoid mistakes being made on the construction site or in design. The literature also emphasizes the importance of considering the implementation of new methods. This requires a good strategy, time and attention. There have been cases reported in which, due to uncritical implementation a reduction in overall performance is observed (Dave, Koskela, Kagioglou, & Bertelsen, 2008).

However, there is no consensus in which way or which solutions should be adopted (Mäki & Kerosuo, 2015). The body of research mainly describes different data forms provided by various interfaces. However, it does not address the implementation from the user point, except for a few specific case-studies (Bryde et al., 2013). These case studies look at the implementation of specific solutions and if a comparison is made, it is with the traditional situation instead of other solutions. In this area, a research gap can be identified. Current research mainly looks at possible uses of BIM and workflows. Whereas this research will attempt to determine, which type of use is currently and in the future, best applicable on the construction site from the perspective of the construction site workers. The study will focus on several aspects of BIM and other innovations which can improve the current form of data provision. For data provision, the interfaces and the data formats which provide information to construction workers are considered. The emphasis will be on how construction workers can be more efficient, decreasing their frustrations and cause fewer construction flaws.

1.2 Research model

In order to conduct this research, a main research question is established, which is sub-divided in three sub-questions. These research questions are listed below and focus on the current state of data provision, preference and acceptance regarding data provision of construction workers and which factors influence preference and acceptance. To give a clear overview of how these questions will be answered a visualization of the research structure is included in Figure 1. This model shows the main approaches which are used to conduct the research and how they are linked to the other steps.

Which aspects of data provision contribute to a successful implementation of innovations on the construction site?

- What are currently the available ways of providing information to the construction site workers? (Q1)
    - How can the forms of data which are currently being applied on construction sites be compared? (Q1.1)
    - How can the types of interfaces which are available for construction sites be compared? (Q1.2)
- Which forms of data provision are more preferred and more accepted by the current generation of employees? (Q2)
    - Are there identifiable groups of employees with significantly different preferences? (Q2.1)
    - What type of interfaces is most preferred for the construction site? (Q2.2)
    - What type of data formats are most preferred for the construction site? (Q2.3)
- Which attributes of data provision contribute the most to the perceived quality and the different forms of data provision? (Q3)
    - What kind of form of data provision is currently best applicable? (Q3.1)
    - Which aspects are important in the introduction of a new way of working? (Q3.2)

For the contextual framework and to establish the need for research on this topic a literature review is performed. Based on this literature review and additional interviews held among different professionals in the construction sector the different alternatives of data provision will be determined. In these alternatives, a differentiation will be made based on the aspects of the different interfaces and the various data formats. The different forms of these categories will be separately compared and will form a base to answer the first question: *What are currently the available ways of providing information to the construction site workers?* This first step can also be seen in Figure 5 and result in answering Q1.

This first step also forms a base to answer the following research questions. In order to answer the second research, question the main questionnaire is set up. In this step, the previously discussed interviews are used to conduct an initial questionnaire. The results will gain more in-depth information about the current state of data provision and the extent of knowledge which construction workers have regarding this topic. The questionnaire will attempt to retrieve additionally to their awareness their preferences, social demographic information, obstacles regarding information provision and their understanding of concepts set out to be used. This information will help to identify attribute levels and define categories for the final questionnaire. In addition, it will indicate the extent of clarification which is needed in order to make sure that the respondents understand the different topics and definitions. The second step is concluded by creating the final questionnaire which includes the stated choice experiment to identify preferences and acceptance as well as to obtain social demographic information. The setup of the main questionnaire will be discussed in paragraph 4.2.

The gathered data will be used in the third step and after analyzing provides the answer on question 2: *Which forms of data provision are more preferred and more accepted by the current generation of employees?* Based on the research performed for question one and two the possibilities to change current information provision can be determined. As well as an advice for future implementation of new forms of data provision. This will be done based on the relative importance which construction workers indicated to have to the various aspects of data provision. By comparing and combining the information of the literature research with the analyzes question 3: *Which attributes of data provision contribute the most to the perceived quality and the different forms of data provision?* can be answered.

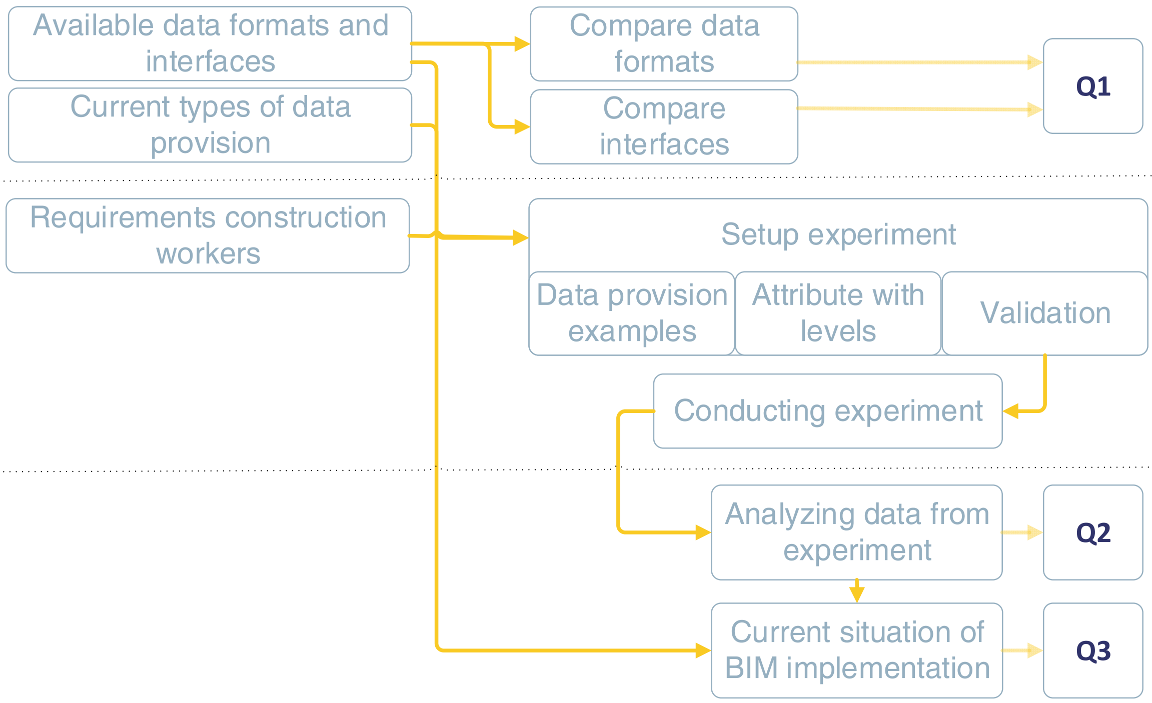

Figure 1: Conceptual framework

1.3 Limitation of scope

This research could be relevant to a large part of the construction industry and can be conducted in many professions. However, in order to make well-founded statements of subgroups either large-scale research or a narrowed down scope is needed. Because of the limited time span of the research, a smaller scope is required. The scope is narrowed down by identifying sub-groups and making a selection based on common characteristics. The research will focus on craftsmen/construction workers, (this group will be more clearly defined in Section 4.4). Because this group is less represented in literature and this group has a large potential to increase the general benefit of BIM. Craftsmen can be active in several phases of the building sector, but this research will be limited to the construction phase seen in Figure 2. This phase is chosen because this is the main phase where they are present. In addition, in this phase, the most benefit can be gained from an improved level of data provision.

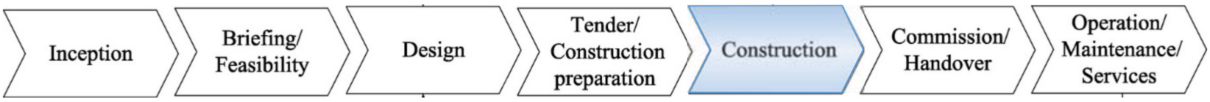

Figure 2: Phases of the construction sector (Xianhai, 2013)

1.4 Motivation

The motivation to conduct this research originates primarily from a gap in the literature. This research can enlarge the general understanding we have of the competencies and preferences of construction workers. Also, a way of comparing the various aspects of alternative ways of working is introduced, which makes a better reflection of new and existing ways of working possible.

From a more practical perspective, it is mainly interesting which methods are best applicable to data provision on the construction site. In researching this insight into the options to enhance productivity (fewer costs, waste, pollution and errors) and overall satisfaction are a strong motivation for companies (Bryde et al., 2013). However, also, the strategies for implementing the measures which should lead to this are essential to them. This is in line with the collaborating construction holding TBI. TBI has the slogan to 'Make the future.' They want to do this as holding of 18 leading, innovative construction and installation companies in the Netherlands. In order to help to realize their slogan, the TBI kennisLAB has been founded; this is an innovation lab in the field of System Engineering (SE) and BIM. One of the main challenges for them is to identify which forms of innovation can be implemented and which medium to use for this. This research will attempt to answer a part of this question and formulate advice regarding the data provision to construction workers.

From a societal viewpoint, it is interesting that this research could contribute to increase the efficiency of the sector. This can result in lower amounts of emission and pollution as well as lower prices to realize constructions which could stimulate the industry.

1.5 Organizational lay-out

This research is structured as follows. The chapter you are currently reading introduces the context and the topic of the research. In addition, the problem is stated and the research question is introduced. The second chapter consists of an extensive literature review, which aims to provide more background information and in-depth knowledge of the current findings on this topic. The literature review addresses; the workflow, definition of BIM, the benefits and challenges of BIM and strategies for implementation of these processes. The third chapter introduces the methodology of the research. Here the setup and theory of the analysis are explained and discussed in depth. In addition, the design considerations based on literature review and initial research are discussed. The next chapter complements this by elaborating on the data collection and a description of the participating companies and respondents. The fifth chapter contains the analysis of the collected data which is primarily done by estimation of Multinomial logit and Mixed Logit model. Concluding with chapter six which summarizes main conclusions and gives recommendations regarding data provision on the construction site.

2.0 LITERATURE REVIEW

This chapter gives an overview of the main processes and innovations in communication and data provision in the construction industry. It also reviews the current state of the industry and the possibilities with their benefits and barriers to implementation. The aim is to place the research in the right context and provide relevant background knowledge.

2.1 Workflow

For the construction industry, the main differentiation is made between "the traditional workflow" and alternative ways of working. Only recently, companies in the AEC-industry started to divert from their traditional way of working. This is done because of the changing processes in the construction sector, which occur as a result of growing project sizes, higher complexity and more involved actors. The conventional type of communication has, therefore, become insufficient (Berlo & Natrop, 2014). In response to these developments, new ways of working have been developed. These have shown to be more capable of handling the current workflows and allowing for innovation (BIR, 2015).

The traditional workflow is mainly based on communication through 2D paper-based drawings. These drawings are nowadays created in a digital environment (either 2D or 3D) but shared in a paper format. The information is shared with various stakeholders as can be seen in Figure 3. These stakeholders gather the for them relevant information from various other stakeholders and generate drawings to execute their expertise. On their turn, they will distribute their drawings among the other stakeholders who adopt the new information if necessary. With a limited number of stakeholders, this process suffices. However, as the number of actors is growing, extensive management is needed in retrieving and returning all relevant information. Current systems are limited in their efficiency and are prone to human error and delays in communication.

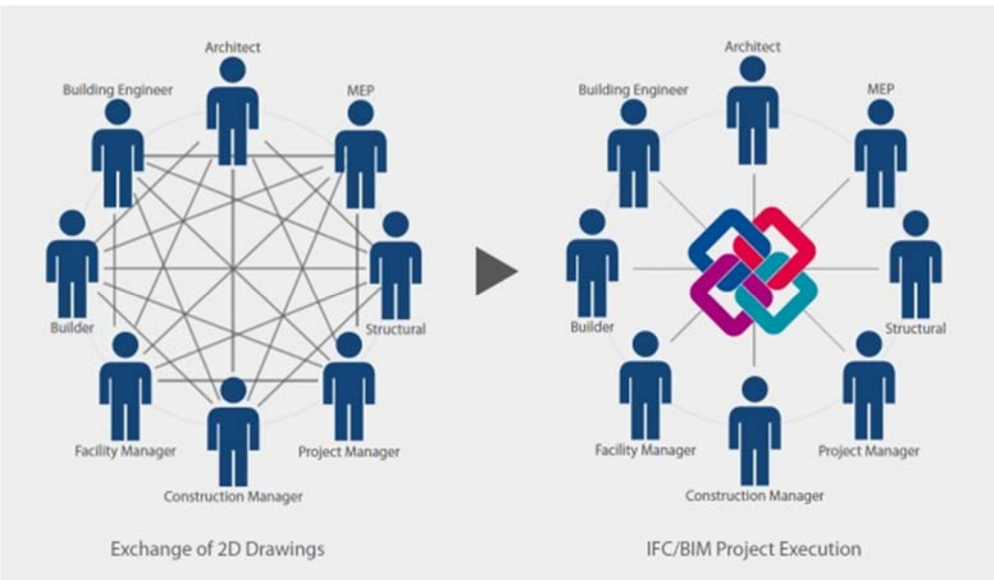

Figure 3: BIM versus traditional communication (Mediaconstruct, 2018)

Becoming more efficient is vital, as clients demand shorter development times and more integrated designs, but also offers companies a competitive advantage (BIR, 2015). A solution which enables improvement of the current workflow is a more centralized communication method as shown in the second visualization of Figure 3 (Mediaconstruct, 2018). Working with a central information model overcomes a lot of the limitations of the traditional workflow and enables faster and more reliable communication between the different stakeholders. A substantial part of the AEC-industry has already adopted this new workflow which is based on a Building Information Model (BIM) as a communication medium. However, not all sectors within this industry show the same rate of adoption of this innovation (Mäki & Kerosuo, 2015). One of the sectors which could adopt BIM to a greater extent is the sector of the contractors.

Currently, the majority of the contractors has adopted BIM in communicating with other stakeholders and management levels. Within the construction companies BIM is only used within certain areas. Therefore the full potential has not been reached. This makes the investment of resources relatively large compared to the benefit. The different contractors and departments within the contractors have varying levels of BIM maturity (BIR, 2015). However, one part of the contractors generally has the lowest level of adaption which is the construction site. The communication on the construction site is still mostly based on the traditional workflow as earlier described. Only a few companies started with pilot projects to implement BIM at the construction site. Recent research indicates that current communication is generally of insufficient quality. According to Ruwanpura, Hewage & Silva (2012), 45% of the craftsmen on the construction site indicate that there is a lack of communication. Almost all craftsmen blame the managers for the lack of information flow from the site/main office to the on-site employees (Ruwanpura et al., 2012). According to Ruwanpura et al. (2012) workers were not always aware of work targets, planning, and technical specifications. In some cases, not even technical drawings were present on the construction site. This can be partially explained by the current need for last-minute clarifications and additional drawings, which must be provided by the foreman to the construction site. This reduces the time left for supervision and instructing of construction site workers (Ruwanpura et al., 2012). The current situation on the construction site leaves much potential for innovation and leaves room for research.

2.2 Definition of BIM

BIM is often seen as the solution for many problems in the AEC-industry. However, the understanding and interpretation of BIM varies a lot. A problem in the understanding is the great variety of definitions. Many researchers, as well as companies, have attempted to formulate a general definition (Barlish & Sullivan, 2012; Succar, 2009). However, no consensus has been reached in this. Barlish and Sulivan (2012) mention that entire journals aim at finding a common definition. However, the focus is more on the differences rather than similarities. Because of the lack of consensus, the definition of “Bouw Informatie Raad” (BIR) will be used, since this is an independent association which represents the complete AEC-industry (BIR, 2015). They define BIM in three coherent definitions: “Building Information Model” a digital representation of how construction is designed, is realized and/or is actually build. The second meaning is "Building Information Modeling" the emphasis is more on the process of cooperating on a digital construction model. Related aspects are integral design, competition engineering, lean planning and sharing of digital information. The third meaning is "Building Information Management," where the information itself is central: the governance and (re)use of digital construction information in the entire lifecycle of the construction. The BIR finds all three meanings equally important and these three definitions cover the complete meaning of BIM. Important to derive from these definitions is that BIM is more than a 3D model or even an information source. It implicates that certain processes are used and an alternative way of information management is used.

2.3 BIM on-site

BIM has evolved substantially over the last two decades. In this period many architects, engineers and consultants adopted this innovation (Bargstädt, 2015). This selective adoption has led to a tool which is mainly focused on design features and the ability to make nice renderings and animations (Davies & Harty, 2013; Huhnt, Richter, Wallner, Habashi, & Krämer, 2010. Whereas, for example, construction companies have different needs to realize the designs. They require besides the geometric data that more specific information is added to the objects, such as: product information, material properties and construction manuals (Svalestuen et al., 2017). This requires a different approach and mindset from many stakeholders in the process. However, this can also add substantial value to the BIM model, as it can be used for other processes. These are processes such as; the planning of construction and the increase in efficiency of modeling site activities and facility management.

As argued in chapter 2.1 despite the promising concept of BIM for the construction field it has not been widely adopted yet. The literature does describe case-studies in which different interfaces are provided to construction workers to enable them to work with BIM. These are for example tablets, digital screens, so-called information kiosks and 3D-models. Also, the option to introduce augmented or virtual reality by means of glasses or a helmet with a visor are discussed in literature (Berlo, Helmholt, & Hoekstra, 2009). However, these innovations have been offered mainly to employees with a higher level of responsibility (Harstad, Laedre, Svalestuen, & Skhmot, 2015). Currently, a growing interest emerges to provide construction workers with these devices, but the knowledge for implementation lacks (Vestermo, Murvold, Lohne, & Laedre, 2016).

2.4 Benefits BIM on-site

In the previous paragraphs, the general advantages of BIM and the workflow of BIM have been discussed. Also, possible applications and the current state of BIM on the construction site have been addressed. This chapter will elaborate on this by providing background to the advantages and opportunities related to the construction site practices.

2.4.1 Change management

The construction sector is still inherent to changes which are frequently last-minute. The consequence is that a request for information (RFI) will be done and that changes are made to the design. Every change implies that information on coherent drawings must be changed. These can be small details but may result in many revisions. Consequently, many drawings out in the field must be replaced, by their revised versions. This process is called version control or change management. Currently, version control is subjected to substantial risk of information losses, which may result in the use of old or wrong documents. Which often leads to rework, which is a type of waste which should be prevented (Ballard, 2000). In which the definition of Svalestuen et al. (2017) for waste is adopted: “waste in construction includes delays, quality costs, rework, unnecessary transportation trips, long distances, improper choice of management, methods or equipment, and poor constructability.” The process of version control should ensure that all information is up to date. However, as mentioned; this is often not the case. According to both construction workers as well as foremen the data which is used on the construction site may be as old as one or two months. That the information used on the construction site is not up to date is also widely acknowledged in literature (Harstad et al., 2015; Ibrahim, Krawczyk, & Schipporiet, 2004; Mäki & Kerosuo, 2015). A server-based system such as BIM is more capable of coping with last-minute changes from the client, contractor or external factors (Bargstädt, 2015; Ibrahim et al., 2004). Replacing the paper-based system with a BIM-based system on the construction site could reduce the risk of outdated and conflicting information (Berlo & Natrop, 2014). Reliable version control is not the only advantage, benefit can also be gained from more easily accessible data and faster feedback on issues.

2.4.2 Information access

In current practice, there are sets of hundreds of drawings, in which each drawing represents an element in the project. These can be elements such as a floor, wall, window, electrical wiring or plumbing (Ibrahim et al., 2004). The drawings also include tables, schedules and list of specifications and measurements. From the available information, the right information must be retrieved, which sometimes can form a challenging task. The gathered information might still lack data needed for the execution of a task, this data has to be retrieved from detail- and specifications books. This is a time-consuming process and is prone to human error. A digital information system such as BIM could have a positive impact on this process. In BIM all data is gathered in one model and information which cannot be directly incorporated in the model is linked to the coherent object within the model. All data of an entire project is gathered in one database, which simplifies searching for the right information. Preselecting data becomes then the most important ability of an interface because the amount of data should not be overwhelming to the user. A benefit of preselection is that the reinvention of tasks can be reduced and data security enhanced. The selection can be done on profession or management level but also leftover to automatization or the end-users themselves (Berlo & Natrop, 2014).

2.4.3 Information richness

Besides easy access, the amount and the selection of data, another important aspect of information can be identified. This is the information richness, which is a concept introduced by Daft and Lengel (1983). The authors suggest that different ways of communication correspond to other levels of information richness. Rich information would be able to provide a substantial amount of new understanding, whereas low information richness offers this to a lower extent. This is relevant as the construction site receives a large amount of data which is mostly new to the construction workers. It would, therefore, be useful to select a medium which can handle rich information. Lengel and Daft (1986) formulated the three most important characteristics such a medium needs; “1) the ability to handle multiple information cues simultaneously, 2) the ability to facilitate rapid feedback and 3) the ability to establish a personal focus.” (Svalestuen et al., 2017). Based on these requirements they analyzed media commonly used by managers and classified them according to their ability to handle rich information. The result can be seen in Figure 4.

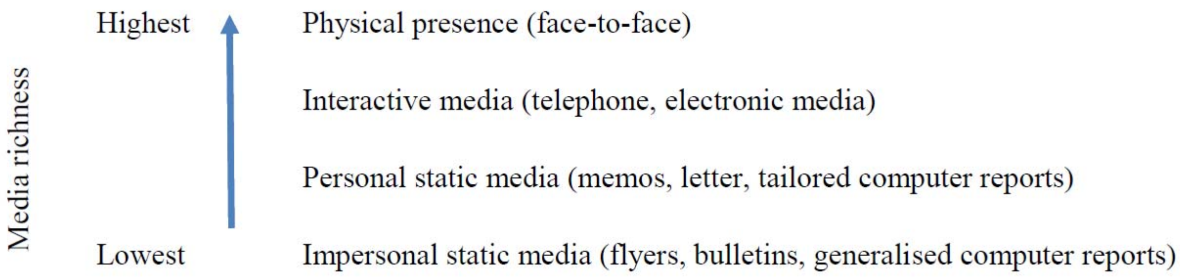

Figure 4: Different types of media and their richness (Lengel and Daft, 1986).

Based on this initial research on information richness a substantial amount of research has been conducted. An interesting example is the model Cockburn (2002) created, shown below in Figure 5. He introduced a differentiation in communication mediums based on the ability to reply on the received information. In his model, he defines “No question-answer” and Question-and-answer” in which the later was the richer medium. The ability to respond to the given information is argued to be of great importance to the communication of information.

The model of Cockburn is further iterated and elaborated by several researchers. This led to the model which is depicted in Figure 6 edited by Svalestuen et al. (2017). This model still describes the relation between information richness and the effectiveness of communication. However, a distinction has been made between Asynchronous and Synchronous communication. The category of synchronous communication can be characterized by the direct sharing of information using hearing, sight and speech. Whereas asynchronous is a remote type of communication which is not conveyed directly in time, this can be through emails, drawings or models. This distinction replaces the differentiation based on the ability to ask questions.

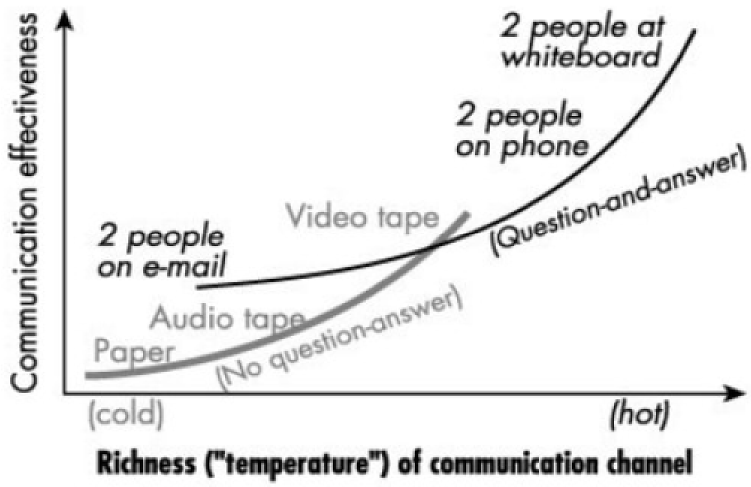

Figure 5: Illustration of richness and effectiveness of different communication channels (Cockburn, 2002)

The principle of the model has not changed it only emphasizes the importance of rich information. In which the need for direct (synchronous) contact is preferable face to face with a medium to be able to show the information. As BIM can contain a combination of visual information and data linked to each other, this way of communication is seen as the most effective way to handle communication (Liu, Xie, Tivendal, & Liu, 2015; Svalestuen et al., 2017). According to Svalestuen et al. (2017) BIM is the richest information source for both synchronous as well as asynchronous communication. They are however critical towards

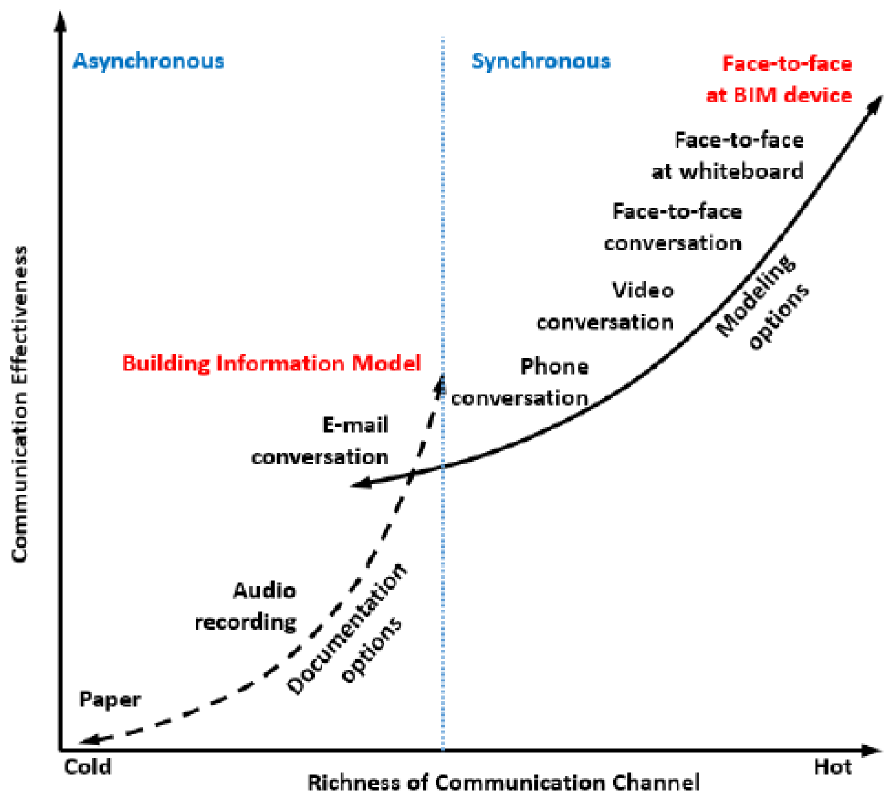

Figure 6: different types of communication channels and how rich and effective they are compared to each other (Svalestuen et al., 2017).

communication with BIM because it cannot serve as a carrier of verbal communication like audio or video. However, Svalestuen et al. (2017) argues that this is negligible as this would not contribute substantially.

It can be concluded that BIM with face to face communication is the richest communication channel. However, it is not always required to use this channel of communication. Effectiveness should not be forgotten in consideration of how to communicate (Svalestuen et al., 2017). As example Lengel et al. (1989) highlights routine activities, the use of synchronous communication for this is usually inefficient.

2.5 Barriers of BIM on-site

As mentioned before, the construction sector is a conservative industry, which has not seen many major innovations. Therefore, the implementation of a new way of working is difficult especially if this requires the majority of the sector to adopt it, in order for the innovation to reach its full benefit. The spread of the benefits of BIM among many stakeholders does not make this any easier. It is harder to convince parties with different business value propositions that they benefit from the proposed way of working because the benefits are spread over several specialties and therefore hard to measure (Vestergaard, 2017).

Other difficulties which are identified in the implementation of BIM are the changes in regulations. Such as the division of labor and the attitudes of companies towards each other and towards BIM (Mäki & Kerosuo, 2015). Other barriers to the construction site are; software and hardware issues, cultural barriers, contractual aspects, lack of commitment and lack of training play a part (Vestermo et al., 2016). These barriers do not form an imminent threat to the implementation of BIM. However, for a successful implementation, they should be taken into account.

2.5.1 ICT solutions

One of the reasons that companies currently do not reach a high level of implementation of BIM lies in their view on ICT. Many companies thought according to Dave et al. (2008) that only implementing ICT solutions would result in substantial improvements. However, merely the approach of simply implementing ICT solutions lacks an integration of employees and business processes. For a business to be successful three elements are identified to be necessary; people, process and information systems. In order to improve business by for example implementing an ICT solution, these three elements should be simultaneously addressed (Dave et al., 2008). Attempts to solve the problem of selectively addressing the issue have been performed with for example “business process re-engineering” (BPR). Also, with other socio-technical approaches, it is attempted to offer an effective way to integrate ICT solutions. However, according to the review of Dave et al. (2008), all prior attempts have only managed to address the problem partially and underexposed one of the three elements. The problem in this is that on the construction site, ill-managed ICT systems and poorly managed processes can disempower employees instead of improving their ability to work.

Therefore, it is important that these three aspects are all addressed mutually in both researches as in business improvement.

2.5.2 Hardware issues

There is reluctance against digital interfaces on the construction site (Harstad et al., 2015; Liu et al., 2015; Svalestuen et al., 2017)). This is mainly caused by worries about the durability, usability and required network of the devices. It is not unreasonable to think that a construction site is not the ideal location for devices such as tablets or large touch screens. The devices will have to endure water, dust, falls and intensive use. Meanwhile, they still have to be usable if they are dirty or when the construction worker is wearing protective gloves. Another aspect is the sensitivity of the information in case of theft or loss of the device.

Many pilot projects have been conducted in which they identified what devices have to endure and what common obstacles are. For all these hardware related issues, a solution has been presented and these issues do not have to form an obstacle for implementation. In the implementation of these devices, this is important to emphasize and prove to both the information managers and the end-users.

2.6 Implementation

The difficulty in showing the actual benefit of BIM for one stakeholder has already been discussed. If the process of BIM would require a relatively small effort and entail low costs, this would not have been a major obstacle. However, as often discussed in literature this is not the case (Bryde et al., 2013; Liu et al., 2015). The implementation of BIM requires a cultural shift within the organization, major progress interventions, learning and will incur costs at the beginning (Harstad et al., 2015). Because the implementation of BIM is demanding it is essential for management staff to have proof that this may lead to an overall benefit. Providing this is attempted in literature by creating measurement tools to indicate the overall gain, but also by formulating implementation strategies which show the usefulness to users (Davies & Harty, 2013; Succar, 2010).

There are several strategies which can be used, and some others are required for proper implementation of BIM. The implementation is an incremental change in the work structure for employees. Therefore, guidance and training of the employees are necessary in order to make them feel confident with the new way of working and to ensure acceptance (Svalestuen et al., 2017). However, because craftsmen tend to be reluctant to learn new things and to change their habits more measures are recommended (Harstad et al., 2015). A possibility is to recruit employees who are interested in the new developments and make them ambassadors of the alternative way of working. This can be done at all management levels. Another option is to promote success stories from projects who adopted the alternative way of working. These success stories can be created through a pilot project. To such a project special attention and resources can be devoted as investment. This can be a learning lesson and a birthplace of ambassadors. Very important is to not over generalize construction workers as they all have different benefits of working with BIM and ambassadors may not be able to convince other professions. According to Svalestuen et al. (2017), there is a difference in reluctance between a group of Mechanical, Electrical and Plumbing (MEP) workers and carpenters. He concludes that MEP workers are significantly more willing to adopt new technologies such as BIM than carpenters. The way to determine the current willingness and readiness to adopt innovations will be discussed in Paragraph 2.7.

Important in the implementation of BIM is how the alternative way of working is implemented in the company structure. The advantages digitalization have on data provision, can only be reached if the process of handling the information also changes (Ibrahim et al., 2004 ; Nourbakhsh, Zin, Irizarry, Zolfagharian, & Gheisari, 2012). This change has to be more than replacing paper drawings with digital versions on a tablet. Another crucial point for construction workers is, which information you offer them. Working in a new way offers opportunities and therefore requires a re-evaluation of the provided information regarding the level of detail, constructability and usability of the information.

2.7 Adaptation new technology

It seems evident that not everyone is ready at the same time for the implementation of an innovation. This makes it important for implementation strategies to identify which people are likely to be ready or not. Roger (1995) acknowledges this and describes this in his model of adoption which can be seen in Figure 7. This model describes the order in which certain groups of potential users start adopting a new product. Starting with the innovators who are risk-immune and the early adopters who are open to change and interest in the opportunities of technology. The early majority follows thig group and is important as they form a substantial part of the market. Good references from them can convince the late majority. Important for the early majority is that a proven business case is shown. “They believe in evolution, not in revolution” (Nijssen, 2014). Succes stories of the early majority are needed for the more conservative late majority which is hard to convince of the utility from new technologies.

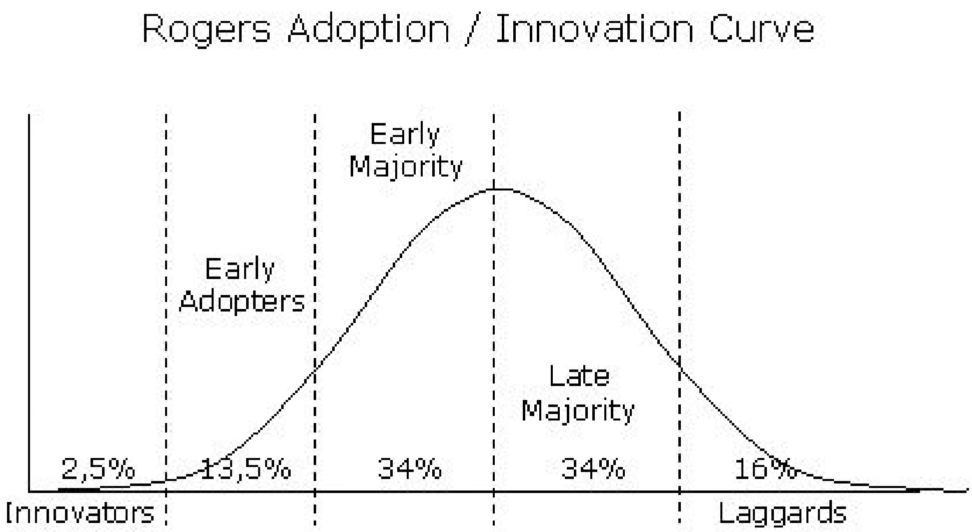

Figure 7: Innovation adoption curve (Rogers, 1995)

Because a substantial group of potential users would like to see others using the innovation first and to see whether it has the promised added value, ambassadors and proves business cases should be used. This helps in convincing to adopt the innovation instead of having to force them to adopt. Finally, for the laggards, the consideration has to be made whether they will be allowed to maintain using the old way of working or if they should be obliged to adapt.

Determining the level of adoption of data provision on the scale of Rogers is rather difficult based on present information within the discussed field. Because whereas most new forms of data provision have only seen small rates of adoption, parts of the innovation such as the use of tablets or computers have already been adopted significantly more in private situations. In addition, construction workers do not always get the choice whether they want to adopt a new technology but are requested by their superiors to do so. The Rogers model describes the process of implementation very well but in this case, lack the ability to indicate the willingness to adopt new forms of data provision by itself. Therefore another model called the Technology Readiness Index (TRI) can be used to complement it. This is “a multiple-item scale to measure readiness to embrace new technologies” developed by Parasuraman (2000) in collaboration with Rockbridge Associates. They aimed to make a questionnaire which can explain “people’s propensity to embrace and use new technologies for accomplishing goals in home life and at work” (Parasuraman, 2000). Whereas this model was developed to describe customers, they also state that it can be used for “internal customers” or in other words employees. The model is based on a set of questions which provide an in-depth understanding of the readiness of potential users to accept and adopt technology, with a focus on digital solutions (Parasuraman, 2000). The question focusses on the favorable and unfavorable aspects of digital solutions by asking the respondents questions based on their optimism, innovativeness, discomfort and insecurity regarding technology.

What differentiates this index from other measurement tools is that this index measures a general acceptance towards innovations. Whereas other measures are product or service specific. These base the readiness of potential users on what they are offering. As this research is dealing with a variety of technologies, the TRI is more suitable for analysis.

2.8 Interface

The previous paragraphs discussed the need, benefits and barriers of new forms of data provision. The following parts will elaborate on the two main aspects of data provision being; the interfaces which would enable BIM to be used and the formats in which information can be provided. These are described by means of properties which are relevant during activities on the construction site.

One of the aspects of data provision which is often considered most important is the interface through which information is provided. New options for interfaces such as mobile devices, large touchscreens and augmented reality have been discussed in literature (Davies & Harty, 2013). Due to the declining price of mobile devices, a growing interest emerges in using these devices on the construction site (Nourbakhsh et al., 2012). In reality, these interfaces do not always directly replace the entire need for paper as the processes have not been completely changed, but it can substitute a substantial part of it (Mäki & Kerosuo, 2015). The new types of interfaces allow the option of communication, for different information and improved accessibility to it. Another advantage described by Vestermo et al. (2016) is that the possibilities of visualization and a higher level of collaboration leads to an improved understanding of the design and requirements. The ability of certain interfaces to combine 2D drawings and 3D models is said by Harstad et al. (2015) to improve the understanding of what should be built. This understanding is important to increase because it could reduce the amount of rework on construction sites.

There has been a broad range of interfaces and solutions presented in the current body of research. The commercial parties already sell solutions in which they work with construction companies and if requested provide implementation support. However, it is still not clear which solution could be best implemented and how this implementation should be realized.

2.8.1 Comparison interfaces

The interfaces which are currently or in the near future available each have different properties which affect their usability on the construction site. In Table 1 the most important properties are listed. Although values are added for these properties it is not possible to select the best interface as the relative importance of the properties has not been determined. The next chapter will explain how this relative importance is obtained in a later stage of this research and how the properties will be analyzed.

The properties described in Table 1 are either about the hardware or the information they provide. As can be seen, the various interfaces have significantly different levels. Both mobile devices and BIM stations score well on most points but have a higher adoption effort. Whereas more familiar forms such as paper-based and computer have a low adoption effort but score less on the other aspects. Augmented reality (AR) and Virtual reality (VR) are interfaces which are currently tested for their possible applications on the construction site. Until now, these are less attractive because of their low durability, high adoption effort and lack of two-way communication. However, the type of information and the unlimited size in which they can display information offers interesting possibilities.

Table 1: Comparison interfaces on the construction site, properties

Interfaces	**Durability**	**Richness info**	**Adoption effort**	**Up to date**	**Size**	**Two-way communication**
Paper-based	-	-	++	--	A4-A0	--
Verbal	++	-	++			++
Computer	--	+	+	+	A4 (>A2)	+
Mobile devices	+	++	-	++	A5-A4	+
BIM station	++	++	-	++	A3-A2	++
AR glasses	-	++	--	++	>	-
VR glasses	-	-	--	+	>	--

-- Stands for a negative rating ++ Stands for a positive rating

Besides the above-listed properties, the interfaces can also be compared on their ability to provide certain data formats. These data formats are listed in Table 2 and are ranked on their information richness level. The digital interfaces have different characteristics but have in common that they can offer a variety of data formats. The provided information can vary from 2D drawings to more advanced 3D views, animations or work instruction videos. The digital interfaces also have the advantages that they can provide up to date information, link information sources and switch between data formats. The possibilities for input shown in Table 3 show similar varieties. The options to request information differ in ease of use (during construction) and ease of adoption.

Table 2: Comparison interfaces on the construction site, data formats

Data formats	2D	3D view	Video	3D model	3D interactive model
Paper-based	x	x			
Verbal					
Computer	x	x	x	x	x
Mobile devices	x	x	x	x	x
BIM station	x	x	x	x	x
AR glasses		x		x	x
VR glasses		x		x	

Table 3: Comparison interfaces on the construction site, input/request for information

Data formats	Input/request for information
Paper-based	None
Verbal	Ask for information
Computer	Mouse, keyboard or voice commands
Mobile devices	Touchscreen or voice commands
BIM station	Touchscreen, mouse, keyboard or voice commands
AR glasses	Gestures with hands, movement head
VR glasses	Movement head

Verbal interaction is most often supportive of the primary interface of communication. This form is as up to date as the primary source is from the moment he/she delivers the message. The conveyed information can be enriched with gestures and body language. Verbal communication is often face to face in this sector but can also be through phone or recordings. A limitation of verbal communication can be found in the memory of the respondent and possible language barriers.

Computer is usually located in the construction site-office and exclusively meant for the foreman or supervisor. In this context, a computer refers to desktops or laptops. Due to its size and form a computer is not convenient to carry or to set up on the construction site, (Harstad et al., 2015). The computer can be however used for work instructions in the construction site office, possibly connected to a larger screen or beamer. In this situation, it is possible to give instructions with the help of various data formats to a large group of construction workers.

Thus far tablets and phones have been used as mobile interfaces on the construction site. Although these interfaces can vary in size, they should be easily portable devices which can be used to retrieve information. The limitations of small screens have to be taken into consideration. Because these devices are portable, they offer great flexibility for construction workers.

On-site touchscreens, the so-called information booths or BIM-stations can provide construction workers with a diverse way of communication possibilities (Ruwanpura et al., 2012). The booths are often small containers or installations which contain a visual device connected to a computer. The booth which is located on the construction site or in the construction is linked to a server and is intended to be used by construction workers. The setup guarantees up to date information on several locations of the construction site (Vestermo et al., 2016). The booths can be used for work meetings, safety instructions or progress tracking (Vestermo et al., 2016). According to Vestermo et al. (2016) during case-studies, the information booths were also seen as meeting places which increased both the internal collaboration as with other disciplines on the construction site and resulted in enhanced problem-solving.

Virtual reality can be used to gain better insights into future situations. VR can be used to visualize building stages, work instructions and safety instructions for certain situations. Virtual reality has limited possibilities during construction in contrary to AR. This is because VR has the limitation that someone cannot work or observe the reality when wearing the VR glasses. AR, on the other hand, does enable this with transparent glasses. AR shows you the reality with an overlay of extra information. On the construction site, this can be used to see elements inside walls or where activities should be performed including the requirements for the process.

2.9 Data formats

According to the Maki and Kerosuo (2015), future research should provide a better understanding of the requirements of information and the level of details, required on the building site. The consensus has been reached that the traditional paper-based interface should be replaced as it limits innovation. Important is that not only the transition to a new interface is taken consideration but also the data format and the way it is provided through the interface (Ibrahim et al., 2004). It seems in the literature that the data format is underexposed compared to the application of new interfaces. Currently, the most used format is still 2D drawings, but other options in 3D are also available. This can be either in the format of 3D views or 3D models. These formats can also be sub-divided into interactive forms which enable moving and zooming through information, or options in which the view is fixed. The second differentiation can be made by the ability to adapt or select elements in the 3D models or obtain non-visual information. This can be measurements, material or location of the element.

3D views have been present for a long time. However, these were mostly created on an architectural level. For construction workers, the architectural form did not offer much relevant information. However, through the introduction of 3D models, these views have become easy to generate. As a result they can be generated for many specific tasks or to gain an overview of building phases. According to Svalestuen et al. (2017), 3D models enable the construction workers to gain a better understanding of the project data and workflow.

A more advanced version of the 3D view format is the 3D model. A 3D model does not give a fixed perspective of an element or building but enables the user to view it from multiple viewpoints. This can be given for a single orientation point, but it is also possible to walk through the model and view different locations. In these models, layers can be selected for different disciplines and stages. The amount of information can be adjusted to the required needs and data linked to objects can be retrieved by selecting them. Augmented reality (AR) can be seen as a variation on the 3D model as it uses information of a 3D model to overlay the imagery of the reality. It can also show elements which cannot be seen to the naked eye as they are for example in the walls or have not been created yet.

Video or animations are most useful in explaining tasks or explaining building principles. The provided information aims more at explaining how to execute tasks or how to do this safely. The instructions are usually more focused on tools and actions but can also show the building order or schedules. Another aspect of data formats is, which data is shown and the amount of information which is (made) available. An example of selecting data is the concept of task-oriented drawings, in which only task-specific information is shown. By leaving out all redundant information, according to Berlo & Natrop (2014), it should be easier to interpret the format and less time is needed in searching or combining information.

2.10 Conclusion

The traditional workflow in the AEC-industry has reached its limits of efficiency and cannot meet the demands of clients anymore nor cope with the growing number of stakeholders and building requirements. The introduction of BIM offers a promising potential to enable innovation in this industry. A substantial amount of companies within the AEC-industry have already adopted BIM. However, the level of adoption is substantially less among the contractors and even lower on the construction sites whereas large benefit could be gained in this sector. Main advantages of implementing BIM on the construction for data provision are; more reliable, faster and more accurate information. Important is that BIM on itself is not the solution for increasing the efficiency and decreasing flaws made on the construction site. More changes and process innovations are needed to reach the full potential of this innovation.

Much research has been conducted on BIM and its implementation. However, the application on the construction site is underexposed and the adoption among construction workers even more. The literature which focusses on this area are mostly analyzing case-studies and lack comparison between the different forms of data provision. Recent innovation in ICT and decline of hardware prices opened up many possibilities to offer information through new interfaces and in other data formats. However, due to a lack of comparison and readiness of potential users to adopt this, it is unclear what kind of data provision should be adopted. Both interfaces and data formats offer varying benefits, limitations and changes for construction workers as well as for the rest of the company. The interfaces and formats which are available now and in the near future are listed in chapter 2.8 and 2.9. This overview provides the answer to the first research question, by showing which interfaces and data formats are available. These two paragraphs also make an initial comparison of both interfaces and data formats, which is elaborated on in paragraph 3.3. The extent to which these aspects are of influence on the preference of a construction worker will help in making the tradeoff for the form of data provision. Also, important to reach the full benefit of BIM is that none of the core business aspects is left out during the implementation. Only innovating the technical aspects of the current workflow is not sufficient. Attention has to be paid to the involved people who have to adopt the alternative way of working and to the process it affects.

3.0 METHODOLOGY

In the previous chapter, the main properties of data provision; *interface* and *data format* are discussed. To determine which type of data provision is most suitable for construction workers, the relative importance of the features has to be identified. The theory on how this can be done will be explained in this chapter, as well as an elaborate description of how the questionnaire is set up and the models which are used for the estimation in the fourth chapter.

3.1 Initial research

To form a scientific base for the research and to find relevant aspects regarding the research topic initial research is performed. This initial research consists out of a literature review, expert interviews and initial questionnaires set out among the potential respondents for the main questionnaire. The literature review is used as a starting point to formulate interviews with a variety of experts such as innovation managers, BIM-managers and construction supervisors. These were conducted in a semi-structured way to ensure consistency within the interviews and to allow the respondent to give deeper insights into their background or expertise (format can be found in Appendix B). These initial interviews have the purpose to indicate missing information in the literature and to identify and validate the aspects on which this research will focus.

In the literature review, limited knowledge from the construction workers perspective was obtained and the experts indicated during the interviews that their opinion was subjected to prejudice. Therefore an initial questionnaire among construction workers was used to get a better idea on their current knowledge, awareness, use and preference regarding data provision. In addition, their socio-demographic information and view on current practices are questioned (the questionnaire can be found in Appendix A). A structured interview format is used in this case to be able to gather a representable group of respondents. In filling out the questionnaire their understanding and willingness to fill out the questionnaire are monitored. Multiple settings are used when filling out the questionnaire varying from one on one, groups to online. This additional information is used for the setup of the final questionnaire and the Discrete choice experiment.

The questionnaire consists out of a variety of open and closed questions. Open questions are included to identify new aspects and barriers from the construction worker perspective. The different forms are also used to evaluate to which extent the questions are properly answered. The questionnaire contains 23 questions of which nine are regarding their socio-demographics eight to identify the preference and awareness and the remaining six to identify obstacles within their daily activities regarding data provision.

3.2 Theory of discrete choice model

The literature review concludes that new types of data formats have not been widely adopted yet, but mostly implemented as trials or pilot projects. This makes the group of people who can be questioned about their revealed preference very small. This is confirmed by the initial questionnaire in which many respondents indicated not to be aware of the more recent innovations (results can be seen in section 4.2). Moreover, because usually more attention is usually paid on the implementation and selection of people in pilot projects, this group might not be representable. Therefore, there is almost no suitable revealed data to be gathered. Using stated preference/choice can be especially useful in this case of comparing new alternatives to current solutions because the new alternatives have not been objected to the choice of potential users in real market situations. The difference between revealed and stated preference is that revealed data refers to a choice made in real market situations whereas stated preference/choice is referring to a hypothetical situation (Hensher, Rose, & Greene, 2015). Using stated preference and choice will make the potential group of respondents substantially larger. An established way to gather the stated preference and acceptance is by means of a stated choice experiment (Hensher et al. 2015). The stated choice experiment is preferable over plainly asking what the preference of construction workers is as it ensures that they do not give their preference for a scenario without constraints (Hensher et al., 2015). The experiment ensures that the limitations of a realistic setting are present.

Setting up a stated choice experiment is relatively time-consuming compared to other questionnaires types (Hensher et al., 2015). This is due to the fact that careful consideration is needed to ensure that the hypothetical scenarios are as close to the reality as possible (Hensher et al., 2015). If this is not the case, the respondents might have personal constraints for which the model does not explain their preference or biased responses are given on the questions. Therefore, it is essential to create realistic scenarios, with the use of actual numbers or applied techniques (Hensher et al., 2015). This requires extensive research which can be done by means of secondary data research, in-depth interviews and focus groups. On the other hand, one must be cautious in creating the list of attributes this list should be universal but finite. Which means that a complete overview of all the relevant attributes should be given. However, this should be to the extent that the respondent is able to make a well-founded choice. If this is done properly, a deep understanding can be gained of the preference of the questioned group of people.

The design of the stated choice experiments is created according to the process for discrete choice experiment of Hensher et al. (2015). The design steps can be found in the following sections. The initial research which is conducted to set up the main questionnaire including the stated choice experiment is discussed in Section 3.1. Based on this research the attributes and levels are identified, this is discussed in Section 3.3. The design considerations are discussed in section 3.4 and how these are incorporated in the main questionnaire is discussed in Section 4.1.

Random utility theory

The dicrete choice experiment is based on the assumptions of economic rationality and utility maximization (Kløjgaard, Bech, & Søgaard, 2012), which means that it assumes that each individual selects the option with the highest personal benefit for him or her which is known as utility. This utility is assumed to be dependent on the utility of the composing attributes and attribute levels (Hensher et al., 2015). Utility consists out of two components: the observed utility and the unobserved utility as shown in Equation (1).

$$U_{iq} = V_{iq} + \varepsilon_{iq} \quad (1)$$

Where:

U_{iq}, is the utility associated with alternative i and individual q;
V_{iq}, is the representative component of utility (observed influences); and
ε_{iq}, is the random or error component of utility (unobserved influences).

The random utility is composed out of unobserved attributes there are; the variations in taste between individuals, measurements errors and functional misspecification (Baltas & Doyle, 2001). The observed part of the utility is calculated by multiplying the weight of the attributes with the choice of the individual. The equation (2) is shown below.

$$V_{iq} = \beta_{0i} + \beta_{1i} f(X_{1i}) + \beta_{2i} f(X_{2i}) + \beta_{3i} f(X_{3i}) + \ldots + \beta_{Ki} f(X_{Ki}) \quad (2)$$

Where:

β_{0i}, is the alternative-specific constant;
β_{K}, is the weight of a parameter of attribute k; and
X_{Ki}, is the value of attribute k associated with alternative i.

The probability for which either alternative i or j will be chosen in a choice set is based on the highest utility. The probability for which a respondent will select the alternatives can be estimated with the following equation (3).

$$P(i|C_q) = P(U_{iq} \geq U_{jq}, \forall j \in C_q) \quad (3)$$

Where:

P_{iq}, is the probability of alternative i being selected by individual q;
U_{iq}, is the utility associated with alternative i for individual q; and
U_{jq}, is the utility associated with alternative j for individual q.

Logit models

One of the most popular choice models is multinomial logit model; this model is based on the random utility theory described in the previous chapter (Hensher et al., 2015). This model is widely used because of its short estimation time and because it provides closed-form model calculations. This means that after applying the model, no further estimations are needed. The formula for this model can be seen below in equation 4.

The utility that person n obtains from alternative i can be formulated as follows:

$$U_{ni} = \beta_i \; X_{ni} + \varepsilon_{ni} \quad (4)$$

Where X_{ni} is a vector of the observed attributes. β_n is the coherent vector of the utility coefficients that vary randomly over people, and ε_{ni} represents the unobserved component of utility.

With the following formula, the probability is estimated for an individual to choose alternative i from the set of J alternatives.

$$\text{Pn(i)} = \frac{\exp^{(\text{V in})}}{\sum \text{j}\epsilon\text{Cn} \exp^{(\text{Vjn})}} \qquad \forall \text{i} \in \text{Cn} \quad (5)$$

Where:
P_{iq}, is the probability of alternative i being selected by individual n;

The second model which is used in this research is mixed logit model. The main differentiation between this model and MNL is the specification of heterogeneity. The ML model can take heterogeneity caused by alternative similarity and individual preference in account. For this equation, the β are not estimated for the total sample but per respondent. The equation (5) for this model is as follows. For a value of βn the probability that an individual n chooses alternative i is.

$$Lni(\beta n) = \frac{e^{\beta n * Xni}}{\sum i \;\; e^{\beta n * X\text{ni}}} \quad (6)$$

The unconditional choice probability is, therefore, this equation integrated over all values of n and weighted by the density of n which is shown in the following equation:

$$\text{Pni} = \int Lni(\beta) f(\beta \mid \theta) \; d \; \beta \quad (7)$$

Where:
P_{ni}, is the weighted average of the probability of alternative i being selected by respondents n;

As the probability approximates the result, it is not exact. Therefore, simulation is used and the β is calculated for many draws. From these draws an average β is calculated and used as an approximate probability as shown in the following equation:

$$SP\text{ni} = \frac{1}{R} \sum Lni(\beta) \quad (8)$$

Where
SP_{ni}, is the probability that an individual n chooses alternative i and R is the number of draws of β.

3.3 Stated choice experiment design

This paragraph describes the selected attributes for the stated choice experiments. Additionally, it gives the context variables and discusses the setup of the design.

3.3.1 Attributes and levels refinement

The initial research and literature review offered a broad view of the relevant aspects of data provision. In selecting attributes and levels emphasis is put on the relevance to construction workers and their awareness. This is done to enable them to make a good decision and create realistic scenarios. However, some new technologies are introduced as these are of interest to both the research field as well as to the involved companies. These technologies and other definitions used in the choice sets are explained to the construction workers in the presentation before the questionnaire is provided. In the next part of this paragraph, the definitions as they are used in the presentation will be listed in cursive, along with an explanation of their relevance. The eventual questionnaire will contain two stated choice experiments one regarding the preference of data provision and the second one regarding the acceptance of innovations. This paragraph will make the differentiation between these designs by referring to labeled design for the preference of data provision and unlabeled design for the acceptance of innovations.

Attributes labeled design
One of the main questions from the literature as well as from the company TBI is whether the construction workers are willing to work with digital formats. Important is to identify not only if they are eager to work digital but also under which conditions. The importance of the conditions was also confirmed by the initial questionnaire and conversation with construction workers. The alternatives for the first stated choice experiment are *Paper* and *Digital,* which implicates it is a labeled design. The definitions of the attributes and attribute levels of both alternatives are explained below. The levels of the attributes are given between brackets after each title.

Data format: (2D/3D)
One of the biggest changes for construction workers might be the transition from 2D to 3D information. Nowadays information is offered rarely in 3D and if so usually only in isometric drawings which are accompanied by 2D drawings or shown in the construction site office by the site manager. The innovations in software enable users now to easily generate 3D views or models and as Svalestuen et al. (2017) stated they offer a richer information source and give more insights in what should be constructed. Both TBI, employees (Figure 8) as well as literature, see potential in transitioning towards data provision through 3D formats. Moreover, the initial research among construction workers also confirmed this

Data format, this can be either 2D or 3D, 2D means you can see the width and the length of an object on a drawing. 3D means you can also see the height, which can be shown on paper or as a digital model.

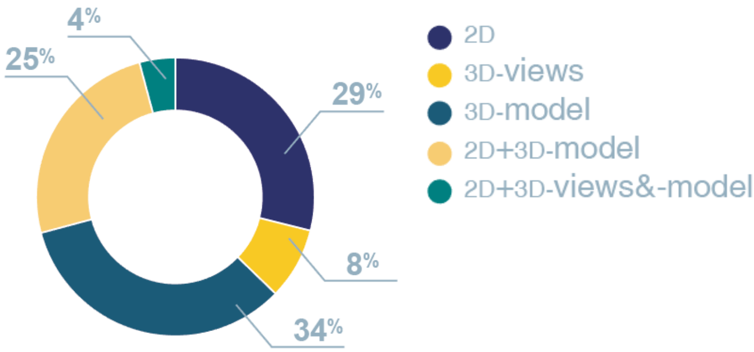

Figure 8: Preference data format (initial questionnaire)

Size canvas: (A3/A0, A4/A2)
Currently, the most used interface on the construction site is paper, which can be printed in various sizes. For this research, the most frequently used paper sizes will be used which are A3 and A0. Digital formats are more limited compared to the paper alternative. Currently, two interfaces are used on construction sites which are tablets and large size screens; these have approximately a size of A4 and A2. These sizes are both half as small as the frequently used paper sizes and therefore, limiting in showing information. Moreover, the A2 sized screens would usually be attached to a wall (in the construction site office) or mounted in an information booth. This significantly decreases the mobility of the information source. However digital formats do have the ability to scroll and move through drawings or models, which might be an advantage. Initial interviews indicated the limitations of a small size canvas, but also the advantages of a zooming functionality. A remark on this is that there is also a substantial amount of construction workers who indicated that they are unable to zoom or move through drawings, let alone have a good overview of what or where something should be realized.

Size canvas, is based on paper sizes. In which A4 to A0 is used. A4 is a standard paper size and about the size of a tablet, A3 is the double size, A2 is the size of a big screen important is for you answer that these are fixed to a wall. And A0 is the standard large foldable drawing.

Integration drawings: (Low/Normal, Normal/High)
The amount of information on a drawing is a delicate balance. In the initial questionnaire, the remark that there is either too much, too few or not the relevant information present was frequently made. Also, Berlo & Natrop (2015) argue that the amount and type of information requires further research. For this research, an important aspect of this issue is considered related to the working method of BIM. With BIM more integral models can be created and better information can be provided on the influence of professions on each other. Therefore, the respondents were asked to take into consideration if they think it is important that they have only the information regarding their profession or whether they prefer additional relevant information from other occupations.

Integration drawings, indicates the level of information, in which a low level only shows one profession and a high level also shows the relevant information of other professions to prevent clashes between professions.

Speed to access: (5/15min., 1/5min.)
An indicated frustration of the construction workers is how fast they can get their information. The needed information often has to be retrieved from the construction site office, has to be found in thick work instruction books or additional detail documentation. This can make retrieving the required information a lengthy process. Moreover, as the present drawings are not always up to date, workers have to ask for revisions or new printouts. With a digital interface, these issues do not have to occur. If well-implemented, workers can quickly browse through drawings and navigate through links and retrieve relevant additional data.

Speed to access, is how fast you can get new information.

Updated every: (2/4 Weeks, 3/7 Days)
The limitations of the change management which are discussed in paragraph 2.4.1 cause paper-based information provision to be often outdated. As soon as the information is printed, it has the risk of becoming outdated. In addition, replacing the old drawings with their revisions is a process which is prone to human error. Whereas a digital interface can be updated more frequently and is only dependent on the approval of revisions. It even allows the option for automatic notifications of changes made in recently used drawings.

Updated every, means how up to date the information is you use.

Attributes unlabeled design
For the stated choice experiment model of acceptance the focus is on the attributes which make construction workers willing to accept an alternative. Therefore, a labeled design is selected instead of an unlabeled design. The alternatives from which the respondents can choose is consequently a generalized term, which are in this case *Innovation 1* and *Innovation 2*. The attributes and their levels are shown again below (in the same format as Section 3.4.1).

New data format: (BIM model, Augmented reality)
To judge whether a respondent accepts to work with an innovation, he needs to know which innovation this would be. Therefore, two innovations have been selected of which BIM model is on the verge of being implemented and Augmented reality will be in the nearby future. This forms an elaboration on the abilities of the digital alternative described in the previous stated choice experiment. Both definitions are explained in the presentation using visualization and the following information:

BIM model is a 3D model which contains all the information to construct a building. You can zoom and move through this building to get information. Important is that in these models the information which you need is already marked and redundant information is left out.

Augmented reality shows you the reality but with an extra layer of information over it from the BIM model. With this, you can see currently hidden or new objects in the surrounding where you are. In this example the infrastructure underneath a road.

Duration training: (1Hour/2Hours/0.5Day/1 Day)
During the initial research, many respondents indicated that they would be willing to adopt new forms of data provision if they would get proper training. They indicated that there was currently a lack of opportunities to get this. Therefore, this aspect is included. The levels are defined together with the company to an extent to which they think training would be useful and feasible.

Duration training; is how much training you get before having to work with the new data format.

Level of guidance: (On-site/Office/None/Online-platform)
Besides the initial training guidance is needed in the process of adopting the alternative way of working. If guidance is not available or not present on-site this is said to lead to resistance of construction workers to adopt innovations, by both experts as the workers themselves. Whereas if guidance is always available, this could increase their interest and enthusiasm.

Level of guidance: is where you can ask questions about the innovation.

User interface: (Tablet/Helmet)
BIM model and Augmented reality can both be shown on a tablet, visor (helmet/glasses) or large screen. As the large screen is not efficient to use for augmented reality, this option is not considered.

User interface: is whether the new information is shown on a tablet or a helmet or glasses

Used by: (Foremen/Competitor/Colleague/None)
As described by Rogers (1995) the majority follows if the innovators and early adopters are already using the new technology. By having people around, you who already adopted a new way of working construction workers might be more willing to adopt it too. The respondents are asked to consider if they find this important and how close this person should be to them.

Used by: who is already using the innovation this can be a colleague, colleague from a competitor or your foreman.

3.3.2 Context variables

Because some attributes of data provision may be more preferred performing certain activities on the construction site a differentiation is made between activities. Four main tasks are identified with the intention to identify differences in preference for data provision. These tasks have been formulated based on the use of tablets formulated by Harstad et al. (2015) and on the interviews with experts. Harstad et al. (2015) identify nine different areas in which tablets may be applied by people with typical control responsibilities. However, most of these actions are also related to construction workers.

- *"Access to blueprints in portable document format (PDF)/drawings (DWG) file format and building information models (BIM) everywhere*

- *Obtaining direct measurements from the blueprints and BIM on site.*
- *Live communication through video chat between site and office*
- *Delegating and monitoring of tasks and responsibilities* ***(receiving)***

- *Documentation work on site*
- *Measurement and monitoring of the progress*
- *Quality assurance work and safety inspections*
- *Communication and request for information (RFI) between design consultants and construction practitioners*
- *Operation and maintenance management" (Harstad et al., 2015)*

As this list is too specific a generalization is made. First, a differentiation can be made between what is required to construct something (receiving information) and between documentation (sending information). In these two categories, significant differences can be identified in receiving information during *Structural* work or *Finishing work,* for sending information a differentiation can be made in *Reporting* flaws and filling out *Checklists/forms*. In the design of the questionnaire, the last four activities/tasks are used to be able to identify the main differences.

3.3.3 Setup Discrete Choice Experiment

The previous chapter partially explains the setup of the stated choice experiments. The model for preference has two labeled alternatives and in addition an option to choose neither "None." Furthermore, it has five attributes with each two levels, of which the levels differ per alternative. This means that the total number of attributes in the model is 10 (two alternatives with both five attributes). Because each attribute has two levels, the full factorial design would include $2^{10} = 1024$ treatment combinations. This number of combinations would be impossible for a respondent to process. Therefore, a substantially smaller fractional design is preferred is this case all main effects can be explained with a model of 12 choice sets. Choice set design can be found in Appendix C and the labeled fractional factorial design in Appendix D, Appendix E contain the unlabeled design. Important in creating this fractional design is that the orthogonality is ensured, to ensure this the programs Ngene and SAS are used. The model for acceptance differs on a few aspects. First of all, this model is unlabeled, secondly, it has 2 x 2 levels and 3 x 4 levels for its attributes. The similarities are that both models have the option to choose "None" and five attributes. The total number of treatment combinations is in this case $2^2 \times 4^3 = 256$. This can be reduced by creating a fractional factorial design to 32.

Both models contain 44 choice sets (12+32) evaluating each of these choice sets might cause fatigue of the respondents. This decreases the quality to avoid this a technique called blocking is applied. This creates sub-sets of the choice sets which can be handled better by the respondents. In this case, both sets are divided into four blocks, this leaves a set of three and of eight. The eventual setup is two blocks of three and one of eight which makes a total of 14 choice sets to be evaluated by each respondent. The choice sets are equally and randomly distributed over the respondents.

Before estimating the data, hypotheses should be formulated. These hypotheses apply to the stated choice experiments which are explained in this section. Both MNL and the ML model will be used to test whether the H_0 hypothesis can be rejected.

Design 1 (labeled)
H_0: The likeliness of a respondent choosing the alternative paper or digital is equal.
H_1: The likeliness of a respondent choosing the digital alternative is bigger than for paper.

Design 2 (unlabeled)
H_0: A respondent is likely to choose one alternative regarding innovation over another.
H_1: The likeliness of a respondent choosing the alternative innovation 1 or 2 is equal.

To determine whether MNL or ML should be used the goodness of fit of the models can be used. Additionally, the heterogeneity of the answers of the respondent can be evaluated. If the standard deviations are significant and therefore the data heterogenic ML should be used because this model takes this into account.

Heterogeneity:
H_0: The answers of the respondents are homogenous.
H_1: The answers of the respondents are heterogenous.

3.4 Conclusion

To identify the relative importance of the aspects stated choice experiments are used. These experiments are used as only the stated preference can be obtained. This is because, for revealed data, there are not enough respondents who have used the technologies, and which are not biased. The setup of the stated choice experiment is done based on the design process described by Hensher et al. (2005). We have chosen for two stated choice experiments the first one regarding the preference of either paper or digital formats. This design has two alternatives and an option to choose neither. Both alternatives have five attributes with each two differing levels. The second experiment focusses on the conditions under which construction workers would accept to adopt a new way of working. This is an unlabeled design, with therefore generalized alternatives called Innovation one and two. This design also has the option to choose “none of both” as an alternative and is composed out of five attributes with two times two levels and three times four levels.

As both experiments would consist out of too many choices sets to answer by an individual, fractional factorial designs are created. These designs have also been blocked into four subsets. This leaves the respondent with two blocks of three choice sets to answer for preference and one block of eight choice sets for acceptance. These blocks will be included in the main questionnaire on which Paragraph 4.2 will elaborate.

4.0 DATA COLLECTION AND DESCRIPTIVE ANALYSIS

For the data collection, the Bergênquete system is used, this is a web-based questionnaire system provided by the Eindhoven University of Technology. This system allows user to program their questionnaire according to their requirements. Assistance and examples to develop this questionnaire are provided by the department of the built environment.

The questionnaire is set up in a way that it can be filled out with and without the presence of someone to guide the respondents. For the respondents, without guidance, an instruction video is included at the beginning of the questionnaire and throughout the questionnaire explanatory error messages are given. Although the questionnaire can be filled out without the presence of the researcher, this is not preferred. The reasons to be present are; an online request has in the initial questionnaire proven to have substantially fewer responses than when the researcher is present. The second reason is that a better representation is obtained of construction workers. In case of physical presence on the construction site, everyone who is present fills out the questionnaire which avoids underrepresentation of certain groups. Whereas the online version show a more selective representation of the socio-demographic profile of construction workers. The third reason to be physically present, is that the questionnaire system occasionally experienced technical errors. When present the respondents were willing to proceed after reloading the questionnaire or to fill out the questionnaire again. The last reason is that a lot can be learned from being present during data collection. Varying from interpretation of questions, awareness and motivation.

4.1 Design questionnaire

The questionnaire is build up out of three main parts namely; socio-demographics, stated choice experiment and the technology readiness index. In addition, a six-minute presentation is given in the beginning. The depth of this presentation is based on the initial research, in which the awareness and use to the construction workers were leading. The awareness of the construction workers can be seen in Tables 4 and 5. The actual web-questionnaire can be found in Appendix H.

Table 4: Awareness about the possibility to use interfaces

Awareness Interfaces	Frequency aware	Percentages	Missing values
Paper-based	21	87,5 %	-
Verbal	24	100 %	-
Mobile device	21	87,5 %	-
Interactive screens	9	37,5 %	-
Computer	14	60,9 %	1
Virtual reality	1	12,5 %	-

The presentation starts with a short explanation of why this research is conducted, how to fill out the questionnaire and more elaborately explains the definitions. This is done to create enthusiasm, understanding how to perform the tasks and to avoid ambiguity of definitions. The presentation is recorded and included in the online questionnaire both in English and

Dutch. The slides and the text used during the presentation can be found in Appendix F and G.

Table 5: Awareness about the possibility to use formats

Awareness Formats	Frequency aware	Percentages	Missing values
2D Drawings	22	91,7 %	-
3D Views	19	79,2 %	-
3D Model	15	62,5 %	-
Task-oriented drawings	16	66,7 %	-
Task-oriented instructions	15	62,5%	-
Video/animation	9	37,5 %	-

In advance of the main parts of the questionnaire, the respondents are asked their preferred language and whether they have already seen the introduction presentation. In the case they have not seen the presentation yet, this will be activated. The questionnaire commences with the socio-demographic part, questioned aspects are shown in Table 6. These aspects have been identified as relevant based on initial research. The gender has been left out as there are no significant amount of female construction workers and regions in which they are active because a substantial part is working throughout the country. This initial research also indicated better quality answers in case of multiple choice questions. Therefore this form of questions is preferred in this questionnaire. As the provided list of choices is not finite the option "otherwise, namely:" is included where needed. For the questions where an integer is asked, certain conditions are added to make sure a correct response will be obtained. The requested information can be seen in Table 6 including the properties which are discussed.

Table 6: Questions socio-demographic, main questionnaire

Asked information	Multiple choices	Option otherwise, namely:	Integer answer
Name of the company you work for	x	x	
Current profession	x	x	
Work experience			x
Birthdate (age)			x
Highest attained level of education	x	x	
Native language	x	x	
Language proficiency in Dutch	x		

The second parts are the stated choice experiments these parts start by asking the respondents what type of tasks they perform in their jobs. They must indicate for the following four tasks if they perform them or not: Structural work, finishing work, reporting flaws and check-lists/forms.
Based on the selection maximum two blocks of choice sets will be activated. The tasks are selected by means of priority rules set by the researcher. The blocks and choice sets are randomly selected from the database. When answering the choice sets for which alternative matches their preference the best, the task for which the questions have to be answered will be clearly indicated.

As indicated there are two stated choice experiments one regarding the acceptance of data provision and the other regarding the preference. First, a maximum of two blocks of each three choice sets will be given for the preferred alternative (total of 6 choice sets). After that, one block of 8 choice sets will be given for acceptance. For each new type of choice set an example is given which explains again how the question should be answered. The respondents have to select the option which is most suitable to their preference or which they find most acceptable. They have to choose this from three alternatives of which one option is the alternative "none," choosing this option implicates that both scenarios are not suiting the respondent. The setup of both experiments is shown below in Figure 9 and 10. In the two figures, all possible options can be seen, the bold attribute levels form a possible scenario for a choice set.

*"Please, read the descriptions in the table carefully and choose the column which you find most suitable to your preference, for the **Finishing work**."*

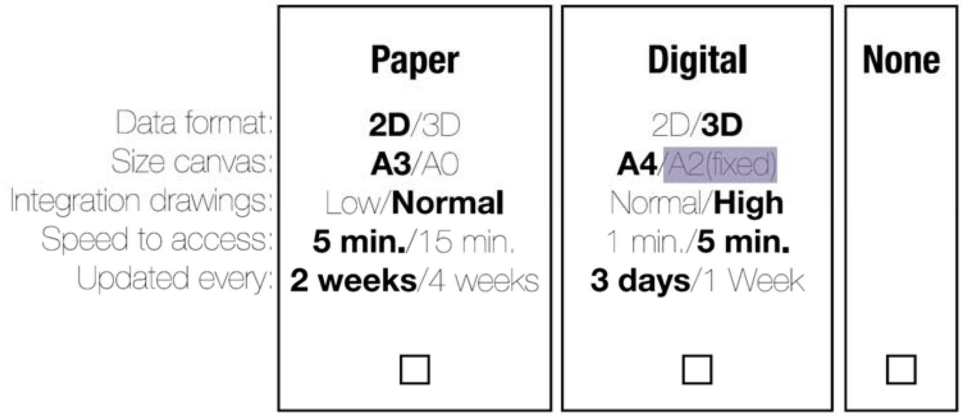

Figure 9: Possible options choice set for preference data provision

"Please, read the descriptions in the table carefully and choose the option you find most acceptable in adopting the new way of working."

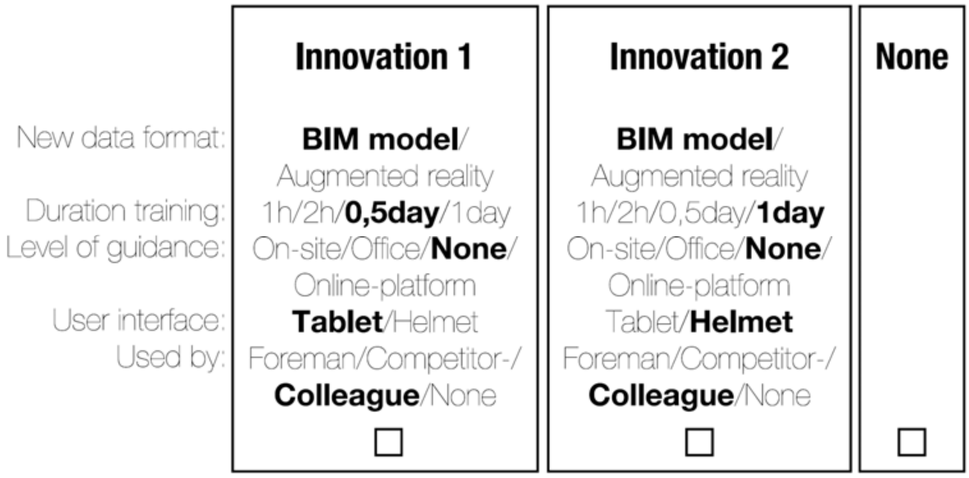

Figure 10: Possible options choice set for acceptance of adopting new ways of working

The last part of the questionnaire is based on the technology readiness index as described by Parasuraman (2000). This part is included as the interviewed experts expect a strong relation between innovativeness and the preference and acceptance of data provision. A selection of ten questions is asked from the TRI categories of optimism and innovativeness. The selection is made based on the relevance to construction workers. The respondents are requested to answer to which extent they agree with a statement on a 5-point Likert-scale. This scale is from Totally disagree too totally agree. With these questions *"propensity to embrace and use new technologies for accomplishing goals in home life and at work. "* (Parasuraman, 2000). In this case, the interest is towards the readiness to adopt new ways of data provision in the work activities of construction workers.

Optimism:
"Technology gives people more control over their daily lives."
"Products and services that use the newest technologies are much more convenient to use."
"You prefer to use the most advanced technology available.
"Technology makes you more efficient in your occupation."
"You feel confident that machines will follow through with what you instructed them to do."

Innovativeness:
"Other people come to you for advice on new technologies."
"In general, you are among the first in your circle of friends to acquire new technology when it appears."
"You can usually figure out new high-tech products and services without help from others."
"You enjoy the challenge of figuring out high-tech gadgets."
"You find you have fewer problems than other people in making technology work for you."

4.2 Data collection

The condition for someone to be a respondent is that they are working on a construction-site and receive and interpret information. The collection within the different companies started by getting permission and creating enthusiasm in various management levels within the companies. The order in which this happened varied as the contact persons obtained from the company supervisor were of different management levels within the company. Another reason why this varies was for differing levels of protection of personal information of employees. A typical procedure would start at an information manager, who would get approval from the boss. Then the information manager would give contact details from a person such as the chief of staff or a project leader. On their turn, they would indicate which foremen to contact, or they would set out the questionnaire online.

The general proposed setup of a visit to the construction site was to gather +/- five respondents per round. Depending on time limitations and the number of construction workers present these groups varied. Each round would consist out of a six-minute presentation and then approximately ten minutes to fill out the questionnaire. Filling out the questionnaire could be done either on personal smartphones or provided tablets. During this part, the respondents could ask questions, but to prevent too much influence, the respondents were first asked to read the explanation again in the cases where this would provide the answer. The alternative way to spread the questionnaire was by letting the foremen request the construction workers verbally to fill out the questionnaire, by email, through an intranet or via Whatsapp. Depending on the willingness and enthusiasm of the person who spread the request one or two reminders were sent, to fill out the questionnaire.

The research is conducted in collaboration with the contractor TBI, therefore, most respondents are from this holding of companies. The companies from the TBI holding who are interested and cooperated with the research are: Comfort Partners, Croonwolter&Dros, ERA contour, J.P. van Eesteren, Koopmans Bouwgroep and Prefab Voorbij. The contribution of each company and their core activity is depicted in Table 7.

Table 7: Percentages respondents and core activity of companies

Company	**Core activity**	**Respondents in percentage**	**Number or respondents**
Berghege	Residential & utility	14,8 %	26
Comfort Partners	Installation (MEP)	5,8 %	10
Croonwolter&Dros	Installation (MEP)	15,8 %	28
ERA contour	Residential	18,0 %	30
J.P. van Eesteren	Utility	6,4 %	11
Koopmans Bouwgroep	Residential	29,6 %	52
Prefab Voorbij	Pre-fabrication	2,0%	4
Others	Various	7,6 %	13

Also, Berghege contributed by providing a significant number of respondents and there were some other respondents from sub-contractors, an overview can be seen in Figure 9. These respondents spontaneously joined the research during my presence on the construction site, but this were relatively small numbers. The companies have various core business activities which can be defined by residential building, utility building and Mechanical, Electrical and Plumbing (MEP) services or a combination of these. The activities of the previously named companies can be seen in Table 7.

From the total 178 respondents, a dataset of 156 respondents is selected who filled the questionnaire out correctly and experienced no technical issues. However, not all the data retrieved with the questionnaire system was usable. One of the main reason for this were technical issues with the Bergênquete system, the cause of this has thus far not been identified. These issues had as a result that 15 respondents could not answer the questions for the Technology Readiness Scale. However, because they did correctly fill out the rest, this data can still be used for parts of the analyses. This also holds up for several cases which show missing values for one of the blocks of choice sets. Five respondents filled in the questionnaire two times, for these individuals, one response for each individual has been removed from the data. For the remaining data, the distribution of the blocks and choice sets is for both the unlabeled as the labeled design equal.

Because almost all data entries were retrieved through multiple choice questions, there were almost no "incorrect" answers. Answers which had to be recategorized were all in socio-demographic parts under the option "other, namely:" In most cases, these respondents fitted in one of the listed categories, some cases required a new category and remaining answers which were given less frequent remain in other. The results of the technology readiness index also had to be recoded to use for analysis. This is done by taking the average for the responses on the tasks per respondent. Based on the frequency of the averages five categories are created. Which represent a scale of acceptance of innovation.

The data has been regularly checked for distribution and unexpected results. The distribution of tasks had to be kept equal manually because beforehand the response was unknown and for statistical purposes, enough data is needed for each category. The assumption in advance was that priority rules for the selection of tasks should be set on *Reporting flaws* and *Check-lists/forms.* Therefore, the initial priority was set on these two tasks. After 77 respondents a significant deficiency was noticed in responses for the task *Finishing work* and priority rules were changed to increase the number of results for this task. After 122 respondents the distribution had returned to almost equal and priority was set again to the initial two tasks and with a light favor of *Finishing work* over *Structural work*. The result of the distribution can be seen in Table 8 and Figure 11 shows the percentage of the responses *Yes* or *No* on the question whether they perform the task.

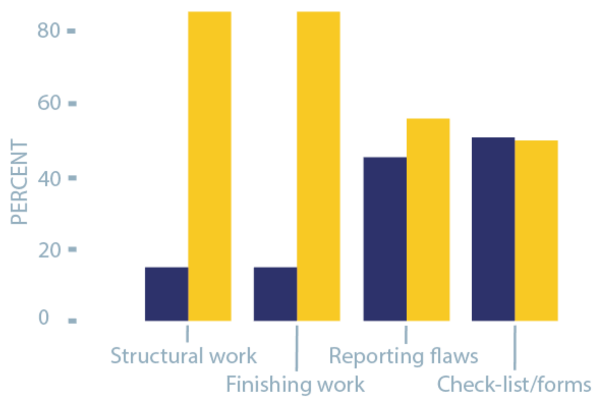

Figure 11: Choices made for performing tasks in their profession

Table 8: Distribution of answers task/activity

Task/activity	**Nr. of respondents**
Structural work	87
Finishing work	87
Reporting flaws	76
Check-lists/forms	66

4.3 Descriptive analysis

The refined dataset is used for a descriptive analysis regarding the choice distribution and the socio-demographics of the respondents. Where possible comparisons between data from the main questionnaire and other sources are made.

4.3.1 Distribution answers

In Table 9 is shown that a substantial number of respondents for the labeled stated choice experiment indicated to prefer only one alternative regardless of the varying attributes. The group who responded with all answers for the same alternative forms almost half of the respondents. This is assumed to be due to a strong preference for the chosen alternative. For the stated choice experiment of acceptance, this occurred substantially less. Which is in line with the unlabeled design in which except for the option "none", no preference should be present for the labels of the alternatives.

Table 9: All similar responses for preference (labeled design)

labeled response	Paper	Digtal	None	Multiple	Total
All similar choices	18	52	2	87	159
Total	72				

Table 10: All similar responses for acceptance (unlabeled design)

unlabeled response	Innovation 1	Innovation 2	None	Multiple	Total
All similar choices	8	3	4	144	159
Total	15				

In the choices made for the alternatives, the distribution of the answers should be almost equal for the alternatives of the unlabeled design. In this case, this is for *Innovation 1* and *Innovation 2*, not for the option *None*. Figure 12 shows a division which almost equal, which implicates that the respondent did not base their choice on the labels. The option *None* has been chosen eight percent of the time, this means that respondents sometimes are not willing to accept one of the two innovation alternatives. Also, for the labeled design the option *None* is occasionally selected. The estimations of the data show a significant preference for the alternative *Digital* confirming the results of the initial questionnaire.

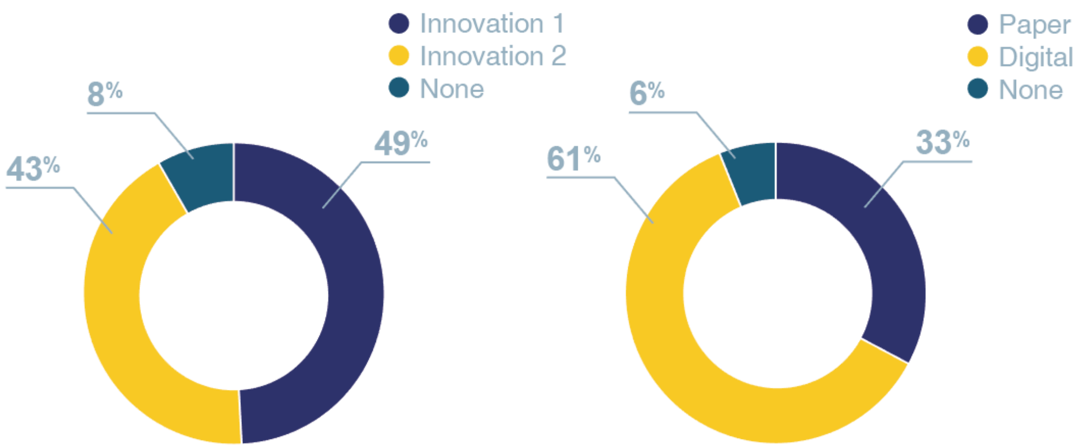

Figure 12: Choices made for alternatives stated choice experiments

4.3.2 Age and work experience

From initial research can be concluded that both age and work experience might influence the preference and acceptance of data provision. Therefore, the year of birth and how long the respondent is currently working in their profession is asked. The age build-up can be seen in Figure 13 as already derived from the initial questionnaire the build-up is not as expected. In ideal circumstances, the percentages for age would be evenly distributed. However, from the bar chart can be seen that the younger age groups are less represented in the current situation. This is the case for both the data of the questionnaire as well as from the data from TBI of all employees who work on the construction site. Moreover, the chart shows that the majority of the employees is aged 45 and over and for the TBI data even 50 and over.

This age distribution can be partially explained by the most recent economic crisis, which lead to a policy of hiring less new employees. Another explanation brought forward during interviews could be a growing number of “ZZP-ers” this is a Dutch definition of self-employed persons who are also hired by the major companies. However, according to data of the CBS which can be seen in Table 11 this is not the case. The ZZP-ers show no significant difference in age distribution.

Table 11: Age build-up among construction workers TBI and ZZP (data CBS)

Age	15-44 year	45-54 year	55+ year
ZZP (CBS data)	38,4%	31,8%	29,8%
TBI company	36,4%	27,9%	35,7%

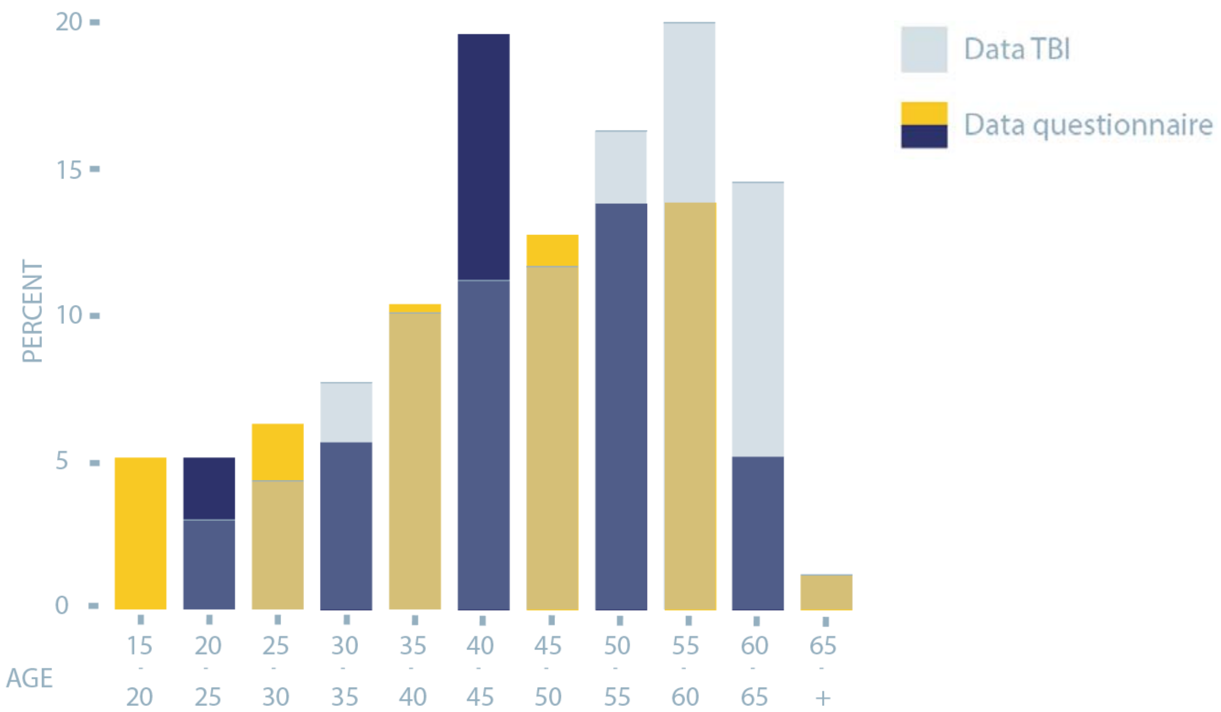

Figure 13: Age distribution, data questionnaire and data TBI

The age distribution is of major concern to TBI because they already experience a growing pressure on current staff. Recruiting or keeping new employees appears to be difficult which can also cause the lack of young employees. As the majority of the employees is currently relative old and will retire within the coming years this problem will grow. In addition, this old generation of workers is less physically fit and generally cannot perform the same intensity of manual labor as younger workers. This will lead to a need for even more new employees or measures which increase efficiency of workers or reduce the need for required labor.

In Figure 14 the work experience in current profession is shown. It shows a more gradual distribution and that a large percentage of the respondents remains in their profession for a long time.

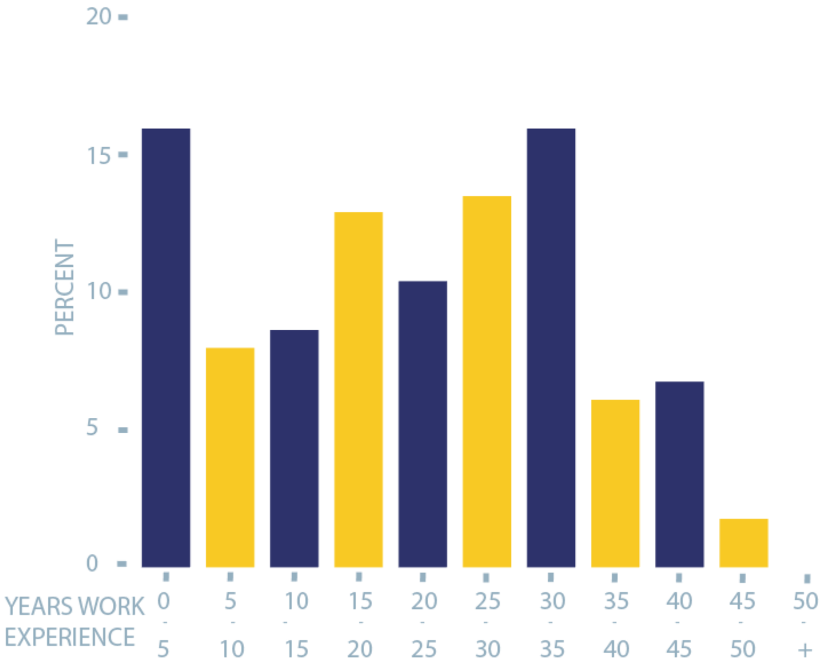

Figure 14: Years of work experience

4.3.3 Highest attained level of education

The distribution of highest attained education level is shown in Figure 15. The majority has attained either the level of Pre-vocational secondary education or Secondary vocational education. The respondents who attained Secondary vocational education have had four more years of education than the respondents attained Pre-vocational secondary education. There is a small percentage (4%) of respondents have attained primary education. From the original data (non-recategorized) can be derived that part of this group did not finish a higher level of education because they are still interns. The group who attained higher professional education of 4%, consist mostly out of project supervisors and site managers. The remaining 8% of respondents attained intermediate vocational education.

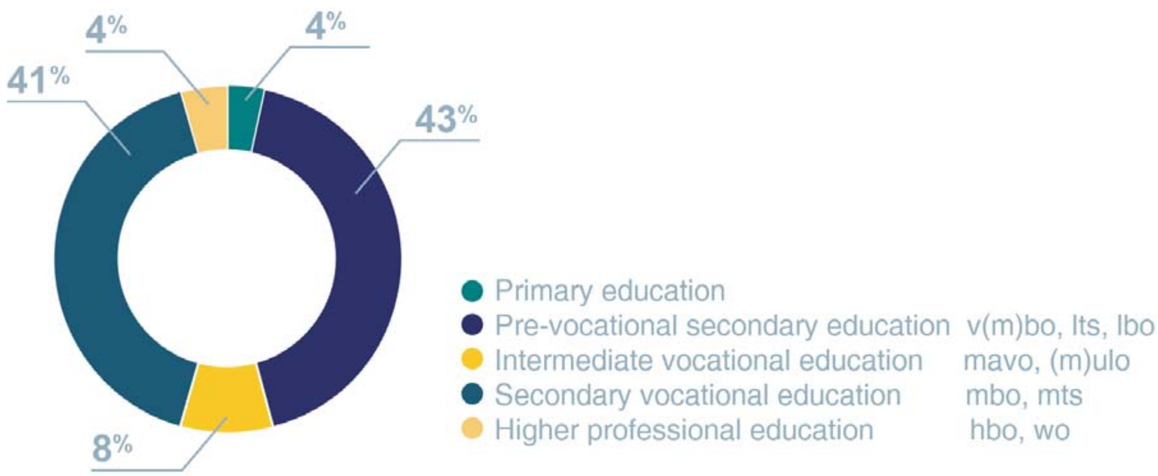

Figure 15: Distribution of highest attained education level

4.3.4 Current profession

In contrast to the other questions the option “otherwise” was chosen more frequently for current profession. From the indicated job titles in the option otherwise, can be derived that the respondent's attached great value to them. Often additions such a “chef” or “foreman” were added to the general job description or another description which differentiated them from their co-workers. From Figure 16 can be seen that the division of the respondents is not equally distributed. This is due to the varying extent of cooperation of companies to provide respondents. The category MEP and Manager have been merged from several other categories. MEP consists out of Mechanics, Electrical engineers and Plumbers, the category managers consist of (assistant)site managers and foremen.

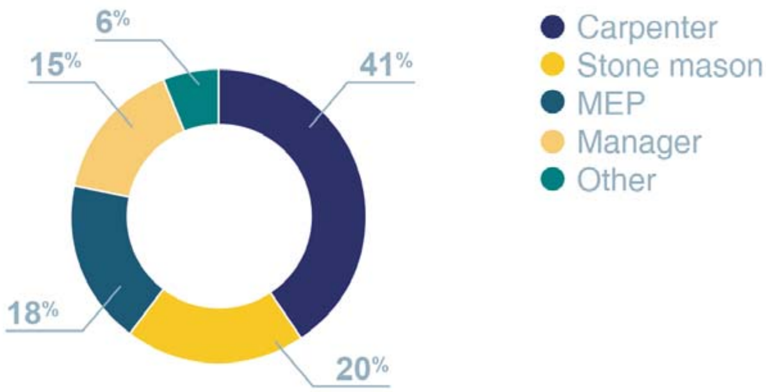

Figure 16: Current profession categorized

4.3.5 Native language and language proficiency

Among the respondents, 89,2% are native Dutch speakers. The remaining 10,8% respondents speak various languages. Therefore, no second language group can be identified. Furthermore, we asked their Dutch language proficiency. The results show that 90.4% of the respondents consider themselves good or very good Dutch speakers. From the remaining group, 7,8% indicates that their proficiency is basic and only 1.8% indicates that it is less than basic. This last group is too small to be able to identify reliable aspects on which these respondents would have a different preference or acceptance regarding data provision.

4.3.6 Technology readiness of respondents

The percentages of the responses on the innovations statements are shown in Figure 17. All questions are positively rated which means that if a respondent Totally agrees they rate themselves as innovative and totally disagree as not innovative. The figure shows a big spread over the scale in which the extremes are chosen less. Over 60% of the answers fall into *neither disagree nor agree (34,2%)* and *agree (32%).* This means that the majority of the respondents is assumed to be moderate innovative to innovative.

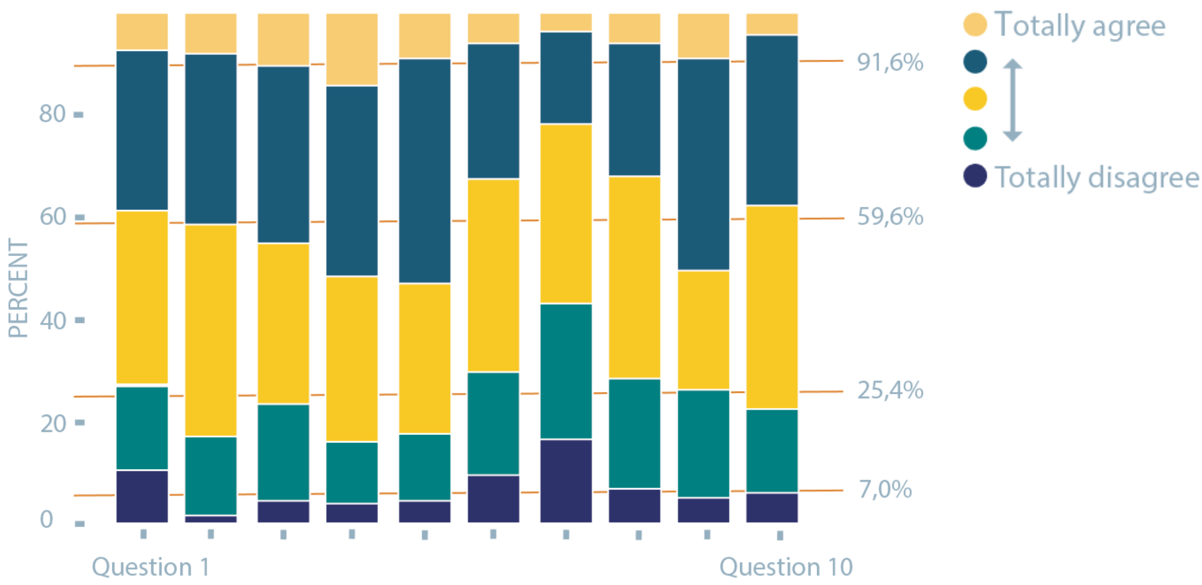

Figure 17: TRI agreement with statements

To ensure the reliability of the ten statements the internal consistency is analyzed with the Cronbach's Alpha. The Cronbach's Alpha ranges between zero and one. The closer it is to one the greater the internal consistency is. According to George and Mallery (2003) the following rule of thumb can be used to judge the coefficient: values below 0,5 are unacceptable, >0,6 questionable, >0,7 acceptable, >0,8 good and >0,9 excellent. The output of the Cronbach's Alpha has a value of 0,864, which means the TRI has a good internal consistency of the statements in the scale.

4.4 Conclusion

In total, 159 valid responses were gathered after eliminating the respondents who have experienced technical failures or other problems. The respondents are mainly from five companies of TBI and one company called Berghege. A descriptive analysis has been performed for variables of age, work experience, current profession, highest attained education level, innovativeness and language. The results indicate that there are relatively few young construction workers. This is a concern for companies but also a point of attention in case of age-based implementation strategies. The construction workers generally indicate to be relative innovative. From the descriptive analysis of the respondents can be concluded that the influence of the following attributes can be used in estimation of the preference and acceptance: Age, work experience, current profession and highest attained level of education. Whereas native language and Dutch language proficiency will be left out because the percentages of respondents who are not native or have a low Dutch language proficiency are too small to analyze. A point of interest is the build-up of the age cohorts within the company, this is not as expected. Initial research into the low number of young people has not resulted in an explanation yet.

5.0 ANALYSIS & RESULTS

This chapter provides the results of discrete choice experiments for data provision preference and acceptance of innovations in section 5.1 and 5.2 separately. Both Multinomial logit model and mixed logit model have been applied. The synergy of these results will be discussed in the conclusion. Focus on the statistical analysis which will consist out of the estimation of the two stated choice experiments with the Multinomial logit and Mixed logit model. The results from these estimations are translated in an overview of the effect of attributes on the preference and acceptance regarding data provision.

5.1 Preference of data provision

The first stated choice experiment is designed to estimate the influence of the attributes on the preference of construction workers regarding data provision. In addition, the socio-demographics are included in the analysis to identify groups with similar preferences. This is done to be able to adopt implementation strategies to the various defined groups. The dataset used for the estimation contains 156 respondents who each answered six questions regarding their preference. For the estimation of effects in this data, both the Multinomial logit(MNL) model and the Mixed logit(ML) model are used. To evaluate their performance the McFadden's rho-square is used. With this value, the "goodness of fit" of a model can be evaluated. The MNL has a rho-square value of 0,13708 which indicates a moderate fit. The ML is estimated with a rho-square of 0,27002, which indicates a significantly better fit than the MNL. This can be explained by the ability of ML to capture heterogeneity among respondents. Consequently, it is expected that the preference of the respondents is heterogeneous. From both models, the coefficients and their significance are shown in Table 12. But only the values from the ML will be used to explain the preference among attributes and the likeliness to choose either digital or paper as a preferred alternative.

The design for preference is labeled with the alternatives: paper, digital and none (of both). For both models, paper is used as reference. This means that if the constant for the other alternative is positive, this one is more often chosen as the preferred over the alternative paper. In case of a negative constant, the respondents are more likely to choose paper as the preferred alternative. The same relation applies to the coefficients of the attribute levels. When a coefficient has (the largest) positive value this option is more likely to be chosen than the other levels for this attribute. Moreover, a positive coefficient of an attribute level contributes positively to the chance for the alternative to be chosen by the respondent.

In Table 12 the constant of the alternative digital can be seen, which has a value of 2,8201. This is a positive value and therefore implicates that it is more likely that respondents choose digital over the alternative paper. The constant has a probability value of 0,1072, this percentage is not enough to reject the H0 hypothesis but because the MNL estimation indicates that the constant is significant for one percent we assume that we can reject the H0 hypothesis. Therefore, it is concluded that digital has a larger chance to be preferred by the respondents over paper. For the alternative none, the coefficient is significant for five percent and has a negative value. This means that the alternative none is less likely to be chosen as the preferred option compared to the alternative paper.

The same table shows the coefficients for the attribute levels underestimate. For the alternative paper the coefficients for data format is significant for 10 percent. The positive coefficient for 2D indicates that this is the option which is more likely to be preferred than 3D. For the alternative digital the attributes size canvas and integration drawings have both significant and positive coefficients. The level A4 of size canvas is more likely to be preferred over A2(fixed). This can be because of the convenience to carry an of A4(tablet) around in contrast to large screens. For integration drawings, a normal level is more likely to be preferred over a high level. This means that construction workers prefer a lower extent of relevant information of other professions in drawings or information models.

Table 12: Results ML & MNL estimates, preference for data provision

Alternative	Attribute	Level	MNL			ML		
			Estimate	Probability		Estimate	Probability	
Paper	Data format	2D	0,1028	0,4945		0,7887	0,0921	.
		3D	-0,1028			-0,7887		
	Size canvas	A3	0,1622	0,2815		0,3725	0,3791	
		A0	-0,1622			-0,3725		
	Integration drawings	Low	-0,1087	0,4740		0,1871	0,6559	
		Normal	0,1087			-0,1871		
	Speed to access	5 Minutes	-0,1026	0,4954		-0,2300	0,5831	
		15 Minutes	0,1026			0,2300		
	Updated every	2 Weeks	0,0508	0,7358		-0,0700	0,8662	
		4 Weeks	-0,0508			0,0700		
Digital	Data format	2D	0,1575	0,2808		0,1922	0,6885	
		3D	-0,1575			-0,1922		
	Size canvas	A4	0,1557	0,2870		1,0984	0,0395	*
		A2 (fixed)	-0,1557			-1,0984		
	Integration drawings	Normal	0,2359	0,1142		1,3445	0,0292	*
		High	-0,2359			-1,3445		
	Speed to access	1 Minute	-0,0425	0,7717		-0,4604	0,3855	
		5 Minutes	0,0425			0,4604		
	Updated every	3 Days	-0,1151	0,4305		-0,8073	0,1489	
		7 Days	0,1151			0,8073		
Digital	Constant		1,3325	0,0061	**	2,8201	0,1072	
	Company	Residential	2,7046			6,9697		
		Installation	-0,0958	0,8023		1,2167	0,3444	
		Residential & utility	-0,8880	0,0002	***	-2,7238	0,0010	***
		Other	-1,7208	6,10E-03	***	-5,4626	0,0007	***
	Current profession	Carpenter	0,5379			3,0892		
		Stone mason	-0,4856	0,05569	.	-1,4719	0,0736	.
		MEP	-0,3826	0,30043		-3,2930	0,0149	*
		Manager	0,6197	0,04354	*	2,6866	0,0157	*
		Other	-0,2895	0,47411		-1,0110	0,4734	
	Work experience	0 - 5 years	0,7435			1,9112		
		5 – 15 years	0,0221	0,95167		-0,6160	0,6697	
		15 – 30 years	0,0067	0,98655		0,0692	0,9665	

		30 + years	-0,7723	0,07943	.	-1,3643	0,4313	
	Age	15 – 25 year	-1,4217			-8,3338		
		25 – 35 year	0,8706	0,04055	*	5,1420	0,0040	*
		35 – 45 year	-0,1449	0,71958		0,7286	0,6523	
		45 -55 year	0,0299	0,94425		0,5489	0,7522	
		55 + year	0,6661	0,19830		1,9144	0,3128	
	Innovativeness	0 – 2.5 score	-1,4592	0,00135	**	-4,0017	0,0003	***
		2,5 – 3,0 score	-0,2924	0,28812		-0,2819	0,7678	
		3,0 – 3,5 score	-0,7114	0,00556	**	-2,4183	0,0062	**
		3,5 – 4,0 score	-0,5128	0,05434	.	-1,9268	0,0380	.
		4,0 + score	2,9758			8,6287		
	Tasks	Structural work	-0,6496			-2,9386		
		Finishing work	-0,3447	0,1822		-0,4802	0,5773	
		Reporting flaws	0,7757	0,0066	**	1,1781	0,0623	.
		Check-lists/forms	0,2186	0,2518		2,2407	0,0021	**
None	Constant		-4,5125	0,0003	**	-6,1503	0,0490	*
	Company	Residential	2,8965			4,1490		
		Installation	-0,4917	0,4958		0,6169	0,7615	
		Residential & utility	-0,8702	0,0985	.	-1,7201	0,2716	
		Other	-1,5345	0,0683	.	-3,0458	0,4040	
	Current profession	Carpenter	-0,8335			-3,7099		
		Stone mason	-0,0761	0,8710		0,8455	0,3105	
		MEP	-1,0797	0,2199		-2,3654	0,2948	
		Manager	0,7110	0,2446		2,9787	0,1738	
		Other	1,2783	0,1404		2,2510	0,4485	
	Work experience	0 - 5 years	5,3167			7,6211		
		5 – 15 years	-0,8041	0,2140		-3,2714	0,2049	
		15 – 30 years	-2,4632	0,0010	***	-2,5341	0,3669	
		30 + years	-2,0494	0,0109	*	-1,8156	0,4364	
	Age	15 – 25 year	-12,6233			-15,0007		
		25 – 35 year	2,7255	0,0069	**	3,4966	0,3419	
		35 – 45 year	2,7081	0,0060	**	3,3542	0,3097	
		45 -55 year	3,3260	0,0011	**	3,4448	0,3164	
		55 + year	3,8638	0,0007	***	4,7052	0,2169	
	Innovativeness	0 – 2.5 score	2,0669	0,0138	*	1,7147	0,2134	
		2,5 – 3,0 score	0,6726	0,4527		0,8803	0,5623	
		3,0 – 3,5 score	1,5783	0,0524	.	1,1902	0,3713	
		3,5 – 4,0 score	1,2658	0,1300		1,1549	0,3272	
		4,0 + score	-5,5836			-4,9401		
	Tasks	Structural work	-0,7989			-3,4323		
		Finishing work	0,2109	0,6594		1,1230	0,3362	
		Reporting flaws	0,3615	0,3539		0,4981	0,5778	
		Check-lists/forms	0,2266	0,5517		1,8111	0,0352	*
	McFadden R^2		0.13708			0.27002		

*Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1*

The estimated coefficients for the attribute levels discussed earlier are means of the estimates performed with the ML model. These means have been taken from the coefficients the ML model estimates for each individual. From these coefficients, the extent of heterogeneity can be derived by evaluating the standard deviation compared to the mean. A small standard deviation indicates that the preferences of the respondents vary minimal. A large standard deviation indicates that the preferences of the respondents are further from the mean and differ more from each other. In Table 13 the standard deviations can be seen for the attributes of the alternatives paper and digital. Except for the attribute integration drawings of the alternative paper all deviations are significant and indicate a heterogeneous preference for the attributes. Because most standard deviations are rather large compared to the means (shown in Table 13) it can be concluded that preferences of the respondents are diverse.

Table 13: Standard deviations of preference estimates from the ML model

Alternative	Attribute	Level	Standard deviation	Probability	
Paper	Data format	2D	2,0773	0,0040	**
		3D			
	Size canvas	A3	1,4310	0,0210	*
		A0			
	Integration drawings	Low	0,0592	0,9442	
		Normal			
	Speed to access	5 Minutes	1,6700	0,0116	*
		15 Minutes			
	Updated every	2 Weeks	1,8461	0,0039	**
		4 Weeks			
Digital	Data format	2D	-2,7279	0,0012	**
		3D			
	Size canvas	A4	3,7369	0,0017	**
		A2 (fixed)			
	Integration drawings	Normal	6,3675	0,0002	***
		High			
	Speed to access	1 Minute	3,3689	0,0020	**
		5 Minutes			
	Updated every	3 Days	3,4060	0,0004	***
		7 Days			

*Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1*

The coefficients of the socio-demographics and their significance are shown in Table 12 as well. These coefficients indicate the likelihood for respondents to prefer one alternative over another. The first part shows the coefficients of digital compared to paper of which the majority of the attributes show some significant coefficients. The second part shows the coefficients for the alternative “none”. This alternative has only one significant coefficient for the socio-demographics aspects. This coefficient is the task filling out Check-lists/forms. It indicates that respondents who respond the choice sets for this task are more likely to choose the option none (of both). This indicates that the attribute levels are less suitable to perform this task compared to the other tasks.

For the digital alternative, the companies in the sector residential & utility and the sector other are less likely to choose digital compared to the sector of residential companies. For the professions in these companies, people with the profession stone mason and MEP are less likely to prefer the digital alternative whereas managers are more likely to choose for digital compared to carpenters. The attribute of age shows only one significant coefficient for the age cohort of 25-35 years old. This group is significantly more likely to prefer the digital alternative compared to the age cohort of 15-25. The innovativeness seems to have a linear relation with the likeliness to prefer the digital alternative. The more innovative a respondent is the more likely they will be to select the digital alternative. Only the group of 2,5-3,0 on the TRI-index shows no significant effect and do not correspond with linear effect. This might be because this level on the index refers to neither agree nor disagree, which is chosen more often out of ease. For the tasks both reporting flaws and check-lists/forms show a significant difference in the likeliness to prefer a digital interface. Respondents who perform these tasks are more likely to prefer digital than if they would perform the task structural work.

5.2 Acceptance of new innovations

The second stated choice experiment goes more in-depth in the digital aspect of data provision and estimates the attributes, which influence the acceptance to adopt innovations. The sub-groups based on socio-demographics are here used to create better implementation strategies for the innovations. The dataset used for this estimation contains the responses of 167 respondents which each made a tradeoff for eight scenarios. The estimation is performed with MNL and ML model, which have a McFadden's rho-square of 0,1458 for MNL and 0,1769 for ML shown in Table 14. Also, for this dataset, the ML model has a better model performance compared to the MNL model.

The design for acceptance is unlabeled with the alternatives: innovation 1, innovation 2 and none (of both). The alternative innovation 1 is used as a reference. The constant of alternative 2 indicates that the alternative is not significantly more likely to be accepted. This is in line with the unlabeled design for which the respondent should nothave any preference for the name of the labels and the orthogonal design should make sure certain attribute levels are not more represented in one of the alternatives. The alternative is significant neither.

Table 14 also shows the estimates for the attributes. First, the similarities between Innovation 1 and 2 will be discussed, most of the significant coefficients are mutual. For the attribute level of guidance, both alternatives show a bigger chance that the respondents choose the option of guidance on-site over no guidance. The coefficients for the attribute user interface indicate that a tablet is more likely to be accepted compared to a helmet with visor. For the attribute used by, which means who already adopted the innovation before the respondent has to start adopting it significant coefficients for both alternatives are found for foreman and colleague. These are both more likely to be accepted over none. For innovation 2 also a colleague of the competitor is preferred over none. Another difference between the two alternatives is that only innovation 1 indicates a significant effect for the attribute new data format. It indicates that BIM-model is more likely to be accepted over an Augmented reality. Although alternative 2 is not significant for this effect is does indicate the same direction of the coefficient.

Table 14: Results ML & MNL estimates, acceptance of innovations

Alternative	Attribute	Level	MNL			ML		
			Estimate	Pr		Estimate	Pr	
Innovation	New data format	BIM model	0,3100	0,0003	***	0,3746	0,0009	***
		Augmented reality	-0,3100			-0,3746		
	Duration training	1 Hour	-0,0709	0,5556		-0,0528	0,7130	
		2 Hour	-0,0824	0,5037		-0,0830	0,5929	
		0,5 Day	-0,0919	0,4380		-0,0812	0,5756	
		1 Day	0,2452			0,2170		
	Level of guidance	On-site	0,7277	1,21E-06	***	0,8482	7,64E-06	***
		Office	0,0956	0,4394		0,0981	0,5226	
		Online-platform	0,2822	0,0242	*	0,3086	0,0341	*
		None	-1,1055			-1,2548		
		Tablet	0,5728	7,98E-08	***	0,8016	4,44E-07	***
	User interface	Helmet	-0,5728			-0,8016		
	Used by	Foreman	0,4467	7,06E-02	***	0,5327	0,0003	***
		Competitor colleague	0,3238	0,0117	*	0,3363	0,0344	*
		Colleague	0,4292	0,0002	***	0,5420	0,0002	***
		None	-1,1998			-1,4111		
Innovation 2	Constant		0,1658	0,5714		0.2260	0.5261	
	Company	Residential	0,0275			-0,0540		
		Installation	0,1371	0,6126		0,2381	0,4700	
		Residential & utility	-0,3405	0,0664	.	-0,4484	0,0434	*
		Other	0,1759	0,5491		0,2642	0,4543	
	Current profession	Carpenter	0,6375			0,9007		
		Stone mason	-0,3940	0,0339	*	-0,5281	0,0217	*
		MEP	-0,2022	0,4682		-0,2741	0,4193	
		Manager	0,1428	0,5175		0,1579	0,5474	
		Other	-0,1841	0,5849		-0,2563	0,5465	
	Work experience	0 - 5 years	0,7842			0,9608		
		5 – 15 years	-0,1144	0,6751		-0,1234	0,7151	
		15 – 30 years	-0,3798	0,1825		-0,4800	0,1587	
		30 + years	-0,2900	0,3690		-0,3575	0,3414	
	Age	15 – 25 year	-1,1383			-1,3934		
		25 – 35 year	0,3778	0,2316		0,4732	0,2512	
		35 – 45 year	0,1083	0,7374		0,1194	0,7727	
		45 -55 year	0,4313	0,1985		0,5391	0,2084	
		55 + year	0,2209	0,5759		0,2616	0,5865	
	Innovativeness	0 – 2.5 score	-0,5078	0,0414	*	-0,6799	0,0276	*
		2,5 – 3,0 score	-0,0774	0,7304		-0,1120	0,6810	
		3,0 – 3,5 score	-0,1206	0,5820		-0,1713	0,5175	
		3,5 – 4,0 score	-0,3577	0,0990	.	-0,4699	0,0787	.
		4,0 + score	1,0635			1,4331		
None	Constant		-1,6075	0,0378	*	-1,2962	0,4140	
	Company	Residential	4,2315			4,9546		
		Installation	-2,0425	0,0013	**	-2,2447	0,0208	*
		Residential & utility	-1,4034	0,0003	***	-1,8031	0,0362	*
		Other	-0,7856	0,1791		-0,9068	0,3334	
		Carpenter	3,1666			4,2748		

	Stone mason	-1,7190	1,15E-02	***	-3,3900	0,0006	***
Current profession	MEP	-2,5305	0,0244	*	-2,4559	0,1533	
	Manager	-0,3716	0,4137		0,0186	0,9813	
	Other	1,4546	0,0095	**	1,5524	0,1355	
Work experience	0 - 5 years	8,0708			8,9852		
	5 – 15 years	-1,2642	0,0138	*	-1,4505	0,0813	.
	15 – 30 years	-3,9544	3,62E-08	***	-4,4862	0,0001	***
	30 + years	-2,8523	2,77E-03	***	-3,0486	0,0010	***
Age	15 – 25 year	-11,9332			-7,9708		
	25 – 35 year	1,5051	0,0266	*	0,8949	0,3623	
	35 – 45 year	2,7552	1,65E-02	***	2,8812	0,0024	**
	45 -55 year	3,8311	7,40E-06	***	3,8517	0,0001	***
	55 + year	3,8417	2,81E-04	***	0,3429	0,0014	**
Innovativeness	0 – 2.5 score	2,0881	0,0023	**	2,1115	0,1172	
	2,5 – 3,0 score	0,7279	0,2922		0,6770	0,6060	
	3,0 – 3,5 score	1,3117	0,0482	*	1,1380	0,3302	
	3,5 – 4,0 score	0,2954	0,6622		0,2184	0,8578	
	4,0 + score	-4,4231			-4,1448		
McFadden R^2		0,1458			0,1769		

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

For the socio-demographic aspects, a few significant coefficients can be observed which indicate a difference between the likelihood of acceptance between alternative 1 and 2. However, because this is an unlabeled orthogonal design, no significant relations were expected. The attribute levels which have significant coefficients are: company residential & utility and current profession stone mason, innovativeness 0-2,5 and innovativeness 3,5-4.0 based on this data these effects cannot be explained but might have been caused by random error.

The alternative none (of both) shows a substantial number of significant coefficients. The sector companies of installation and residential & utility have a lower likelihood to choose none compared to residential. For professions, this is the case for stone masons and the category other compared to carpenters. For work experience, all age cohorts are less likely to choose none then the youngest group. Whereas for the attribute age the all categories are more likely to choose none compared to the youngest cohort.

In Table 15 the standard deviations can be seen for the attributes of the alternatives innovation 1 and 2. A great variety can be observed between significant deviations from the mean and none significant ones. New data format and User interface indicate clearly heterogeneity of the responses and interface used by only for the attribute level foreman. Because a substantial amount of the standard deviations is rather large compared to the means (shown in Table 14), it can be concluded that preferences of the respondents are diverse.

Table 15: Standard deviations of acceptance estimates from the ML model

Attribute	Level	Standard deviation	Probability	
New data format	BIM model	1,0011	0,0013	***
	Augmented reality			
Duration training	1 Hour	0,0317	0,9911	
	2 Hour	-0,0245	9,94E-01	
	0,5 Day	0,3924	0,4241	
	1 Day			
Level of guidance	On-site	0,1801	0,8593	
	Office	-0,0205	0,9939	
	Online-platform	0,2575	0,7082	
	None			
User interface	Tablet	1,2429	1,27E-06	***
	Helmet			
Used by	Foreman	1,1360	0,0072	***
	Competitor colleague	0,4201	0,4914	
	Colleague	0,4173	0,4019	
	None			

*Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1*

5.3 Conclusion

For both stated choice experiments an estimation with the MNL and ML model is performed. The goodness of fit is for both these estimations is good for the ML model and moderate for the MNL model. The better fit of ML results from the heterogeneity of the responses which can better be explained by ML. Therefore, the results of the ML model estimations are leading in the analysis. The first stated choice experiment indicated a higher likeliness that the alternative digital is chosen over paper. Whereas, the alternative none has a relatively small chance to be chosen. The main effects which influence this likeliness to choose an alternative are the attribute data format for the alternative paper. For the alternative digital of influence are; size canvas and integration drawings. For the socio-demographics, all attributes except work experience have a significant effect on the likeliness to choose for a digital interface. Based on this information an estimation can be done per company, profession and employee how likely they are to prefer a digital interface. The second stated choice experiment elaborates on the digital alternative by estimating the likeliness that construction workers accept certain innovations. This estimation shows no significant difference between alternative innovation 1 and 2 what is in line with the type of design. The option none is substantially less likely to be chosen by the respondent, which indicates that the respondents are not reluctant to choose an innovative alternative. An alternative for innovation is more likely to be chosen if it includes the use of a BIM model via a tablet, under the condition that support is provided on-site and that either a colleague or foreman already adopted the innovation. Notifiable is that all estimated socio-demographics indicate an effect on the likeliness to choose for the option none (of both) alternatives, except for the technology readiness index.

6.0 CONCLUSION & DISCUSSION

The result of the research is, on the one hand, the set up of an interviewing model which identifies the aspects of the acceptance and preferences of construction workers regarding data provision. On the other hand, it is a recommendation derived from this model, which aims at improving communication towards construction workers and general efficiency.

6.1 Research findings

This study contributes to the knowledge on data provision on the construction site. In which the focus is on the aspects of data provision which influence construction workers. Structure is applied to the research by defining research questions; the main research question is: Which aspects of data provision contribute to a successful implementation of innovations on the construction site? This research question is divided into sub-questions according to which the report is structured. In the following part, the sub-questions will be answered which conclude the results of the performed research.

What are currently the available ways of providing information to the construction site workers?
Many researches have been conducted into the possibilities to apply new technologies and data formats. From a technical perspective, there are many possible solutions. However, not everything has been proven yet to be cost-efficient. Case-studies and practice show examples such as tablets, BIM-booths, information screens, Augmented and Virtual reality and the traditional paper format. Initial research has identified criteria on which interfaces can be compared on their properties, input and abilities to show data formats. These aspects have been used to formulate trade-off options for the stated choice experiments.

Which forms of data provision are more preferred and more accepted by the current generation of employees?
From the estimation of the first stated choice experiment, it can be concluded that construction workers are more likely to prefer a digital interface. Important attributes which increase this chance are a tablet sized interface and a normal level of integration of the drawings. The second stated choice experiment analysis the digital scenario more in-depth. From this analysis, it can be concluded that construction workers prefer a BIM-model over augmented reality and a tablet over a helmet with visor. It also concludes that guidance during implementation of the innovation on the construction site and a colleague or foreman who already adopted the innovation increases the likeliness of acceptance of an innovation.

Based on the analysis it can be concluded that 2D information is still more likely to be preferred over 3D. Concerning the integration level of drawings, a normal or even low level is more likely to be preferred over a high level of integration. Finally, it can be concluded that many aspects of socio-demographics have a significant influence on the preference and acceptance of construction workers. This means that indications can be given for the likeliness of preference and acceptance of sub-groups within sectors or companies.

Which attributes of data provision contribute the most to the perceived quality and the different forms of data provision?
From the analysis, it is concluded that there is a significantly larger preference for working digital. However, not all construction workers are ready for this change. Ambassadors who initiate adoption and are available for guidance can increase the acceptance of innovating. Therefore, a phased transition period might convince the early and late majority of the benefit of innovation. Initially, this transition is recommended to be to using tablets as an interface with both 2D and 3D information. After adoption, a re-evaluation should be done to evaluate if workers will become more acceptant towards innovation.

The new technologies and innovations offer overall a better value proposition compared to the current way of working. Working digital has many advantages among which a reduction of waste and flaws. The exact interface can be disputed, but currently, construction workers are more recipient to tablets. Also, new data formats are indicated to offer better insights in what should be constructed. However, more research has to be done on how much and which information should be shown.

6.2 Discussion

The outcomes of the main questionnaire are mostly in line with the results from the initial interviews and questionnaires. However, there is a discrepancy with the literature. In literature, the construction sector is indicated to be very conservative, which is enforced by Harstad et al. (2015) who indicates that construction workers are reluctant to innovate. However, this research shows a more progressive mindset of construction workers. They are likely to prefer a digital interface over paper and the majority is not reluctant to choose for an innovation. A possible explanation for the less conservative attitude is that the indicated conditions for implementation have a positive effect. Another aspect might be the adoption of the technologies in their home environment which creates more trust. During the expert interviews, there was also cautious to initiate innovation among construction workers because construction workers would not be willing or able to adapt. These experts also indicated that this caution was mostly based on prejudgments or a few incidents. This might implicate that part of the conservatism in the construction sector originates from an unawareness of acceptance and abilities of the workers.

From both literature and the interviews, the conclusion can be drawn that up to date information and fast access to this is very important (Bargstadt, 2015; Berlo & Natrop, 2014; Ibrahin et al., 2004). Therefore, these aspects are included in the labeled stated choice experiment as attributes. The estimation results, however, do not verify this effect. No significant effect is indicated for faster or more up to date information. These aspects might still be relevant to construction workers but to a lesser extent than the other attributes. Of the socio-demographics, the innovativeness defined by the Technology readiness index of Parasuraman (2000) is in line with the expectations. The less innovative people are less likely to prefer to work digitally. The estimations of the tasks confirm what the experts indicated; digital interfaces are more preferred in performing the reporting of flaws or checking lists or forms.

The unlabeled stated choice experiment includes several attributes based on the adaptation theory of Rogers (1995). These are attributes based on the assumption that the majority of potential users of an innovation needs to be convinced by example or ambassadors. The estimation results indeed show that people who already use the innovation and accessible guidance increase the likeliness of acceptance. Only the duration of training does not seem to have any effect. Also, the results of the remaining two attributes can be explained by the theory of Rogers. Respondents are likely to choose for the less innovative option which has proven itself to be useful.

This research has shown that there is great potential to innovative on the construction site. Moreover, that common prejudgments about construction workers might not be true and that this potential can be realized faster as might have been thought. To confirm this and to elaborate on these findings future research is necessary. More attributes can be defined for data provision as this research was not exhaustive. The needs and preference for data format and provided content could be analyzed more thoroughly and per specific task to get more accurate estimations. The language and cultural barrier are also identified to have effect on the data provision. To analyze this not only data from contractors but also from sub-contractors should be gathered as they employ most foreign workers.

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8.0 APPENDIX

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Appendix A: Initial questionnaire English version

Technische Universiteit Eindhoven University of Technology

GRADUATION THESIS

This questionnaire is designed for the purpose of a graduation research conducted on behalf of the Eindhoven University of Technology. The questions will concern the data provision on the construction site. As this research is aimed at the Dutch building sector, it is requested to fill in the questionnaire based on projects in the Netherlands.

1. **Name of the company you work for**

2. **Current profession**

3. **Years in work experience in current profession**

   ☐ 0-2 years ☐ 2-5 years ☐ 5-10 years ☐ 10 + years

4. **Region in which you work most frequently**

5. **Native language** (If Dutch skip question 6)

6. **Proficiency in Dutch**

   ☐ Very well ☐ Well ☐ Basic ☐ Not at all

7. **Gender**

   ☐ Male ☐ Female

8. **Age in years**

9. **Highest obtained education level**

   ☐ None
   ☐ Lower education
   ☐ VMBO/LBO/MAVO = Pre-vocational secondary education
   ☐ HAVO = Senior general secondary education
   ☐ VWO = Pre-university education
   ☐ MBO/LTS/MTS = Secondary vocational education
   ☐ HBO = Higher professional education
   ☐ WO = University education
   ☐ Otherwise

Appendix A: Initial questionnaire English version

Technische Universiteit Eindhoven University of Technology

10. Are you aware of the possibility to use the following interfaces on the construction site?

Paper-based (drawings, books)	☐ Yes	☐ No
Verbal (work instructions from supervisor or collogue)	☐ Yes	☐ No
Mobile device (tablet)	☐ Yes	☐ No
Interactive screens on the construction site	☐ Yes	☐ No
Computer	☐ Yes	☐ No
Virtual reality (VR glasses)	☐ Yes	☐ No

11. Which types of interfaces have you used on the construction site?

Paper-based (drawings, books)	☐ Yes	☐ No
Verbal (work instructions from supervisor or collogue)	☐ Yes	☐ No
Mobile device (tablet)	☐ Yes	☐ No
Interactive screens on the construction site	☐ Yes	☐ No
Computer	☐ Yes	☐ No
Virtual reality (VR glasses)	☐ Yes	☐ No

12. How satisfied were you with ease of use of the following interfaces?

	very satisfied	satisfied	neutral	dissatisfied	very dissatisfied	haven't used
Paper-based (drawings, books)	☐	☐	☐	☐	☐	☐
Verbal	☐	☐	☐	☐	☐	☐
Mobile device (tablet) 3D	☐	☐	☐	☐	☐	☐
Interactive screens	☐	☐	☐	☐	☐	☐
Computer	☐	☐	☐	☐	☐	☐
Virtual reality (VR glasses)	☐	☐	☐	☐	☐	☐

13. Which interface did you prefer and why?

14. Are you aware of the possibility to use the following data formats on the construction site?

2D Drawings	☐ Yes	☐ No
3D Views	☐ Yes	☐ No
3D Model (interactive)	☐ Yes	☐ No
Task-oriented drawings	☐ Yes	☐ No
Task-oriented instructions	☐ Yes	☐ No
Video/animation	☐ Yes	☐ No

15. Which types of data formats have you used on the construction site:

2D Drawings	☐ Yes	☐ No
3D Views	☐ Yes	☐ No
3D Model (interactive)	☐ Yes	☐ No
Task-oriented drawings	☐ Yes	☐ No
Task-oriented instructions	☐ Yes	☐ No
Video/animation	☐ Yes	☐ No

Appendix A: Initial questionnaire English version

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16. **How satisfied were you with the usefulness of the information provided through the following formats?**

	very satisfied	satisfied	neutral	dissatisfied	very dissatisfied	haven't used
2D Drawings	☐	☐	☐	☐	☐	☐
3D Views	☐	☐	☐	☐	☐	☐
3D Model (interactive)	☐	☐	☐	☐	☐	☐
Task-oriented drawings	☐	☐	☐	☐	☐	☐
Task-oriented instructions	☐	☐	☐	☐	☐	☐
Video/animation	☐	☐	☐	☐	☐	☐

17. **Which format did you prefer and why?**

18. **What are in your opinion the main obstacles for good communication on the construction site?**

19. **What is in your opinion important in data provision?**

20. **Which interfaces do you currently use to obtain information?** (see question 10)

21. **How long does it take on average to obtain the instructions for a new task?** (in minutes)

22. **How long does it take on average to retrieve information on questions or changes?** (in minutes)

Appendix A: Initial questionnaire English version

23. What is in your view the cause for the duration of obtaining information? (positive/negative)

If you have any remarks or suggestion feel free to leave them below

Thank you for filling in this questionnaire. If you are willing to answer additional questions in the future than please leave your contact details below.

Name:

Email:

Phone:

Appendix B: Setup semi-structured interviews, professional experts

Setup interview:

1) Are the ICT innovations or process innovations leading for the development of data provision of the company?
   - How do ICT innovations and process relate to each other?
   - On which aspect will the future focus be?

2) How has the offered information to craftsmen been adapted in the last decade and how should it develop in your opinion? (amount of information, ICT tools, degree of specification of information and responsibilities)
   - Through which type(s) of interface should the information be offered?
   - What kind of type(s) of data formats are offered to the craftsmen? (2D/3D/4D, paper/digital)

3) With which types of interfaces have been used or is experimented with?

4) What causes currently the main perceived benefit in the new way of working for construction workers? (Tablet, BIM, changed processes)

5) What causes the biggest time savings with the new way of working?

6) Is the content made available through tablets the same as in the old project folders or has this been rethought and changed?

7) Are the new processes and technology applicable to all project sizes?

8) Is the new digital way of working accepted by all craftsmen or are there exceptions?

9) Are there identifiable (generation) groups amongst craftsmen with common characteristics?

Appendix C: Setup choice set design, including all attribute levels

Tasks:

- Structural work
- Finishing work
- Reporting flaws
- Check-lists/forms

Indicate preference regarding information provision for: Task

		Paper	Digital	None
2	Data format:	**2D**/3D	2D/**3D**	
2	Size canvas:	**A3**/A0	**A4**/A2(fixed)	
2	Integration drawings:	Low/**Normal**	Normal/**High**	
2	Speed to access:	**5 min.**/15 min.	1 min./**5 min.**	
2	Updated every:	**2 weeks**/4 weeks	**3 days**/7 days	
		☐	☐	☐

Indicate acceptance regarding new interfaces

		Innovation 1	Innovation 2	None
2	New data format:	**BIM model**/ Augmented reality	**BIM model**/ Augmented reality	
4	Duration training:	1h/2h/**0,5day**/1day	1h/2h/0,5day/**1day**	
4	Level of guidance:	On-site/Office/**None**/ Online-platform	On-site/Office/**None**/ Online-platform	
2	User interface:	**Tablet**/Helmet	Tablet/**Helmet**	
4	Used by:	Foreman/Competitor-/ **Colleague**/None	Foreman/Competitor-/ **Colleague**/None	
		☐	☐	☐

Appendix D: Fractional factorial labeled design

Choice situation	alt1.a	alt1.b	alt1.c	alt1.d	alt1.e	alt2.a	alt2.b	alt2.c	alt2.d	alt2.e	Set
1	2D	A0	Laag	5 Minuten	4 Weken	3D	A4	Normaal	5 Minuten	3 Dagen	1
2	2D	A3	Normaal	15 Minuten	4 Weken	2D	A2 (vast)	Normaal	1 Minuut	3 Dagen	1
3	3D	A0	Laag	5 Minuten	2 Weken	2D	A2 (vast)	Normaal	1 Minuut	1 Week	1
4	2D	A0	Laag	15 Minuten	2 Weken	2D	A4	Hoog	1 Minuut	3 Dagen	2
5	3D	A3	Laag	15 Minuten	2 Weken	3D	A2 (vast)	Normaal	5 Minuten	3 Dagen	2
6	2D	A3	Laag	5 Minuten	4 Weken	2D	A2 (vast)	Hoog	5 Minuten	1 Week	2
7	2D	A3	Normaal	5 Minuten	2 Weken	3D	A4	Normaal	1 Minuut	1 Week	3
8	3D	A0	Normaal	15 Minuten	4 Weken	2D	A4	Normaal	5 Minuten	1 Week	3
9	3D	A0	Normaal	5 Minuten	4 Weken	3D	A2 (vast)	Hoog	1 Minuut	3 Dagen	3
10	3D	A3	Normaal	5 Minuten	2 Weken	2D	A4	Hoog	5 Minuten	3 Dagen	4
11	2D	A0	Normaal	15 Minuten	2 Weken	3D	A2 (vast)	Hoog	5 Minuten	1 Week	4
12	3D	A3	Laag	15 Minuten	4 Weken	3D	A4	Hoog	1 Minuut	1 Week	4

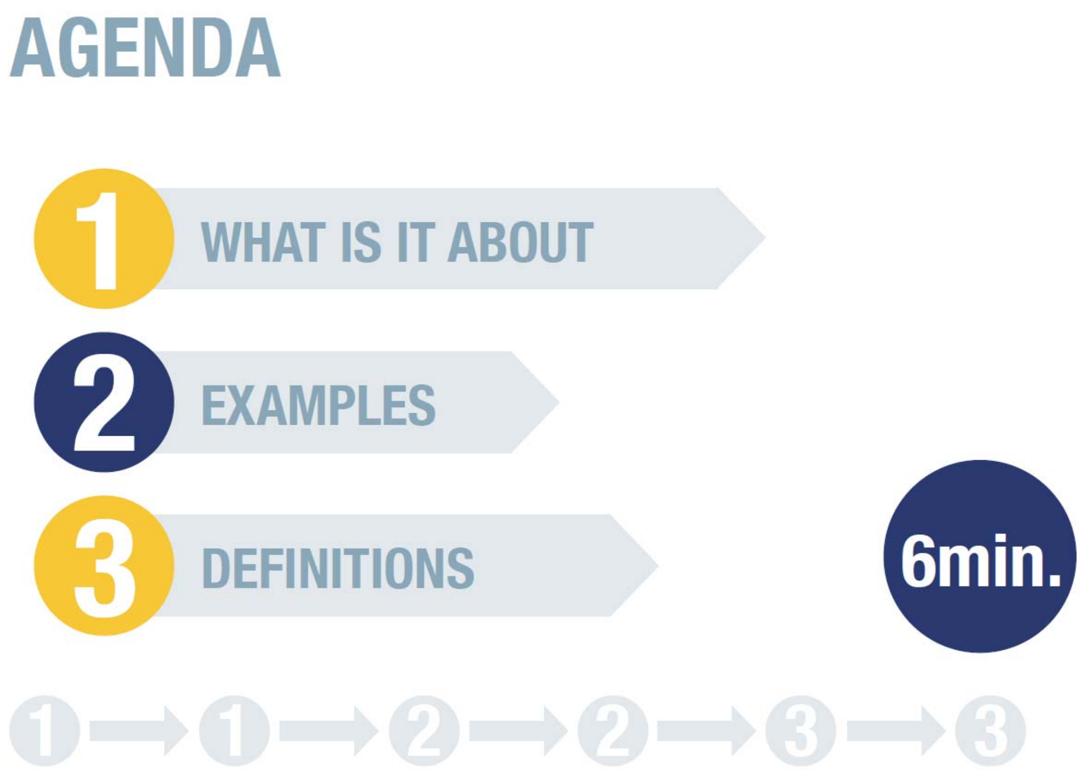
Appendix E: Fractional factorial unlabeled design (1/2)

Choice situation	alt1.a	alt1.b	alt1.c	alt1.d	alt1.e	alt2.a	alt2.b	alt2.c
1	BIM model	1 Day	Online-platform	Tablet	Competitive Colleague	Augmented reality	1 Hour	None
2	Augmented reality	1 Hour	None	Tablet	Foreman	Augmented reality	1 Day	Online-platform
3	BIM model	0.5 Day	Online-platform	Helm	None	BIM model	0.5 Day	Office
4	Augmented reality	2 Hour	None	Helm	Colleague	BIM model	2 Hour	Construction site
5	Augmented reality	0.5 Day	Office	Helm	Foreman	Augmented reality	1 Hour	Construction site
6	BIM model	1 Hour	Construction site	Tablet	None	BIM model	2 Hour	None
7	Augmented reality	1 Day	Office	Tablet	Colleague	BIM model	0.5 Day	Online-platform
8	BIM model	2 Hour	Construction site	Helm	Competitive Colleague	Augmented reality	1 Day	Office
9	BIM model	1 Hour	None	Helm	Colleague	BIM model	1 Hour	None
10	BIM model	0.5 Day	Office	Tablet	Colleague	BIM model	1 Day	Office
11	BIM model	1 Day	Construction site	Helm	Foreman	BIM model	1 Day	Construction site
12	Augmented reality	1 Hour	Construction site	Helm	Competitive Colleague	Augmented reality	0.5 Day	Online-platform
13	Augmented reality	2 Hour	Office	Tablet	None	Augmented reality	0.5 Day	None
14	Augmented reality	0.5 Day	Online-platform	Tablet	Competitive Colleague	Augmented reality	2 Hour	Construction site
15	BIM model	2 Hour	Online-platform	Tablet	Foreman	BIM model	1 Hour	Online-platform
16	Augmented reality	1 Day	None	Helm	None	Augmented reality	2 Hour	Office
17	BIM model	1 Hour	Online-platform	Helm	Colleague	Augmented reality	0.5 Day	Construction site
18	Augmented reality	1 Hour	Office	Helm	Competitive Colleague	BIM model	1 Hour	Office
19	Augmented reality	2 Hour	Construction site	Tablet	None	BIM model	1 Hour	Construction site
20	Augmented reality	0.5 Day	None	Tablet	Competitive Colleague	BIM model	1 Day	None
21	BIM model	1 Day	Office	Helm	Foreman	Augmented reality	2 Hour	None
22	BIM model	2 Hour	None	Tablet	Foreman	Augmented reality	0.5 Day	Office
23	BIM model	0.5 Day	Construction site	Tablet	Colleague	Augmented reality	2 Hour	Online-platform
24	Augmented reality	1 Day	Online-platform	Helm	None	BIM model	1 Day	Online-platform
25	BIM model	1 Day	None	Tablet	Competitive Colleague	BIM model	0.5 Day	Construction site
26	BIM model	0.5 Day	None	Helm	None	Augmented reality	1 Hour	Online-platform
27	Augmented reality	0.5 Day	Construction site	Helm	Foreman	BIM model	0.5 Day	None
28	Augmented reality	1 Hour	Online-platform	Tablet	Foreman	BIM model	2 Hour	Office
29	Augmented reality	2 Hour	Online-platform	Helm	Colleague	Augmented reality	1 Day	None
30	BIM model	2 Hour	Office	Helm	Competitive Colleague	BIM model	2 Hour	Online-platform
31	BIM model	1 Hour	Office	Tablet	None	Augmented reality	1 Day	Construction site
32	Augmented reality	1 Day	Construction site	Tablet	Colleague	Augmented reality	1 Hour	Office

Appendix E: Fractional factorial unlabeled design (2/2)

Choice situation	alt2.d	alt2.e	Set
1	Helm	Foreman	1
2	Tablet	Foreman	1
3	Helm	None	1
4	Tablet	None	1
5	Helm	Competitive Colleague	1
6	Tablet	Colleague	1
7	Helm	Colleague	1
8	Tablet	Competitive Colleague	1
9	Helm	Competitive Colleague	2
10	Tablet	Foreman	2
11	Helm	Colleague	2
12	Helm	None	2
13	Tablet	Competitive Colleague	2
14	Tablet	Colleague	2
15	Tablet	None	2
16	Helm	Foreman	2
17	Tablet	Foreman	3
18	Tablet	Colleague	3
19	Helm	Foreman	3
20	Helm	None	3
21	Tablet	None	3
22	Helm	Colleague	3
23	Helm	Competitive Colleague	3
24	Tablet	Competitive Colleague	3
25	Tablet	Competitive Colleague	4
26	Tablet	Colleague	4
27	Tablet	Foreman	4
28	Helm	Competitive Colleague	4
29	Helm	Colleague	4
30	Helm	Foreman	4
31	Helm	None	4
32	Tablet	None	4

Appendix F: Presentation main-questionnaire (slides)



Appendix F: Presentation main-questionnaire (slides)

WHAT IS IT ABOUT

CHANGES

- Digitalisation
- New type of data
- Your opinion is needed

WHAT WILL BE ASKED

- General information
- Preference
- Acceptance
- Personal interests

Appendix F: Presentation main-questionnaire (slides)

EXAMPLES

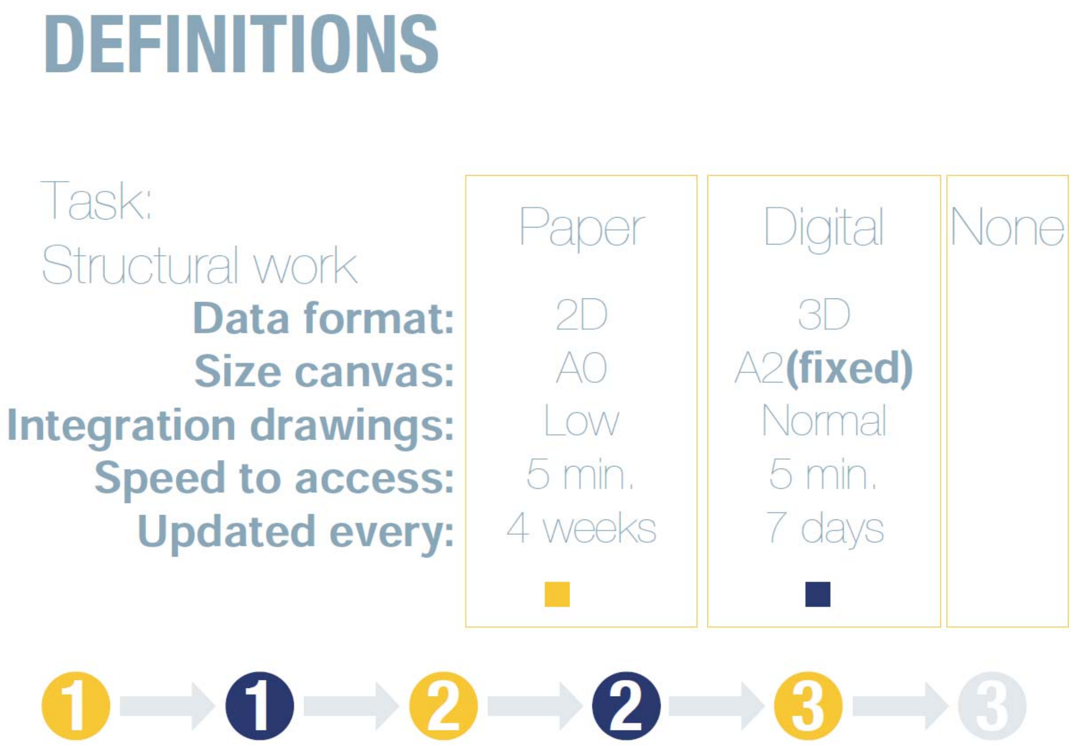
Tasks:
- Structural work
- Finishing work
- Reporting flaws
- Check-lists/forms

EXAMPLES

Task:
Structural work

	Paper	Digital	None
Data format:	2D	2D	
Size canvas:	A0	A2(fixed)	
Integration drawings:	Low	Normal	
Speed to access:	5 min.	5 min.	
Updated every:	4 weeks	7 days	

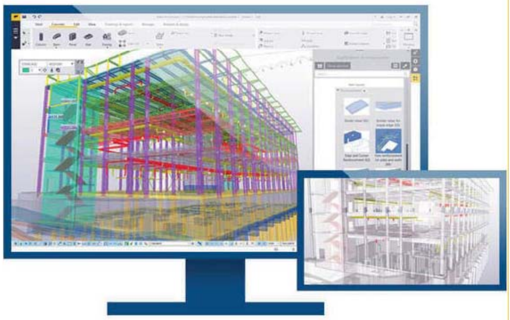
Appendix F: Presentation main-questionnaire (slides)



Appendix F: Presentation main-questionnaire (slides)

DEFINITIONS

BIM model



Augmented reality

1 → 1 → 2 → 2 → 3 → 3

DEFINITIONS

	Innovation 1	Innovation 2	None
New data format:	BIM model	Augmented re-ality	
Duration training:	2 hour	1 day	
Level guidance:	On-site	Office	
User interface:	Tablet	Helmet/glasses	
Used by:	Colleague	Foreman	

1 → 1 → 2 → 2 → 3 → 3

Appendix F: Presentation main-questionnaire (slides)

Appendix G: Presentation main-questionnaire (text)

Hi there, I am Laurens van der Schaft a graduate student at the Eindhoven University of Technology.

Together with the TBIkennislab I am conducting a research into the data provision on the construction site.

I will tell you shortly in this presentation what it is about,

I will give some examples for the second part which is a questionnaire and I will explain the definitions which will be used.

This presentation will take about 6 minutes

What is this presentation about?

Currently, the construction sector is undergoing some changes, as you might have noticed we are starting to become more digital and some processes are changing.

This offers the opportunity to work in new ways and to offer new types of data.

However, we need your opinion in order to make the most of this.

What will be asked

In the next part you will get a questionnaire with multiple choice questions, important to know is that this will be anonymous and will be used for research purposes.

The questionnaire will ask you regarding general information about your profession.

Your preference for data provision

Your acceptance of the introduction of new ways of working

And your personal interests regarding innovations

In the next slides, a few examples will be shown of the questions which will be asked.

Appendix G: Presentation main-questionnaire (text)

For the question about the tasks you perform it is important that you fill in all the tasks, you perform in your profession. The questionnaire will select automatically two tasks for which questions will be selected for the next part.

This is one of the scenarios which you might see, pay attention to the task. And please read the description of the options carefully.

You will be asked to choose the option which matches the best with your preference. You should only fill in None if you disagree completely with the other two options.

The next type of questions asks you how much you agree with a statement.

In this case: Your friends learn more about the newest technologies than you.

Please try to be honest with yourself in answering this question.

In the next slides, I will shortly explain what I mean with the definitions.

Data format: this can be either 2D or 3D, 2D means you can see the width and the length of an object on a drawing. 3D means you can also see the height, which can be shown on paper or as a digital model.

Size canvas: Is based on paper sizes. In which A4 to A0 is used. A4 is a standard paper size and about the size of a tablet, A3 is the double size, A2 is the size of a big screen important is for your answer that these are fixed to a wall. And A0 is the standard large foldable drawing.

Integration drawings indicates the level of information, in which a low level only shows one profession and a high level shows also the relevant information of other profession to prevent clashes between professions.

Speed to access: is how fast you can get new information

Updated every: means how up to date the information is you use.

I will explain the two new data formats on the next page.

Duration training: is how much training you get before having to work with the new data format

Appendix G: Presentation main-questionnaire (text)

Level of guidance: is where you can ask questions about the innovation

User interface: is whether the new information is shown on a tablet or a helmet or glasses

Used by: who is already using the innovation this can be a colleague, colleague from a competitor or your foreman.

These are the two innovations for which you will get questions.

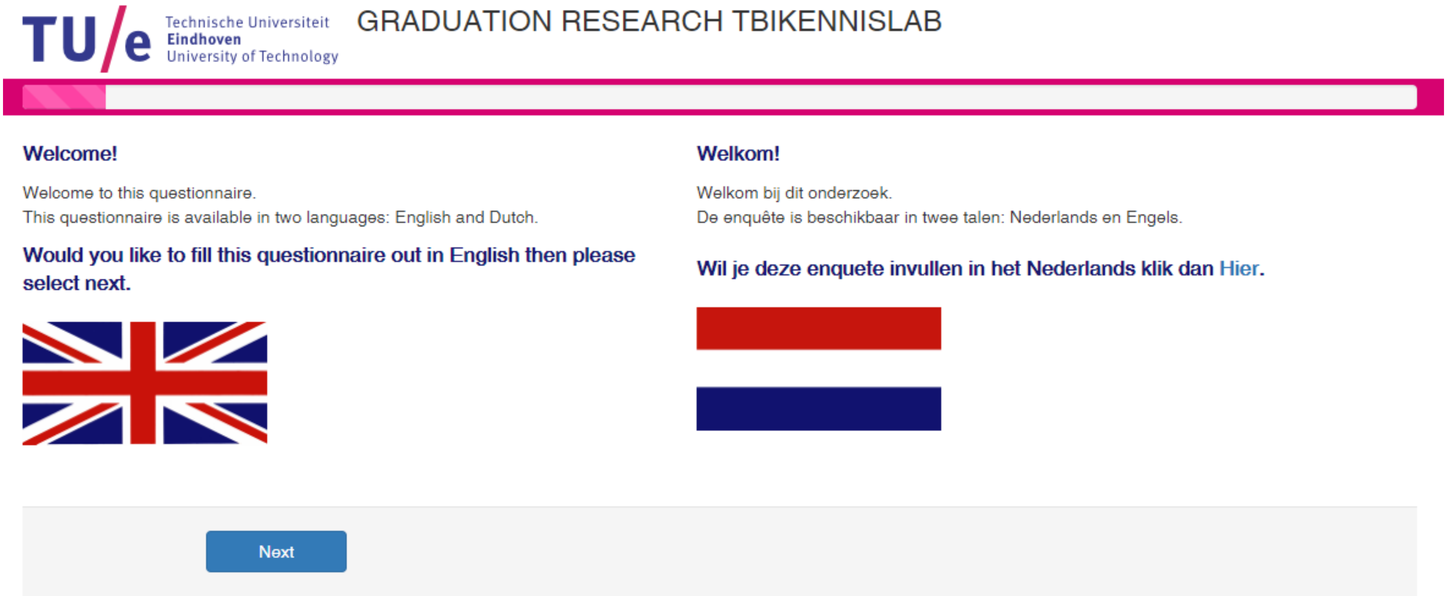
BIM model is a 3D model which contains all the information to construct a building. You can zoom and move through this building to get information. Important is that in these models the information which you need is already marked and redundant information is left out.

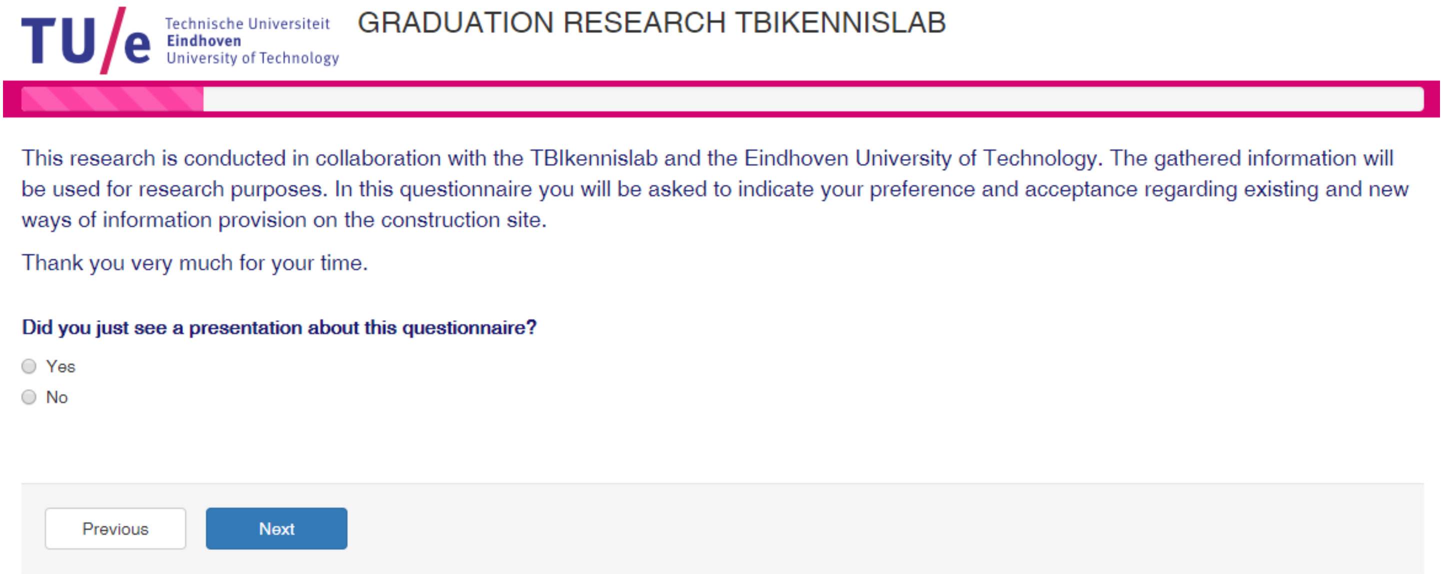
Augmented reality shows you the reality but with an extra layer of information over it from the BIM model. With this, you can see currently hidden or new objects in the surrounding where you are. In this example the infrastructure underneath a road.

I hope that with this information everything is clear

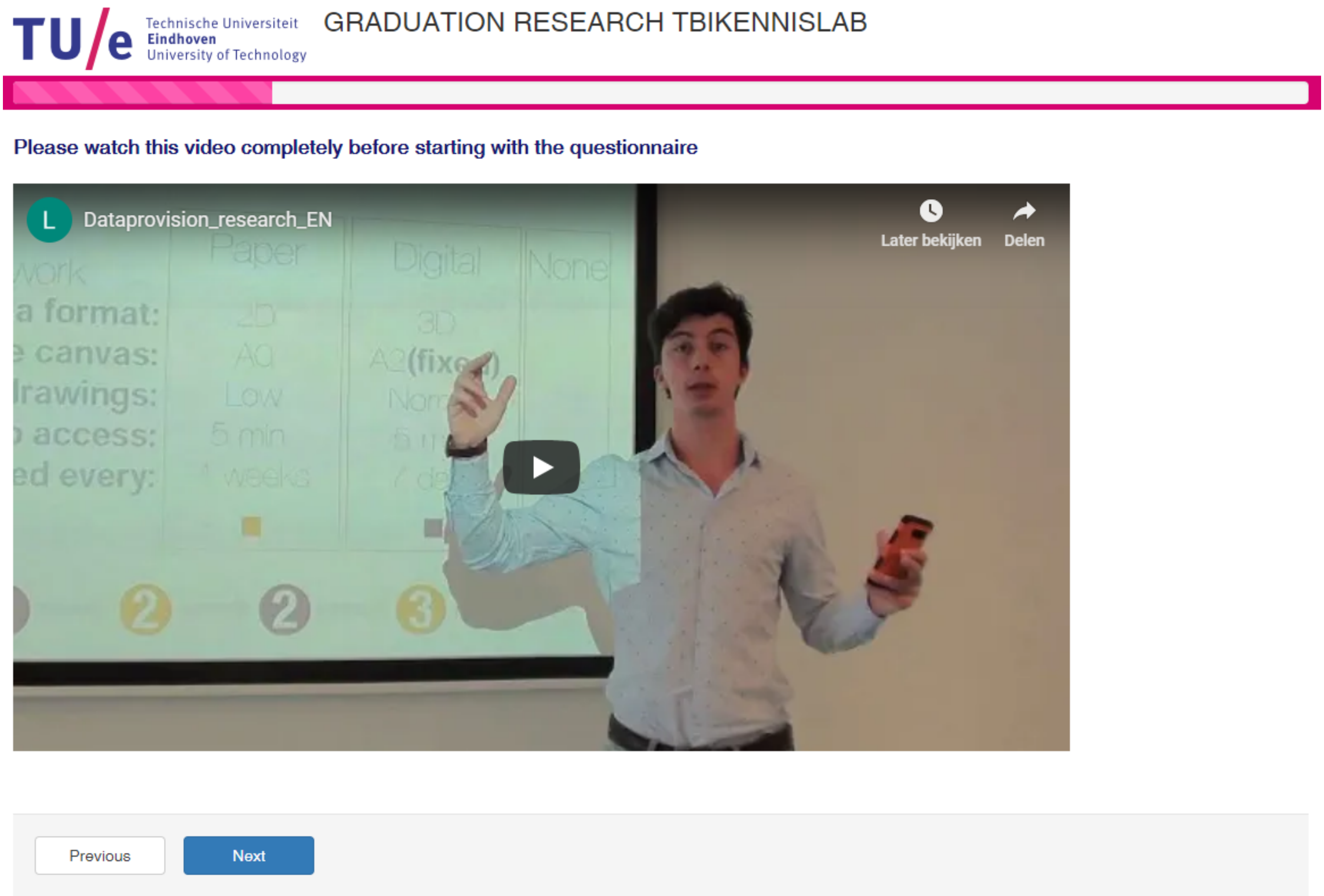
And I would like to thank you in advance for filling in the questionnaire.

Appendix H: Main-questionnaire on web-platform





Appendix H: Main-questionnaire on web-platform



Appendix H: Main-questionnaire on web-platform

GRADUATION RESEARCH TBIKENNISLAB

Part 1: Personal information

Name of the company you work for

- ○ Berghege
- ○ Comfort partners
- ○ Croonwolter&Dros
- ◉ Dura Vermeer
- ○ ERA Contour
- ○ Groothuis Wonen
- ○ Hazenberg Bouw
- ○ J.P. van Eesteren
- ○ Koopmans Bouwgroep
- ○ Mobilis
- ○ Strukton
- ○ Otherwise

Otherwise, namely:

What is your current profession?

- ○ Carpenter
- ○ Structural worker
- ○ Planner
- ○ Plumber
- ○ Foreman
- ○ Mechanic
- ○ HVAC-mechanic
- ○ Electrical engineer
- ○ Stone mason
- ○ Otherwise

Otherwise, namely;

How long are you currently working in your profession in years?

In which year are you born (19--)?

What is your highest reached level of education?

- ○ Primary education
- ○ Pre-vocational secondary education (v(m)bo, lts, lbo)
- ○ Intermediate vocational education (mavo, (m)ulo)
- ○ Secondary vocational education (mbo, mts)
- ○ Otherwise

Otherwise, namely:

Appendix H: Main-questionnaire on web-platform

What is your native language?

- ○ Bulgarian
- ○ Croatian
- ○ Czech
- ○ Danish
- ○ Dutch
- ○ English
- ○ Estonian
- ○ Finnish
- ○ French
- ○ German
- ○ Greek
- ○ Hungarian
- ○ Irish
- ○ Italian
- ○ Latvian
- ○ Lithuanian
- ○ Maltese
- ○ Polish
- ○ Portuguese
- ○ Romanian
- ○ Slovak
- ○ Slovenian
- ○ Spanish
- ○ Swedish
- ○ Otherwise

Otherwise, namely: ______

How good is your language proficiency in Dutch?

- ○ Very well
- ○ Well
- ○ Basic
- ○ Minimal
- ○ Very minimal

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Appendix H: Main-questionnaire on web-platform

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GRADUATION RESEARCH TBIKENNISLAB

Part 2: Choice-experiment

Select **ALL** the tasks you perform in your profession.

Do you perform the task 'Structural work' in your profession?

- ○ Yes
- ◉ No

Do you perform the task 'Finishing work' in your profession?

- ◉ Yes
- ○ No

Do you perform the task 'Reporting flaws' in your profession?

- ◉ Yes
- ○ No

Do you perform the task 'Check-list/forms in your profession?

- ○ Yes
- ◉ No

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Appendix H: Main-questionnaire on web-platform

Technische Universiteit **Eindhoven** University of Technology   GRADUATION RESEARCH TBIKENNISLAB

Part 2: Example choice-experiment

This is an example: When answering **the following 3 question**, imagine performing **'Finishing work'**.

Please read the descriptions in the table carefully and choose the column which matches the best with your preference (select now next).

Finishing work	Paper	Digital	None
Dataformat	2D	3D	
Size canvas	A3	A4	
Integration level	Normal	High	
Speed to access	5 Minutes	5 Minutes	
Updated every	2 Weeks	3 Days	
Your choice	**example**	**example**	**example**

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Technische Universiteit **Eindhoven** University of Technology   GRADUATION RESEARCH TBIKENNISLAB

Part 2: Choice-experiment

Please, read the descriptions in the tabel carefully and choose the column which you find most suitable to your preference, for the **Finishing work**.

Finishing work	Paper	Digital	None
Dataformat	2D	3D	
Size canvas	A3	A4	
Integration level	Normal	Normal	
Speed to access	5 Minutes	1 Minute	
Updated every	2 Weeks	1 Week	
Your choice			

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Appendix H: Main-questionnaire on web-platform

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Part 3: Example choice-experiment

Please, read the descriptions in the tabel carefully and choose the option you find most acceptabel in adopting the new way of working.

	Innovation 1	Innovation 2	None
New dataformat	BIM model	BIM model	
Duration training	0.5 Day	1 Day	
Level of guidance	None	Online-platform	
User interface	Tablet	Helmet	
Used by	Colleague	Foreman	
Your choice	**example**	**example**	**example**

This was an example. We hope you can judge **the next 8 scenarios** based on this explanation.

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Part 3: Choice-experiment

Please, read the descriptions in the tabel carefully and choose the option you find most acceptabel in adopting the new way of working.

	Innovation 1	Innovation 2	None
New dataformat	BIM model	Augmented reality	
Duration training	1 Hour	0.5 Day	
Level of guidance	Online-platform	On-site	
User interface	Helmet	Tablet	
Used by	Colleague	Foreman	
Your choice	○	○	○

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Appendix H: Main-questionnaire on web-platform

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Part 4: Attitude towards technology adoption

In the next questions you will be asked how much you agree with the given statements. Please answer these questions according to your own view.

Technology gives people more control over their daily lives

- Totally disagree
- Disagree
- Neither disagree nor agree
- Agree
- Totally agree

Products and services that use the newest technologies are much more convenient to use

- Totally disagree
- Disagree
- Neither disagree nor agree
- Agree
- Totally agree

You prefer to use the most advanced technology available

- Totally disagree
- Disagree
- Neither disagree nor agree
- Agree
- Totally agree

Technology makes you more efficient in your occupation

- Totally disagree
- Disagree
- Neither disagree nor agree
- Agree
- Totally agree

You feel confident that machines will follow through with what you instructed them to do

- Totally disagree
- Disagree
- Neither disagree nor agree
- Agree
- Totally agree

Appendix H: Main-questionnaire on web-platform

Other people come to you for advice on new technologies

- Totally disagree
- Disagree
- Neither disagree nor agree
- Agree
- Totally agree

In general, you are among the first in your circle of friends to acquire new technology when it appears

- Totally disagree
- Disagree
- Neither disagree nor agree
- Agree
- Totally agree

You can usually figure out new high-tech products and services without help from others

- Totally disagree
- Disagree
- Neither disagree nor agree
- Agree
- Totally agree

You enjoy the challenge of figuring out high-tech gadgets

- Totally disagree
- Disagree
- Neither disagree nor agree
- Agree
- Totally agree

You find you have fewer problems than other people in making technology work for you

- Totally disagree
- Disagree
- Neither disagree nor agree
- Agree
- Totally agree

Please press submit

Thank your for filling in this questionnaire

Previous Submit

ABSTRACT

The Architecture, engineering and construction industry needs to keep up with current developments. Data provision is an important aspect in this. One specific sector is identified to require more attention, namely the construction site. Construction workers get information still mostly in a paper-based format, whereas many other alternatives are possible. These alternatives offer information through a digital interface. Which reduces the risk of outdated or wrong information. In addition, it enables the use of new data formats which can offer more insights into the building process. This has the potential to reduce waste and flaws in this sector. This research aims to identify how new communication technologies aid to innovation on the construction site. By means of literature review and expert interviews a stated choice experiment has been set up which evaluates the preference and acceptance of construction workers regarding data provision. In which data provision consist of the interfaces and data formats which provide information. The data is retrieved by a web-based questionnaire among construction workers. For the analysis estimations are done with both Multinomial and Mixed logit model. Main conclusions from these estimations were that construction workers are less reluctant towards innovation as expected and are more likely to prefer digital interfaces. This would imply that the frequently observed prejudice that this group would be reluctant to accept innovation is unjustified. However, despite there is also a group who is less willing to adopt innovations therefore a phased implementation of a medium such as a tablet is advised. On this interface a combination of both 2D and 3D data formats could be provided.