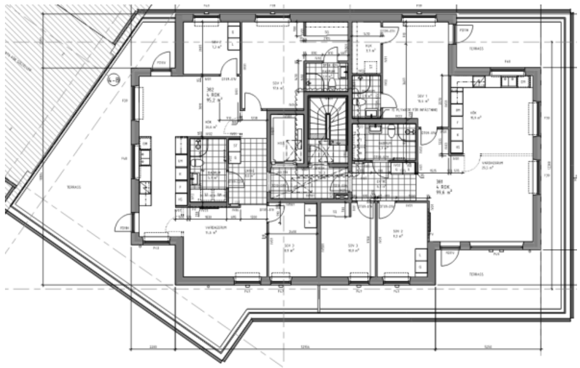

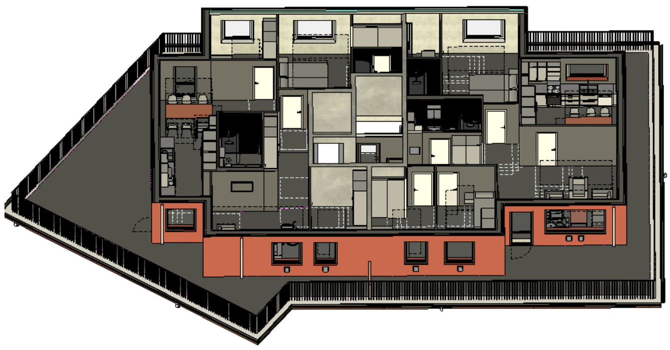

Improving Construction Information Flow

BIM Versus 2D Drawing

Master’s thesis in Design and Construction Project Management

Björn Engman Otréus
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DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2021
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MASTER’S THESIS ACEX30

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BIM versus 2D drawing (Authors' own picture)
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ABSTRACT

In today's construction industry legal construction documents consist of 2D drawings and specifications. These documents include all the construction information that are presented graphically and in text. Construction documents are delivered in separated pages which are linked to each other through symbols and codes. Large-scale construction projects are presented in large number of 2D drawings and specification documents that make it difficult and time consuming to extract necessary information from them in construction processes. On the other hand, BIM models that are emerged during past decades, are introducing new ways of representation of construction information. 3D nature of BIM models along with information windows and different computational features that they provide, make information take-off and quality control quicker and more efficient. But there are big obstacles in the way of making BIM models the main source of information including lack of experience and education and resistance towards change. In addition, the individual and organizational benefits of implementing BIM in the construction projects are never evaluated or clarified. This lack of evaluation along with mentioned obstacles prevent construction industry to develop further towards becoming a total BIM-based industry. In this research, the benefits of using BIM models in construction projects are investigated in detail through literature review, a survey study and a cognitive test. For this matter, a number of 50 professionals from 6 different construction project within a large-scale construction company are investigated in terms of their cognitive perception in using different construction documents. Furthermore, a proposal of applying 2D drawings inside the environment of BIM models is presented and tested on construction professionals. This proposal introduces 2D drawings as complimentary documents for BIM models and investigates how BIM models complemented by 2D drawings, can compensate each other's shortcomings, optimize information flow in construction projects, provide better cognitive perception and encourage professionals to use BIM models as the main source of construction information. Through this investigation, it is aimed to facilitate the way of developing towards total BIM-based construction process for the researched company and following that the construction industry.

Key words: Improving construction documents, BIM, building information management, implementing BIM, cognitive perception of construction information, towards BIM-based construction industry, contiguity principle, mental workload.

Förbättrat Informationsflöde utav Bygghandlingarnas Redovisningsformer

BIM VS. 2D-Ritningar

Examensarbete inom mastersprogrammet organisering och ledning i bygg- och fastighetssektorn

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SAMMANFATTNING

I dagens byggprojekt är det främst beskrivningar med tillhörande 2D-ritningar som står som kontraktshandlingar i ett byggprojekt. Dessa dokument innehåller alla nödvändiga byggdetaljer presenterat i både text och grafisk form. Bygghandlingarna levereras i separata dokument och är länkade med varandra genom symboler, förkortningar och koder. Ett byggprojekt innehåller vanligtvis ett stort antal 2D-ritningar och långa beskrivningar vilket gör det komplicerat och tidskrävande att uppfatta och hämta information. Användningen av BIM-modeller har vuxit fram under de senaste decennierna och introducerar nya sätt att redovisa ett byggprojekt på. Genom BIM-modellens 3D-miljö och tillhörande information, går det enklare och snabbare att uppfatta och tolka information, men den ger även upphov till nya möjligheter. Möjligheter att på ett effektivt sätt genomföra fler och snabbare analyser och simuleringar av hög kvalitet. Dock finns det stora hinder för en implementering av BIM som den huvudsakliga informationsbäraren i ett byggprojekt, hinder så som brist på kunskap, utbildning och förändringsmotstånd. Dessutom har inte implementering av BIM's individuella och organisatoriska fördelar i byggprocessen varken utvärderats eller klarlagts i tillräckligt hög grad. Denna brist på utvärdering, tillsammans med ovannämnda hinder, hindrar byggbranschens transformation mot en Total BIM byggprocess. I detta examensarbete undersöks fördelar och nackdelar utav olika informationsmedium under produktionsfasen i detalj genom en litteraturstudie, en enkätstudie samt ett kognitivt test. Totalt 50 yrkesverksamma från 6 olika byggprojekt hos det undersökta företaget har deltagit i undersökningen. Undersökningen fokuserade på deras kognitiva uppfattning under användning av olika typer av bygghandlingar, så som 2D-ritningar och BIM-modeller. Vidare presenteras och testades ett förslag på en integrering av 2D-ritningar i 3D-miljö ihop med BIM-modellerna. Detta förslag introducerar 2D-ritningar som ett komplement till BIM-modellen och undersöker hur denna kombination utav medium kan kompensera varandras brister, och därmed optimera informationsflödet ur ett kognitivt perspektiv och därtill uppmuntra yrkesverksamma att utöka användningen av BIM-modeller. Genom detta examensarbete syftar författarna till att underlätta transformationen i hopp om att detta kan vara en katalysator på vägen mot en Total BIM-baserad byggprocess åt det undersökta företaget men inte minst, byggbranschen.

Nyckelord: Förbättra bygghandlingar, BIM, byggnadsinformationshantering, implementera BIM, kognitiv uppfattning om bygginformation, mot BIM-baserad byggindustri, anknytningsprincipen, mental arbetsbelastning.

Table of Contents

Table of Figures

Preface

This study is carried out during fall semester 2021 *as* the thesis work of the master's program "Design and construction project management" at Chalmers university of technology and in collaboration with Skanska Hus Göteborg. The literature review and empirical study consisting of a survey study and a cognitive test resulted in valuable findings and conclusions that can help the researched company and following that, the construction industry in the course of facing digitalization through supporting facts. The process and findings of this study also provide us with a helpful experience and a wider knowledge in the field of digitalization and information management within construction industry. It encourages us to take the next steps doubtlessly into our professional lives.

This thesis work is a product of hard work and support. This study could not be carried out without the people who supported us in our investigation. We are so grateful to our supervisors in Skanska, Patrik Johansson and Peter Samuelsson for their supports and helpful advices, and also our supervisor in Chalmers university of technology, Mattias Roupé.

We are also grateful to all of professionals within the field who participated in our survey study and also attended to our cognitive test. Without them it was impossible to improve the validity and accuracy of this study. We also thank the student opponents Karin Hammarqvist and Lovisa Lundblad for their valuable feedbacks on our research work and thesis report.

Gothenburg December 2021

Sam Nemati and Björn Engman Otréus

1 Introduction

This thesis is written in a collaboration with Skanska Sweden and their construction department in Gothenburg, Sweden. Skanska is one of the largest and leading construction companies in Sweden and the world with around 9000 employees in Sweden and almost 35000 employees globally (Skanska, 2021a).

The values of Skanska are to contribute to a sustainable future for their customers and society. They believe that digitalization is a huge part of more efficient construction projects, sparing the environment and to have safer construction sites. Furthermore, they believe that digitalization can create a more equal working environment by letting the employees have access to *the right information in right time*, but also that the employees can benefit from digitalization by reducing demanding work tasks and make time (Skanska, 2021b).

1.1 Background

Efficiency and digitalization are two of the main focus areas in today’s construction industry (Skanska, 2021c; Kulotie, 2020; Hodzic and Vikbrant, 2019). Boverket (2018) has conducted a mapping report of recurring shortcomings and construction quality defects which shows that common issues that affects productivity and efficiency. These issues include lack of time, competence, resources, motivation, and difficulties in communicating a common project goal for the whole project team. Furthermore, the mapping demonstrates that the reasons for shortcomings and quality defects lies within both the design phase and construction phase.

The project teams in construction projects consist of a large number of team members where most are specialists in different areas, such as Architects, Structural engineers, Electrician designers, Electrician labour workers, Plumbers etc (Jongeling, 2008). On the top of it, all disciplines have their own construction documents containing drawings, descriptions and Building Information Models (BIM) to describe how to plan and build the infrastructures (Jongeling, 2008; Leon, van Berlo and Mathijs Natrop, 2015). The large number of different construction documents that are prepared in the design phase and built according to in the construction phase, creates a confusion and difficulties on perceiving information which further leads into a high mental workload of recipients (Jongeling, 2008; Leon, van Berlo and Mathijs Natrop, 2015).

Even though BIM as a concept was mentioned the first time in the 1970’s, the implementation has still not been successful (Eastman, et al., 2018; Babic & Rebolj, 2016). The primary goal of BIM was to combine all drawings from different disciplines into one document. This is still one of the most common uses of BIM today, where the design teams perform coordination and check models for clashes (Jongeling, 2008; Czmoch and Pekala, 2014; Eastman, et al., 2018). Today there is a strong belief that BIM is an important tool to enhance decision making, increase efficiency and quality but also to decrease errors in planning and building (Czmoch and Pekala, 2014). BIM does not only provide same information as 2D drawings, but it also enables more opportunities to facilitate and improve the building process, such as 3D simulations in time (4D BIM), economical simulations (5D BIM), and energy calculations (Jongeling, 2008; Leon, van Berlo and Mathijs Natrop, 2015; Eastman, et al., 2018).

The implementation of BIM in the building process have been studied and investigated for several years (Sundquist et al., 2020). Even though BIM was mentioned and conceptualized a long time ago, studies on implementing BIM shows that there still are several obstacles to overcome, including lack of education, competence, knowledge and resources etc. (Sundquist et al., 2020). In addition, construction projects are also continuously undermining the BIM models by updating 2D drawings much more frequently than the BIM models, even though most 2D drawings are exported from BIM models (Eastman, et al., 2018). Another issue that counteracts the implementation of BIM is legalizing BIM models in contracts. This is highly affecting the perception of the importance and usage of BIM models (Babic & Rebolj, 2016; Czmoch and Pekala, 2014; Eastman, et al., 2018). Furthermore, BIM designing software and designers are not mature enough, thus BIM models are not detailed to completely replace all the 2D drawings (Eastman, et al., 2018). This is due to that object information are often not specified enough and detail levels down to structural details are more difficult to be modelled in 3D than drawn in 2D (Eastman, et al., 2018). Although, other studies have suggested that 3D models can create a better perception of information and higher ability of spatial rotation than 2D drawings (Dadi, Goodrum, et al. 2014). Studies have also claimed that use of 3D models increases motivation and productivity in projects (Jongeling, 2008).

During past few years, the concept of Total BIM projects has been introduced and implemented in construction projects. The most mentioned project in Sweden, executed through this method is Celsius project which is an office and lab building in Uppsala science park. This project is planned, designed and executed based on BIM model as the only information source. The BIM-based design and construction helped this project to be executed under the budget and schedule which demonstrate the strength of building information modelling. Although this project was supposed to be drawing-free, still some electrical and plumbing drawings were produced as supporting documents attached to the BIM model as PDF files (Project Celsius Presentation - Buildingsmart Construction awards, 2020). This combination of 2D drawings and BIM models seems to be necessary in today's construction industry in order to take the first steps into future's total BIM-based industry.

Therefore, this study will contribute to the construction industry with possible solutions to facilitate the transition from 2D drawings to BIM models. This is an attempt to find out which dimension (2D or 3D) is crucial for specific construction information, also to look for parts of construction documents where different dimensions deliver equal information. The expected result was a proposal for reduction of 2D drawings and thereby the amount of construction documents. The possible outcome of the proposal is meant to provide groundworks into a step forward regarding both efficiency and digitalization in the construction industry.

1.2 Aim

Through investigating how construction documents are used and presented in today's construction industry, this thesis aims to analyze the main information lacking in BIM models that can be fulfilled through a combination with traditional design documents. The objective of this thesis is to provide the design and construction teams with a proposal of how the construction information should be presented and used in order to facilitate the construction processes properly for preventing miscommunications and misunderstandings. In this proposal, different construction documents will complete each other instead of presenting the same information in different dimensions.

This thesis also studies the limitations of human mind in perceiving information from traditional construction documents. Furthermore, how traditional documents could be combined with BIM models in order to reduce the mental workload and promote an easier perception of spatial rotation for the recipients. The outcome of this investigation is expected to benefit construction firms, as a compliment to the project information management in a cross-organizational level.

1.3 Research Questions

To fulfill the aim and objective of this thesis, following research question will be taken into consideration:

- How are different information sources being used in today's construction projects?
- What aspects are important to consider for supporting human perception of construction information?
- How can construction information be structured to reduce cognitive workload?

1.4 Delimitations

The empirical study is carried out within the Swedish construction industry, meanwhile the literature study will be conducted with global sources in order to not become limited by lack of data. Furthermore, the study focusses on project management aspects and therefore this study is not aiming to compare different BIM software or go into their details. The reason is that this thesis is investigating on how the information in construction projects are distributed and perceived instead of how the data is created.

Also, the scope of this study is due to the limitation of time and workload, only consider the design and construction phases of construction projects since these are the phases where the contract documents and 3D models are designed and mainly used. Furthermore, the focus group for empirical data will be contractors and subcontractors in the construction phase of construction projects within the studied company. The reason is that these groups are the main stakeholders regarding the use of the construction documents.

Even though a reason for carrying out the study is that BIM models are not considered as legal construction documents yet, this thesis is not aiming to propose new regulations in any case. Instead, this study focusses on introducing a proper combination of BIM models and drawings as a more efficient source of information than the legal construction documents. Following that, even though the outcomes of this thesis can be used as inputs for a new setup for procurement of construction projects, this thesis does not study the procurements directly within its content. Furthermore, the thesis is not aiming to suggest strategies for implementing the presented solutions or organizational change.

1.5 Structure of Thesis

The thesis is developed based on the following structure:

- Chapter 2: The methodology based of which the study is conducted is explained in this chapter. The collecting method of empirical and theoretical data and how they are evaluated are included in this chapter.
- Chapter 3: This chapter presents the theoretical framework which is conducted through a systematic literature review.
- Chapter 4: The results from survey and the cognitive test are presented and analyzed in detail in this chapter.
- Chapter 5: The empirical data and theoretical framework are compared, and related contradictions, similarities and important findings are discussed in this chapter.
- Chapter 6: In this chapter the answers to the research questions based on all findings of the thesis are presented. Suggestions for the investigated company and further research are also presented in this chapter.

2 Method

The method process of this thesis is developed based on an abductive approach, see Figure 1. Furthermore, the empirical study is divided in two parts, a survey and a test. The literature study and the first part of the empirical study are conducted in parallel in order to support a greater perception of the stated problem (Bell, Bryman and Harley, 2019). Also, they were both used and analyzed for conducting the second empirical part, which is a cognitive test with realistic tasks regarding use and perception of construction documents in the construction phase.

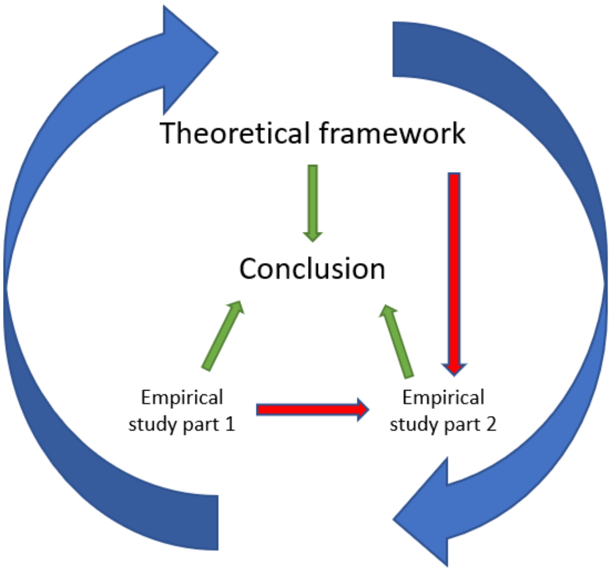


Figure 1 - Visualization of the abductive approach, adapted from Bryman, Bell and Harley (2019) (Authors' own figure)

2.1 Theoretical Approach

The selected literature and the review of them, provide a basis but also enables an analysis of collected data and comparison between theoretical and empirical data (Bryman, Bell and Harley, 2019). The basis of this thesis primary contains of data which are collected from scientific articles, construction industry specified handbooks and construction industry reports. Furthermore, the literature search took place through databases such as Scopus and Google Scholar, but also within the library of Chalmers University (both physical and online). In addition to the literature written within the field of construction industry, literature in the subjects of humans' characteristics in perceiving information were identified, such as *confirmation bias* and the *contiguity principle* due to the benefits of the abductive approach.

To find suitable literature, keywords of the investigated topic were identified through mind mapping and latter elaborated and refined as deeper knowledge and understanding was obtained. Following are sample selections of keywords and sentences*: BIM, Solibri, building information modeling, 2D CAD, 3D CAD, 2D vs 3D, cognitive perception, confirmation bias, human perception of construction, Neuroscience, mental workload, construction documents, BIM model, 2D drawings, from 2D towards 3D, constructability, level of development of BIM, LOD, contiguity* *principle, BIM implementation, design phase, construction phase, 3D recognition memory, 3D representations, perception vs interpretation.*

2.2 Empirical Approach

The first part of the empirical data is a questionnaire related to documentation efficiency in construction projects within the construction phase in the studied company. The questionnaire has primarily answered in the form of a grading scale between 1-5 and is thereby of a quantitative nature. Also, there are a few free-answer following-up questions in order to gain deeper understanding of issues.

The questionnaire was a strategical decision, enabling a faster data collection in order to save time for creating the second part of the empirical study, but also the possibility to reach out to a larger sample group (Bryman, Bell and Harley, 2019). The questionnaire was distributed among six larger construction projects within the areas of both commercial buildings and housing. Furthermore, the focus group were professionals working in these six projects, with roles such as Project managers, Site managers, Supervisors and Labor workers, both employees of the studied company but also subcontractors within the selected construction projects. This decision was taken to involve as many professionals as possible but still manageable for a broad and transparent view and understanding of the end-users of construction documents. The final sample size of respondents in the questionnaire are 50 out of 174 professionals working in these projects. In other words, the sample size of the questionnaire is more than 28% of the investigated population. Although, the purpose of the questionnaire is to determine strong correlations in responses. The results of the questionnaire are analyzed in detail through a grading system and SPSS software. Correlations and means related to gathered data, are carried out carefully and turned into inputs for the cognitive test which is the next step in empirical study of this thesis, but also used in discussion and conclusion.

Through a cognitive testing method, based on the results of the questionary, the level of perceiving information in different parts of construction documents and models are measured. The sample group of the cognitive test is 19 out of 50 professionals who participated in the questionnaire, and covers all different roles from the questionnaire, from project managers to labor workers and subcontractors. The cognitive test also provides qualitative data through analysis of the errors, open questions but also observations of respondents while performing the cognitive test. Furthermore, the cognitive test is created to mimic realistic work tasks and uses of construction documents. Using Solibri Office for the BIM models, as it is a widely used BIM software for on-site personnel, and Bluebeam Revu software for 2D drawings, which is also a widely used 2D drawing software.

To identify the natural advantages and disadvantages of various types of construction documents and dimensions, the questions are the same for various types of information and time limits were added to the questions. Also, a pre-test was performed in order to ensure that the questions fulfill the purpose of this cognitive test, and also to define proper time limits for each question. The final time limits are based on the shortest time duration for answering each question in pre-test session. This decision regarding time limits was made to identify which type of data is more difficult than necessary to retrieve and perceive.

After the practical part of the cognitive test, an interview was performed and documented, inspired by the NASA Task Load Index (TLX) to measure the respondents own perception of workload for performing tasks in various construction documents.

Finally, the results from questionnaire and cognitive test were used and, on some occasions, coded to fit in IBM's software, *Statistical Package for the Social Sciences* (SPSS). IBM SPSS is one of the most used software for analysis of quantitative data and were used to identify strong relationships and trends which enabled a deeper analysis (Bell, Bryman and Harley, 2019).

2.3 Ethical Considerations

There are four ethical principles that are important factors in research according to Bryman, Bell and Harley (2019), *harm of participants, lack of informed consent*, *invasion of privacy* and *deception* and should preferably be overlapping each other in some aspects. Those factors have been thoroughly considered in the empirical part of this thesis.

Both questionnaire and cognitive test are performed out of free will and presented and kept anonymous for everyone except the authors of this thesis. The reason of keeping the respondents anonymous out of this thesis is to keep their information secure which leads to even more honest answers. (Bryman, Bell and Harley, 2019). The decision of not having the respondents anonymous for the authors were due to efficacy reasons in the questionnaire, but also technical reasons in the cognitive test. The efficacy reasons are the possibilities of saving data to reuse it in the comparison analysis between questionnaire and cognitive test.

Within the invitation emails, as were sent as *Blind Carbon Copy*, there were both general information about the questionnaire, but also clear and transparent information that this thesis is written at Chalmers University and in collaboration with Skanska. Furthermore, the Respondents were also briefed regarding the purpose of the empirical parts that they participated in. For example, the focus for the cognitive test is on how well construction information is presented in order to optimize information flow and perception, not evaluating individual skills or knowledge. This clarification is extra important to not stress the respondents and reduce their insecurity of future career prospects (Bryman, Bell and Harley, 2019).

The invasion of privacy was limited to working title, discipline, education, and number of years in the construction industry. This was to enable categorizing of respondents in a general way which was the purpose, as these characteristics are considered in this thesis as enough information to perform an analysis. Also, the studied company is large enough to make it impossible for the reader to recognize the respondents through their response.

2.4 Evaluation of Research Method

The approach of questionnaire and self-constructed cognitive test provides both quantitative and qualitative advantages and disadvantages. Through the questionnaire, it was possible to reach out to a larger sample group then with interviews, but also because it is more convenient for the respondents. The possible disadvantages are that there is no possibility to ask follow-up questions and assist respondents and further explain questions where they don't know what or how to answer (Bryman, Bell and Harley, 2019). To face validity and reduce those issues, the questionnaire was tested on three testing-respondents to identify and clarify unclear questions, but also to identify where free-answer follow-up questions were of interest. The cognitive test enabled deeper understanding through observations and possibilities to interact with the respondents. Although, this qualitative method is challenging through the aspect of subjectiveness (Bryman, Bell and Harley, 2019).

Due to the issue of generalizing results into patterns and conclusions, SPSS was used in order to find correlations which is a measure of relationships between variables (Bryman, Bell and Harley, 2019). The questionnaire is constructed with mostly *Likert scales* and the cognitive test were coded into ones and zeros (correct or incorrect answers) for importing data in SPSS.

The used mix of research methods as described below in Figure 2, is called an *Explanatory sequential design* and enables a process to both explain, but also to elaborate on the results (Bryman, Bell and Harley, 2019). Furthermore, this research design combines and opens for a larger sample group and therefore a broader perspective thanks to the questionnaire, but also the ability to further investigate and elaborate on identified findings through the cognitive test. This process investigates and increases reliability and stability through test-retest and validated through analysis such as identification of correlations and general analysis (Bryman, Bell and Harley, 2019).

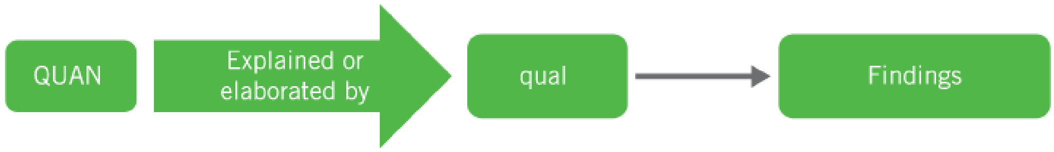


Figure 2 - Exploratory sequential design (Bryman, Bell and Harley, 2019)

Finally, to reduce contaminating influence of the authors biases and values, the questions and structure of this thesis empirical study is added into the appendix for transparency and the possibility of replication (Bryman, Bell and Harley, 2019).

3 Theoretical Framework

In this chapter, based on a systematic literature review, firstly different construction documents in relation with each phase are explained and compared. The construction documents based on this thesis' methodology are divided into 2D drawings, construction specifications and BIM models. Furthermore, the findings are narrowed down to how humans perceive information from different types of construction documents, separately and in combination. As a result, different principles and aspects which are crucial in perceiving information are investigated.

3.1 The Construction Documents

According to Boverket (2020), construction documents are the documents being created in design phase to provide clients, managers and building committee with an overall picture of the building, the static mode of operation, details of spaces and building elements, load conditions and other specifications that serve construction phase.

The building process of a construction project consists of two phases and a large number of different actors and disciplines (Jongeling, 2008; Bergenudd, 2003; Kamari and Pimplikar, 2015). The first phase is the design phase in which the design team starts with conceptualizing the customers' ideas and speculations into primary documents such as physical models, drawings and technical specifications (Freire and Alarcón, 2002). In order to prepare architectural design and specifications, client assigns an architect. When the architectural design is ready, technical designs such as structural design, ventilations, electrical specifications etc, are being developed (Alarcon and Mardones, 1998). Bergenudd (2003) describes the purpose of the first phase (design phase) in the building process to determinate and plan the future infrastructure. Furthermore, the determination and planning will be developed into several types of construction documents, such as 2D drawings, Building Information Modelling (BIM) models and project descriptions, see Figure 3 (Bergenudd, 2003; Jongeling, 2008). 2D drawings are traditionally the legal documents with spatial and technical communication in the project even though BIM models are presenting the 3rd dimension in a move convenient way (Dadi, Taylor, et al., 2014). Dadi, Taylor et al. (2014) further writes that BIM models opens new possibilities due to the possibility of attaching object specific information to building elements that can be added for various calculations and simulations.

Figure 3 - Representation of the same floor level in 2D drawing and BIM model (Authors' own image)

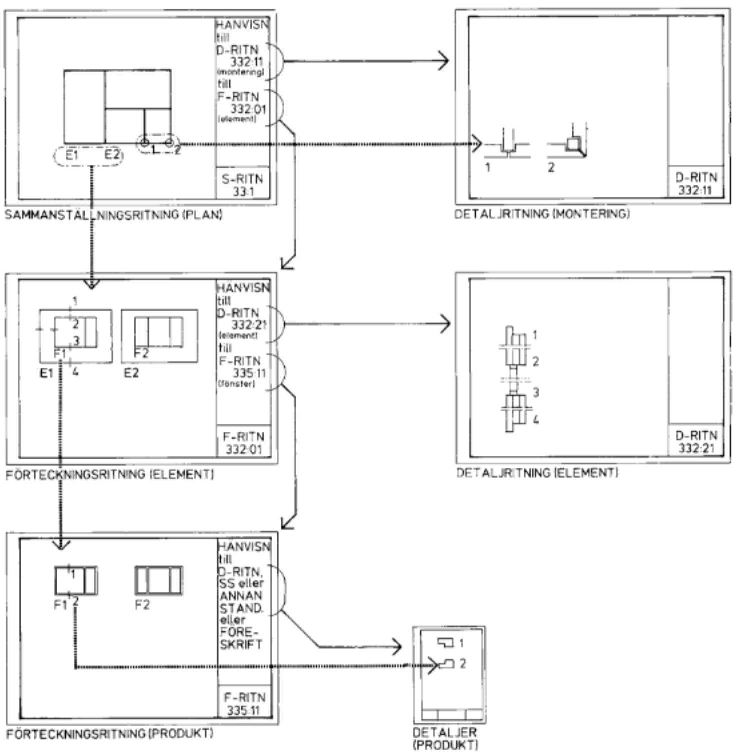
The second phase is the *construction phase* where the construction documents are used and refined into an infrastructure (Jongeling, 2008; Bergenudd, 2003). The construction phase, the same as the design phase, consists of many different actors and disciplines who work together in order to achieve the same end product although they have different economical goals (Jongeling, 2008). Boverkets report (2018) draw conclusion that one reason of low efficiency, takes place when the contracts are divided into subcontracts. The reason is that subcontractors mainly focus on their own parts of the project while their related construction documents are specified through their particular contracts. This tunnel vision reduces the comprehensive perception of the project and will easily lead into issues and errors. According to a study of Jongeling (2008), short comings in coordination and misinterpretations of construction documents are common problems that needs to be resolved on the construction site and will often result into 5-10% additional costs of project. These errors derive from the design phase due to shortcomings in coordination and misinterpretations and will also affect the working environment on construction site negatively. Other commonly reasons of shortcomings and errors in the production process are lacking competence, motivation and new untested structural methods (Boverket 2018) which in combination with stressed time schedule, cause errors and makes it difficult to deliver infrastructures with right quality within the time schedule and the financial budget (Boverket 2018; Jongeling 2008). Although, first phase should be accomplished before starting the second phase, building processes of today often have the design phase ongoing parallel with construction phase. As a result, the design documents are not completed when the construction phase is started (Jongeling, 2008).

Through a study conducted by Boverket (2018), it is shown that many problems can be avoided in construction phase when the design is well-executed. It is also shown that in the Swedish construction industry, one of the main reasons of time inefficiencies and cost pressures is connected to design phase. Design failures mostly happen because designers are far from construction phase and not aware of how the production is been executed on the project sites. Construction stage is a separated phase executed by contractors which are, in most cases, assigned separately by the clients (Alarcon and Mardones, 1998). This separation causes difficulties in communication and information management between different sectors. All these issues are transmitting to construction process through construction documents produced in design phase. Bergenudd (2003) entitles construction documents as a way of communication between the design and construction phases. He further points out the importance of standardized, simplified, and appropriate information in construction documents to easily be perceived correctly. Even though construction documents should be easy to perceive, they are aimed at professionals (Bergenudd, 2003; Lam, Kumaraswamy and Ng, 2001).

3.1.1 2D Representation of Construction Information

2D drawings and how to use and develop them by the help of lines and symbols started thousands of years ago in ancient Egypt and partly Greece (Babic & Rebolj, 2016). These 2D drawings were used for presentations, visualizations and also an analytical tool through the process of design and communication. Drawings were being developed by the social role of architects and builders and cooperation between them (Babic & Rebolj, 2016). This shows the deep effect of social connection in developing the methods of design, presentation and visualization.

In today's construction industry and specifically in Sweden, 2D drawings are primary communication tool between design and production teams, and the legal source of construction information (Jongeling, 2008). This legal information source, which is provided by the design team and presented to construction sector is divided into different 2D views by a discipline-specific approach followed by specified descriptions (Boverket, 2018). Different views of the construction projects are presented in floor plans, sections, elevations and details (see Figure 4) (Boverket, 2018). Several drawings are usually needed for showing a complete presentation of a part of the construction project. It is due to the need of different actors to develop a complete understanding of the project, based on the discipline they are responsible for (Jongeling, 2008). Drawings are presented in different scales and by precise dimensions. They refer to other drawings in order to simplify the information flow and common understanding of the project (Jongeling, 2008). There is another type of standard 2D drawings called isometric views which incorporate three dimensional visualizations mostly coordinated in 45^0 and 90^0 (Dadi, Taylor et al, 2014). These types of drawings are often used for the mechanical, electrical and plumbing representations of building documentations which gives the specific actors information about e.g. the type of bend needed for the pipe run (Dadi, Taylor et al, 2014).



5.52g Hänvisningsgång mellan sammanställnings-, förtecknings- och detaljritningar vid redovisning av ytterväggselement. Se även Del 1.(Ritningsnummer enligt tidigare tillämpning)

Figure 4 - Schematic mapping of different drawings and their relations (Hertzell and Bergenudd, 2003)

There are both advantages and disadvantages to these type of documentation in construction industry. 2D drawings are been applied to the organizations and construction projects for many years and all actors are familiar with them. They are also cheap to produce since they have been the main way of documenting the design information for so long (Czmoch and Pekala, 2014). Since construction drawings are the legal construction documents, there are mandatory requirements attached to these documents, including defined accurate dimensions (height, length, width and distance) (Bergenudd, 2003).

On the other hand, in the 2D-based construction projects, it is normal to expect large differences between final drawings and schematic or conceptual documents. It happens mostly because of different interpretation that schematic drawings provide for different individuals through the design process (Czmoch & Pękala, 2014). Other disadvantages of 2D approach in documenting information is that cost, energy and climate analysis need to be done manually, the same as how it is done for many years. This results in long working times, human errors, reworks, logistic problems and inaccurate quantities. It also makes up a non-modern image for the companies who work in this way (Jongeling, 2008).

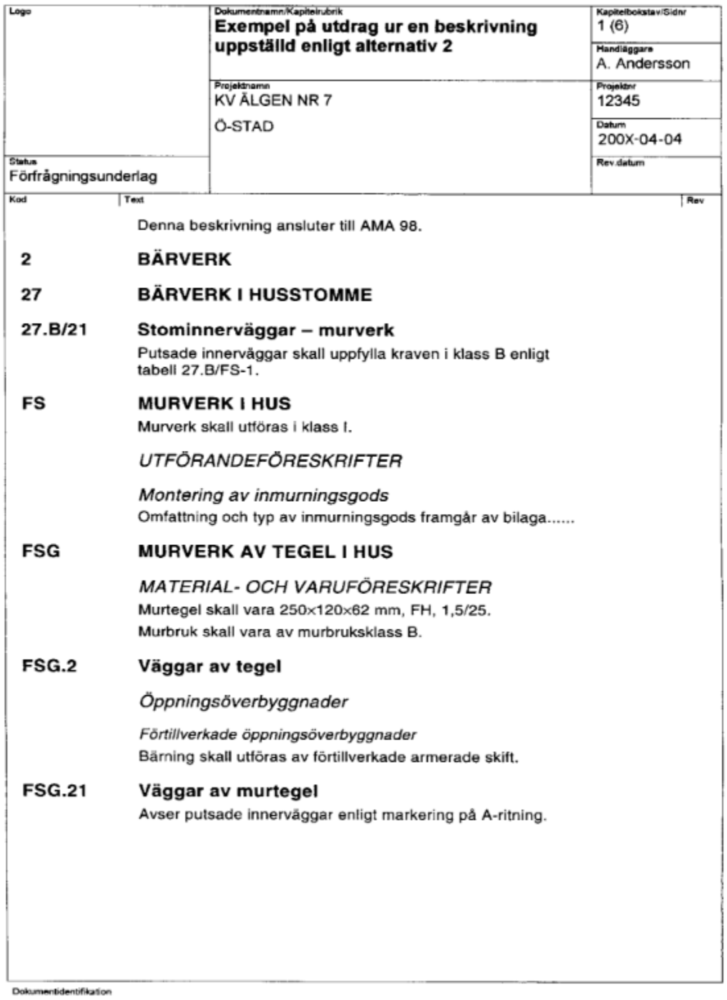
In addition to disadvantages that drawing cause for the design team, there are several issues with 2D drawings in construction phase. 2D drawings consist of lines and symbols which can be interpreted by only a limited number of actors (Jongeling, 2008). In other word, the understanding level that design team presents through 2D documents is limited which leads to wrong interpretations and coordination problems further in construction phase (Babic & Rebolj, 2016). This results in uncertainties that every stakeholder may not interpret the 2D drawings in the same way, but also that all stakeholders may not be able to participate in the decision-making as much as they need or want to (Jongeling, 2008).

There are so many other mistakes that are promoted through 2D construction drawings. These mistakes can be very small, like not using the right scale label on the 2D drawing, or they can be huge, like inconsistent information or poor details in junctions (Designing Buildings Ltd, 2020a). But in both cases these mistakes can result in large scale reworks and huge changes in budget and time schedule.

There are so many different PDF reader and CAD-programs for working with 2D drawings which cover all the activities from drawing them in design phase to read them in construction phase. Bluebeam Revu is the program used in construction phase in most of construction firms in Sweden including the researched company (Deigert et al. 2020). This software is a 2D collaboration platform in interdisciplinary organizations and comes along other document management tools such as Procore, BIM 360, PlanGrid etc. Bluebeam Revu increases the communication efficiency and provides a paperless communication platform in design and construction. Bluebeam Revu is also one of the computer programs that make it possible to link the drawing to each other and facilitate the navigation between large number of drawings and specification documents (Deigert et al. 2020).

3.1.2 Construction Specification Documents

The necessary written information for the construction phase of a facility, is developed by engineers and architects (Rosen & Heineman, 1990). This written document is called specifications and they are a part of contract documents. Specifications are mainly requirements of equipment, system standards, materials and workmanships, see Figure 5 (Rosen & Heineman, 1990). Construction specifications is the main source of communicating procedures and quality standards between the design and construction teams, thus the documents are supposed to complete drawings by clearing out ambiguities (Lam, Kumaraswamy and Ng, 2001). Construction specifications should contain the clients’ requirements and also fit the purpose with right information and well-balanced details. Well conducted construction specifications can save both time and money and otherwise lead to miscommunication and result into rework and possible disputes (Lam, Kumaraswamy and Ng, 2001).


Logo

Dokumentnamn/Kapitelrubrik
Exempel på utdrag ur en beskrivning uppställd enligt alternativ 2

Kapitelbokstav/Sidnr
1 (6)

Handläggare
A. Andersson

Projektnamn
KV ÄLGEN NR 7
Ö-STAD

Projektnr
12345

Datum
200X-04-04

Status
Förfrågningsunderlag

Rev.datum

Kod	Text	Rev
	Denna beskrivning ansluter till AMA 98.	
2	**BÄRVERK**	
27	**BÄRVERK I HUSSTOMME**	
27.B/21	**Stominnerväggar – murverk** Putsade innerväggar skall uppfylla kraven i klass B enligt tabell 27.B/FS-1.	
FS	**MURVERK I HUS** Murverk skall utföras i klass I. *UTFÖRANDEFÖRESKRIFTER* *Montering av inmurningsgods* Omfattning och typ av inmurningsgods framgår av bilaga......	
FSG	**MURVERK AV TEGEL I HUS** *MATERIAL- OCH VARUFÖRESKRIFTER* Murtegel skall vara 250×120×62 mm, FH, 1,5/25. Murbruk skall vara av murbruksklass B.	
FSG.2	**Väggar av tegel** *Öppningsöverbyggnader* *Förtillverkade öppningsöverbyggnader* Bärning skall utföras av förtillverkade armerade skift.	
FSG.21	**Väggar av murtegel** Avser putsade innerväggar enligt markering på A-ritning.	

Dokumentidentifikation

2.31b Exempel på utdrag ur en beskrivning.

Figure 5 - An excerpt from a construction specifications example (Bergenudd, 2003)

Since most of specifications are written in design phase, the separation between design and construction phases can affect the performance of the specification documents (Bröchner and Silfwerbrand, 2019). The development of detailed specification into performance specification is a long and complicated process which can take place rather bottom-up or top-down. In today’s construction industry this transition takes place mostly bottom-up, which starts from already existing detail specifications and analyzing them and continues with turning them into formulations of construction performances (Bröchner and Silfwerbrand, 2019). Top-down transition starts from specifying the main performances and broad requirements and continues with creating or defining the needed details. This approach is considered ambitious in today's industry. Description and specifications can be extended to detailed collaboration descriptions, logistics information, detailed cost estimations etc (Bröchner and Silfwerbrand, 2019). In order to achieve right relationship between specifications and drawings, it is important that developing specification take place hand-in-hand with producing drawings, which needs the whole design sector to be coordinated in this process. But what makes specifications hard to execute is lack of coordination between design and construction sectors (Rosen & Heineman, 1990).

The construction projects produce and specifies a large number of different construction documents of which a large part is unusable due to either too technical language or over / under-specified specifications (Lam, Kumaraswamy and Ng, 2001). Technical language relies on the construction team to have competence for interpreting the descriptions and specifications (Lam, Kumaraswamy and Ng, 2001) although construction teams are often consisting of unexperienced site management (Boverket, 2018). Over-specified specifications will reduce readability due to lengthy text, inconsistency and repetitions that cause more confusion than facilitate (Lam, Kumaraswamy and Ng, 2001). One reason for over-specified specifications are the variability of contractors' competence and onsite prerequisites.

Even though some construction projects are of similar characteristics, the construction specifications can vary widely in consistency, level of details and structure of the information provided (Lam, Kumaraswamy and Ng, 2001). A commonly used phrase when specifying products by consultants is "specific product or equally", this can easily lead into disputes between the client and the contractor due to different interpretations of equally products (Lam, Kumaraswamy and Ng, 2001). Another issue of vague descriptions is the encouragement of innovation, this results into unspecified descriptions but with end requirement properties, this flexibility further leaves the contractor with mandate of how to build as long as the end result fulfils the requirements (Lam, Kumaraswamy and Ng, 2001).

3.1.3 Building Information Modelling

Models based on building information management, known as BIM models, are object-oriented 3D models which contain information about the products, the construction process etc (Jongeling, 2008). By the help of BIM models several 3D models of a project from different disciplines can be combined in one model which contains all needed information for construction stage. The main use of BIM models in today's Architecture, Engineering and Construction (AEC) industry is rationalizing construction operations and streamlines in addition to sharing information between different actors (Jongeling, 2008).

By implementing BIM methods, all the information created in design phase can be integrated in one 3-dimensional information source. Following that, inter-disciplinary coordination can be simplified (Czmoch & Pękala, 2014). In addition, updating the projects for new changes can become a lot faster. BIM models by the help of BIM-based computer programs also provide efficient clash detection, information take-off, cost estimation etc (Czmoch & Pękala, 2014). Since all the information is tied to gather, one change can cause all necessary changes in the whole model. BIM models can easily provide the materials needed for visualizations and make this process cheaper and faster, however they cannot provide live changes while the model is updated (Jongeling, 2008).

There are different degrees of implementing BIM in a construction project based on how much information is imported into the model. Some of the information elaborated in a BIM model is for the use of all actors but some of them is completely discipline specific (Jongeling, 2008; Leon, van Berlo and Mathijs Natron, 2015). Lack of developed working methods inside organizations and also shortcomings of file formats are two main obstacles which prevent all information to be integrated in a BIM model. In addition, there are also technical and strategic reasons which result in only a fraction of information being imported into BIM models (Jongeling, 2008).

But there are not only obstacles that result in summarized BIM information. A part of the information management is providing just enough information for controlling the quality and quantity of the materials and also efficient communication between clients and the organization without making unnecessary complications (Latiffi et al. 2015). Level of development (LOD) is a classification system referring to how much information is supposed to be included in a BIM model based on procurement, inner organizational regulations and clarification of all project processes. Different LOD levels can be described as the list below and illustrated in Figure 6 (Latiffi et al. 2015):

- **LOD 100** “The Model Element may be graphically represented in the Model with a symbol or other generic representation, but does not satisfy the requirements for LOD 200. Information related to the Model Element (i.e. cost per square foot, tonnage of HVAC, etc.) can be derived from other Model Elements.”
- **LOD 200** “The model element is graphically represented within the model as a generic system, object or assembly with approximate quantities, size, shape, location and orientation. Non-graphic information may also be attached to the Model Element.”
- **LOD 300** “The model element is graphically represented within the model as a specific system, object or assembly in terms of quantity, size, shape, location and orientation. Non-graphic information may also be attached to the Model Element.”
- **LOD 350** “The model element is graphically represented within the model as a specific system, object or assembly and interfaces with other building systems. Non-graphic information may also be attached to the Model Element.”

- **LOD 400** “The model element is graphically represented within the model as a specific system with detailing, fabrication, assembly and installation information. Non-graphic information may also be attached to the Model Element.”
- **LOD 500** “The model element a field verified representation in terms of size, shape, location, quantity and orientation. Non-graphic information may also be attached to the Model Element.”

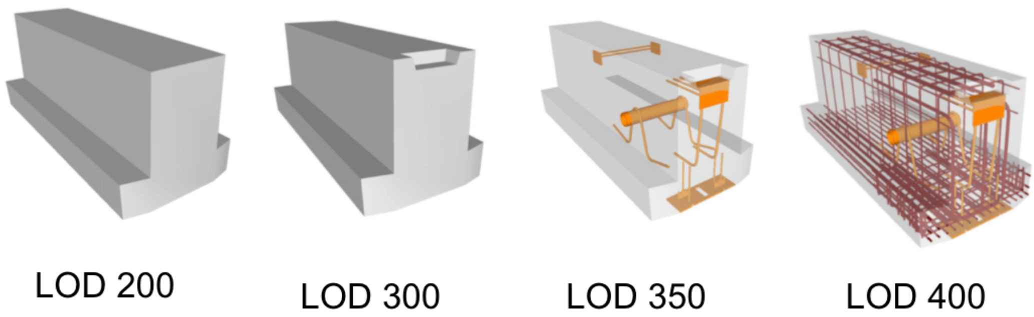


Figure 6 - Illustration of geometric detail progression of different LOD levels (Grani, 2016)

The ability to use BIM models and visualise the infrastructures are a prerequisite in the today’s construction projects (Jongeling, 2008). The use of BIM models is also shown to be more motivational and inspiring than the traditional construction documents using 2D drawings. Jongeling (2008) further says that the quality of information take offs becomes more accurate and reduces around 50% of the time for doing information take offs. Although that data retrieval gets higher quality, it sets high demand on good quality regarding which and how information is set in the BIM models.

The basis of BIM models is that they reveal same information as 2D drawings, but Jongeling (2008) also indicates that the basis of BIM models opens up more opportunities than that (Leon, van Berlo, Mathijs Natron, 2015; Jongeling, 2008). For example, BIM models can be used for powerful analyses such as 4D and 5D simulations (Jongeling, 2008; Dadi, Taylor et al., 2014). 4D BIM are simulations of the time schedule and gives the possibility to visually analyse and improve the planning of construction progress (Dadi, Taylor, et al., 2014). In the case of 5D BIM simulations, economic analysis and cost estimations are added to the BIM models as the 5th dimension. These extra dimensions in BIM models can improve accuracy and following that efficiency of the projects (Lee et al., 2020). They also can enhance the decision making and coordination between different stakeholders in a construction project. These advantages never can achieve in 2D CAD workflow. Adding these extra dimensions is an additional function empowered by building information management, which can reduce technical errors and miscommunications significantly (Lee et al., 2020).

On the other hand, there are some disadvantages related to working with BIM methods. In order to create a well-functioning model, long working hours and expensive hardware are needed. Skill of the team who are working with BIM model also stands as a higher degree of importance in comparison with traditional methods (Czmoch & Pękala, 2014). Human error can also have a larger effect on the whole project. Smallest mistakes and miscalculations can result in major problems and complication (Czmoch & Pękala, 2014). On the other hand, BIM models are not legal construction documents which causes them to be considered as less important material which leads to not completed models and misunderstandings on the investor-designer-executor line (Czmoch & Pękala, 2014). The other disadvantages with use of BIM models are that hardware isn't good enough for high detailed BIM models, but also the user interface of BIM software is often customized for professionals and not easy enough for everyone to use (Jongeling, 2008).

In addition, implementing BIM to a construction project on an advanced level, needs a proper BIM execution plan in order to avoid risk of unnecessary complexities in the model and consequently, in construction process (Azhar, 2011). For conducting a proper execution plan, the design team and representatives from other attending disciplines coordinate to define a holistic vision and a detailed plan for developing the BIM model for all phases of the project (Azhar, 2011). Architects and technical consultants believe that they spend longer working hours for making BIM models and filling them up by necessary information in comparison with 2D drawings. It is also needed to work more closely and integrated with other disciplines during the design process when a BIM model is integrated into the project (Jongeling, 2008).

There are some computer programs for designing and supporting the modelling process of the BIM models such as Autodesk Revit (Liu & Issa, 2014). These programs provide the modelling possibility in a 3D environment and also possibility for exporting the models in so many different formats for different aims. For exporting the 3D models in BIM-directed goals the most regular format is IFC format which provide the possibility of transmitting all the elements' information written in different layers of 3D-CAD program to a BIM model able to be used in different platforms. One of these platforms is Solibri which is known as an efficient IFC optimizer and BIM model checker. Solibri makes a lot of different uses of the model possible, including clash control, information take-off, rules' check, measurements etc. Solibri and other BIM-reader programs make it possible to use the BIM model in construction phase (Liu & Issa, 2014).

3.1.4 Various Information Mediums in the Construction Phase

The flow of information between design and construction phases is defined by the term *Constructability,* where constructability is defined by Kazaz et al. (2017) as "*The effective and timely integration of construction knowledge into the conceptual planning, design, construction, and field operations of a project to achieve the overall project objectives in the best possible time and accuracy at the most cost-effective levels.*". Thus, if the input data for the design phase is difficult to perceive, the constructability of construction documents in construction phase will be complicated to interpret (Kazaz et al., 2017). Furthermore, the flow of information is a one-way flow, where the recipients decode the information with individual interpretation (Dadi, Taylor, et al., 2014). Thus, the construction documents and which medium to use, should be considered carefully and designed with focus of facilitating the recipients in order to reduce potential noise in the flow of information (Dadi, Taylor, et al., 2014). Hence, it is important to have discussions and get feedback from the users of construction documents to improve its' readability and perception (Lam, Kumaraswamy and Ng, 2001).

In a study done by Santos and Ferreira (2010) the efficiency of 2D and 3D information sources in construction industry was compared (see Figure 7). This study investigated the whole 3D and 2D design process and error correction after the design is done and construction phase is started. This analysis showed that 3D design process is 30 % more time efficient and only a negligible fraction of the correction process is devoted to non-value-adding activities, while in the case of 2D documentations and corrections, this number is more than one third of all activities which goes against Lean Thinking.

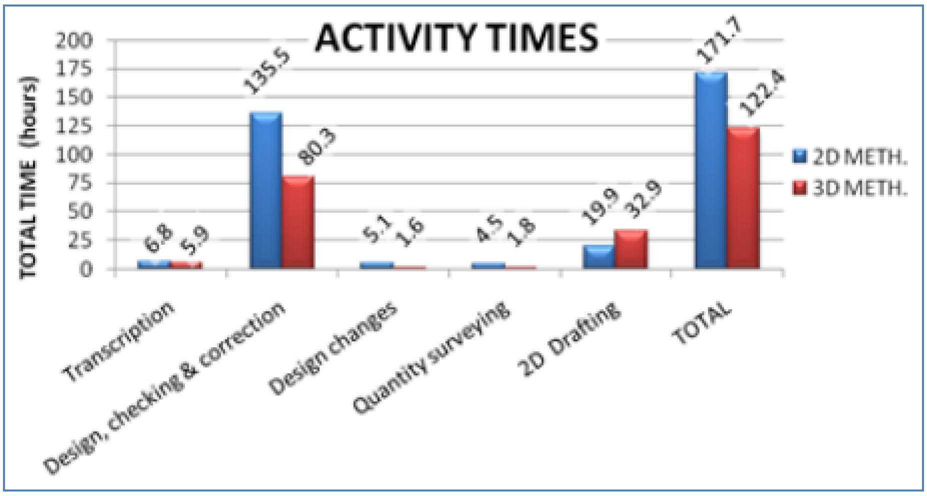


Figure 7 - Total time for generic / aggregated activities for 2D and 3D methods (Santos and Ferreira, 2010)

Abstract nature of 2D representations makes them more time consuming to be interpreted that results in more errors which take time to be corrected (Santos & Ferreira, 2010). On the other hand, quantity surveying is supported by most of 3D/BIM software and design changes are more straight and less time consuming (Santos & Ferreira, 2010).

Many professionals believe that there are many interferences and overlapping elements in BIM or any kind of 3D model which makes it harder to use. Santos and Ferreira (2010) indicate based on their study that 3D models have the potential to clarify these interferences which are not understood or even predicted in 2D documentations of building elements. It is why in most projects which are documented only in 2D, these interferences appear in construction phase and not design process, which cost a lot of money, time and energy to correct them. Santos and Ferreira (2010) also point out that most of the mentioned interferences in 3D models take place when information is being modeled from 2D drawings and these problems were not predicted in 2D documents.

3.2 Human Perception and Construction Information

There is a mental process taking place while humans are acquiring information through experience and human senses. This process is called cognition. In human brain, cognition is followed by the ability of understanding, storing and even reacting to the information in the brain. This ability is known as perception (Norenzayan et al. 2007).

The world that we live in is three-dimensional and we perceive it as 3D since the first day we open our eyes. But we learn to perceive 2D representations of our world such as pictures and maps through time (Groen and Baker, 2019). In this chapter a literature review is conducted in order to investigate how different it is to perceive information from these two dimensionally different representations. The investigation cover from the basic human perception of these two dimensions to how we perceive construction documents in different representations and the cognition process which leads to that perception (2D and BIM). The findings are achieved from different fields of science.

3.2.1 Cognitive Workload and Spatial Perception

Insufficient or improper delivery of information will, to a large extent, affect the work productivity, thus the delivery and management of construction documents are impacted of the efficiency and productivity in construction projects (Dadi, Goodrum, et al., 2014). Furthermore, the spatial design of infrastructures is communicated through both two-dimensional drawings and three-dimensional models. Also, the different dimensions demand different amount of cognitive workload from the end user due to professional experience and spatial ability (Dadi, Goodrum, et al., 2014).

The number of mental resources used for interpreting and perceiving the information when completing a task are called *Mental workload* (Hart, 2006). Mental workload is of large concern related to fields of psychology within performance and error rates (Dadi, Goodrum, et al., 2014). When performing a task, the mental workload should be balanced. Too high workload can reduce the performance, meanwhile too low workload will lead to difficulties to focus (Dadi, Goodrum, et al., 2014).

One category when measuring mental workload is the subjective measures which is nonintrusive. Measuring mental workload through a nonintrusive approach can be achieved by subjective measurements and are often performed after completion of a task (Dadi, Goodrum, et al., 2014). One of the most used tools for administration and interpretation of mental workload within nonintrusive approach is *NASAs' Task Load Index* (NASA-TLX) (Hart, 2006; Dadi, Goodrum, et al., 2014). The NASA-TLX is a multidimensional scale which asks the task operator to answer by self-evaluating six variables in order to subjectively measure the mental workload after completed a task (Hart, 2006). Dadi, Goodrum et al. (2014) describes them as following:

- *Mental* demand is subjectively measuring of the degree of difficulty of the task.
- *Physical* demand measures how strenuous the task is.
- *Temporal* demand which measures the rate subjective pace of completing the task.

- *Frustration* experienced when performing the task, if the operator felt stressed or irritated. *Effort* put for completing the task, how hard the operator had to work for completing the task.
- And finally experienced *performance* by grading how successful and satisfied the operator think he / she was when performing the task

A cognitive task experiment performed by Dadi, Goodrum, et al. (2014) was conducted by asking the participants to assemble a model provided with different common construction spatial designs, such as a physical 3D printed model, a BIM model and 2D drawings (see Figure 8). The Spatial designs was provided in different sequences to investigate different learnings curves. The experiment showed that highest experienced subjective workload performance was when the operator was firstly provided with the physical 3D printed model, then BIM model and lastly the 2D drawing. The experiment also showed that the sequence with lowest subjective performance was when provided with the sequence of 2D drawing, BIM model and lastly physical 3D printed model. Furthermore, several demographical factors were identified in this test which affected the subjective workload of experiment operators. Factors of interest were frequency of field experience that required use of drawings, CAD design experience, degree of education and construction industry experience. This study concluded that use of BIM models for spatial representation can result in significant performance improvements when considering cognitive demands. The conclusion is due to that it is easier for the practitioners to create a better mental image of the end product but also facilitate stepwise break down of the infrastructure.

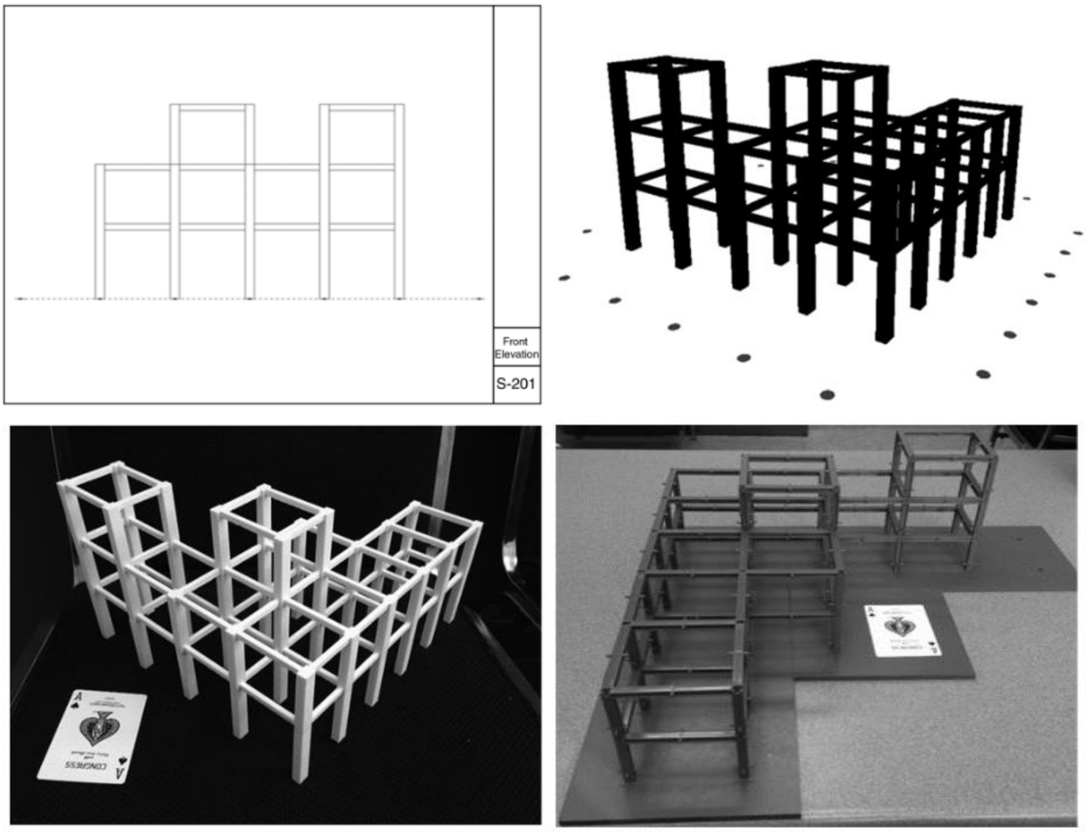


Figure 8 - 2D drawing, 3D model, 3D printed model and Scale-model of Cognitive task experiment (Dadi, Goodrum, et al., 2014)

3.2.2 Comparison of Perception in 2D and 3D Representations

In the field of neuroscience, so many experiments have been conducted in order to compare brain's ability in perceiving information from different types of information sources.

In order to compare the brain's perception of 2D and 3D information representation, highly complex visual scenes consist of 3D objects in 3D backgrounds were generated (Groen and Baker, 2019). Then participants were shown short movies of navigating in these scenes and FMRI (Functional magnetic resonance imaging) responses in three scene-selective regions of their brain was measured (Groen and Baker, 2019). The same test was conducted by showing the participants a navigation movie of a 2D low-level representation of a scene. The activity of Scene-selective areas of their brain such as PPA (parahippocampal place area) and OPA (occipital place area) was higher with more variances when the 3D movie representations were shown in comparison with the 2D representations (Groen and Baker, 2019). It is interpreted by the authors that the perception of 3D scenes was taking place faster and closer to real life experience, than 2D representations.

In another study conducted by Snow et al. (2014) in the field of Neuroscience, a series of real objects, 2d realistic images and 2d black and white line drawings were shown shortly to a group of 72 second year psychology students. Thereafter, they were asked to recall the objects that they could remember. The results demonstrate that the number of real-life 3d objects which were being memorized by participant were significantly higher than 2d images and line drawings. While there was not a big difference between color images and line drawings. It can point out that the 3d perception of real-life objects which we are grown up with is a lot stronger than image perception which we started to get familiar with in childhood and developed an understanding of it through time (Snow et al. 2014).

3.2.3 Contiguity Principle

Traditional construction documents consist of specifications, 2D drawings and written descriptions. Usually, these written descriptions are included in the drawing which can provide the reader with necessary information about different parts of the drawing (Designing Buildings Ltd, 2020b). This information includes abbreviations, numbers, basic symbols, scales, units etc. This information is not always easy to perceive, especially in the case of abbreviations. The main reason is mostly that the information is not structured and associated with the drawings properly because of enormous amount of texts, numbers and symbols required for a drawing illustrated in Figure 9 (Designing Buildings Ltd, 2020b). According to Holsavana et al. (2009), graphical materials which are provided together with their written descriptions in an unclear relationship, need to be linked consciously to the descriptions by the reader while being read. As a result, it can be difficult for the reader to grasp the information and keep concentrating on the documents consistently.

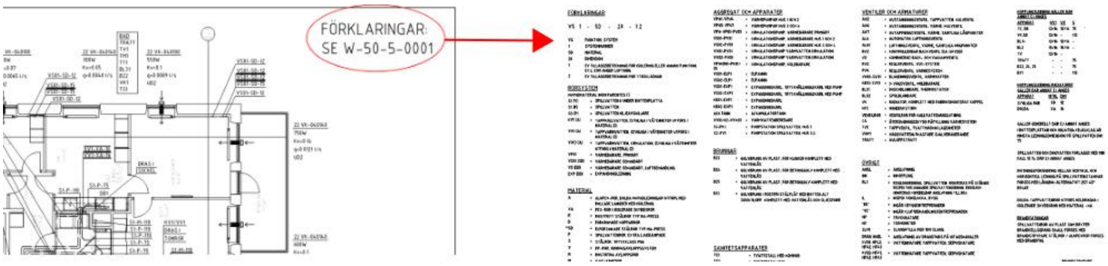


Figure 9 - Plumbing drawing and its related explanatory drawing (Authors' own image)

On the other hand, as it is mentioned before in this paper, construction specifications which are provided by the design team, come usually as long written descriptions located in separated pages from drawings. Holsanova et al. (2009) indicates that when text and graphics are separated from each other readers mostly interpret them as two self-contained sources of information. So, the whole material can be difficult to perceive. Accordingly, they choose one of them (the information graphic) and ignore the other one (the text) and they do it subconsciously. It can be interpreted that it is easier to ignore nonintegrated than integrated material.

In the separated format, readers mostly interpret the two sources of information as self-contained. But if the material is pre-processed and spatially structured, the text-picture integration makes the material easy to grasp and in addition to catching the reader's attention, it can sustain their interest (Holsanova et al, 2009).

3.2.4 Confirmation bias

Confirmation bias is a state of human behavior in which individuals, or a community subconsciously tend to search, perceive or even interpret information which support their prior beliefs (Nickerson and Raymond, 1998). It can include even selective attention. In this case individual or the community choose to pay attention to the information that is more familiar or supports prior knowledge and perceptions. All human beings have resistance to change in their nature, however they do not react in the same manner to this natural resistance (Davis and Songer, 2002).

Bias in not accepting new technologies or ways of working is also a very regular type of confirmation bias. It happens that experts in a field do not pay enough attention to new technologies or methods which effect their ways of working (Elsbach & Stigliani, 2020). It comes mostly from the fear of large changes which effect the whole routine of professions. New technologies and methods seem to be interpreted as complex, difficult to perceive and time consuming to learn. In a study conducted by Hultman (1998) the common reason for resistance towards change is described as lack of any incentive for change. So, there is not enough motivation to take the course of change among employees of an organization most of the times. Hultman (1998) emphasizes lack of confident among individuals towards change, because they cannot be completely sure that change can be successful and in most of the times change sounds harmful and needs the individual to come out of their comfort zone (Hultman, 1998).

One of the most important challenges in construction industry during the past decade is implementing BIM as a new technology or method of working in different stages of the building process. Resistance toward BIM is keeping professionals and even organizations from implementing BIM in their working processes (Gustavsson & Vass, 2017). Organizations do not see enough economic benefits in changing their work method. Individuals also feels it necessary to educate themselves in the field of building information modeling and they also do not see enough benefit in doing so. On the other hand, there is not enough research and information to support the fact that implementing BIM and developing the industry towards more digitalization is beneficial both individually and organizationally (Gustavsson & Vass, 2017).

Gustavsson and Vass (2017) propose that for accelerating the implementation of BIM in construction industry in Sweden, public client, which is the most influential in Swedish AEC industry, need to change its business value model to more BIM based procurements.

Davies and Harty (2013) on the other hand, propose that for make it possible to benefit from BIM in construction industry, change agents need to try to align today's ways of working with tools that BIM provides. This change process should be slow and continuous. They also emphasize that what promotes resistance towards BIM is the perception that proposes the whole AEC industry should have a sudden change towards implementation of BIM.

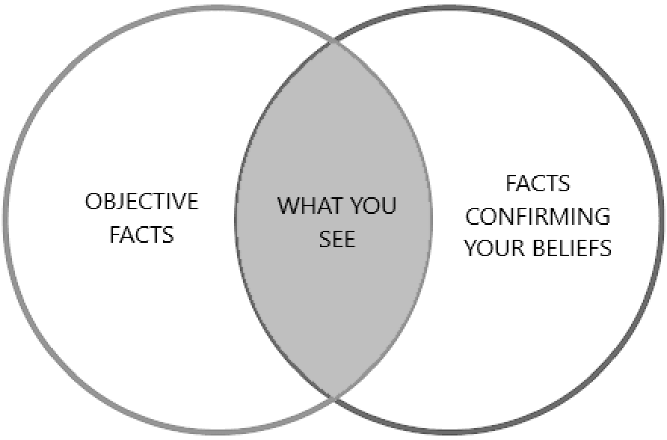


Figure 10 - Illustration of confirmation bias (Aghdaei and Tabrizi, 2021)

4 Empirical Results and Analysis

In this chapter the empirical study and its findings are presented and analysed. Empirical study is divided into two separated but connected parts. First a questionnaire was distributed to 174 professionals who work in six different construction projects procured by the researched company. 50 professionals out of those 174 responded the questionnaire. Based on the findings of this questionnaire and also literature review, a cognitive test was designed and conducted in which 19 out of 50 professionals participated. The results are recorded, analysed and presented in this chapter.

4.1 Questionnaire Results and Analysis

Questionnaire is divided into 4 different chapters. Chapter one is about general information about the respondents. Second chapter aims to investigate how professionals use 2D drawings and specifications in their daily work and third chapter is to investigate the same information but on BIM models. Fourth and final chapter consider al of construction document and information sources as a whole and compare them based on professionals' opinion and experience.

4.1.1 General Information of Respondents

We got more responses from supervisors, then site managers had second place in the most responses we got. In total, the responds are coming from most of the disciplines participating in 6 projects within the investigated company.

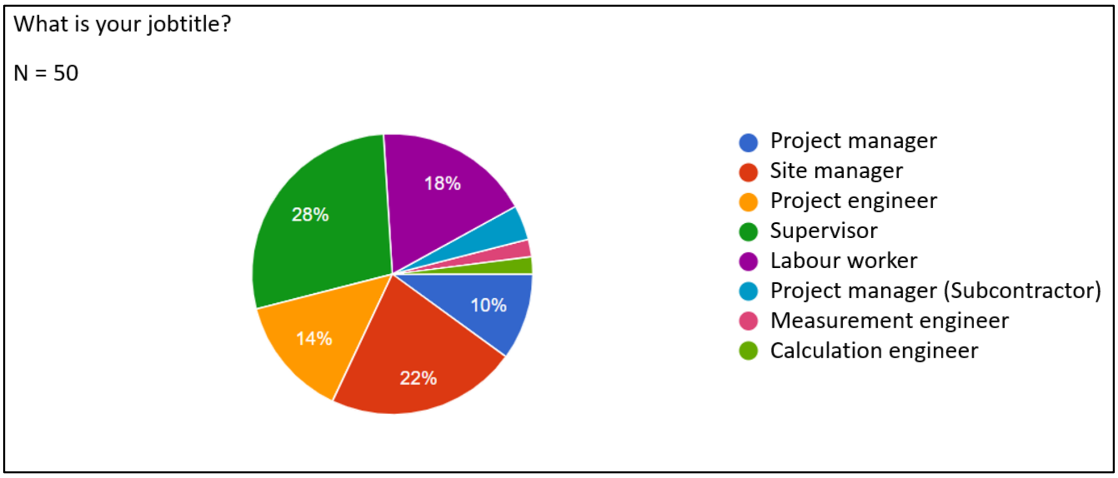


Figure 11 - Respondents' different job titles (Authors' own figure)

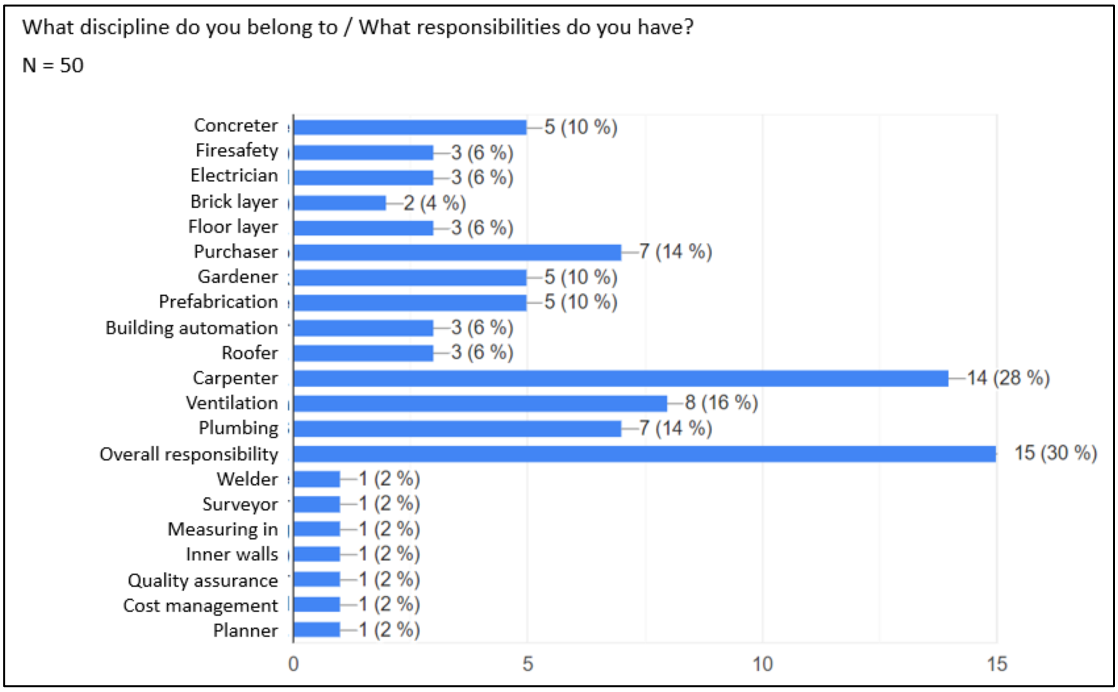


Figure 12 - The respondents discipline fields in detail (Authors' own figure)

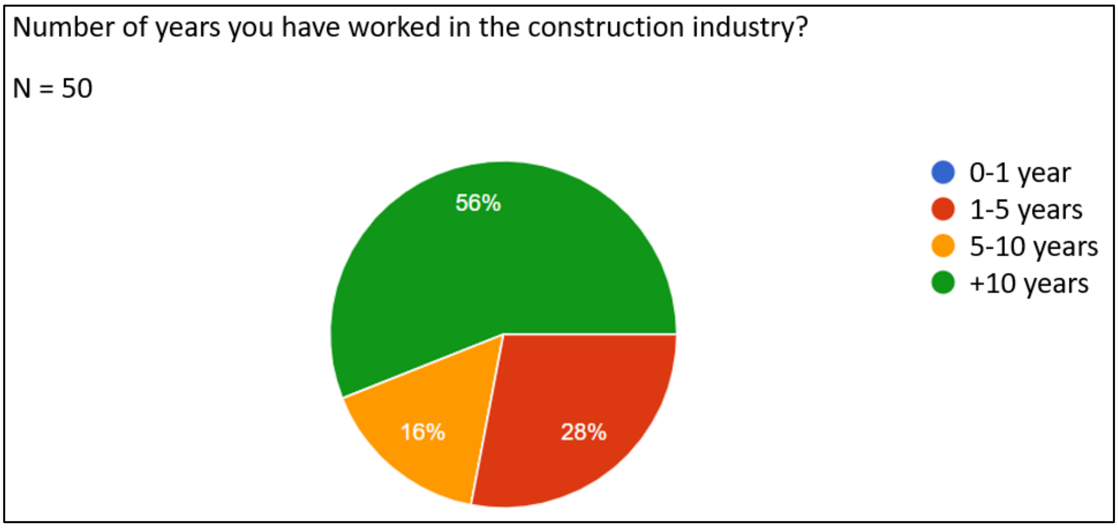


Figure 13 - The number of years that respondents have worked in the construction industry (Authors' own figure)

4.1.2 Usage Frequency of Various Information Sources

Drawings are used 86% everyday by the sample group. The rest 14% uses drawings less often but still they use it several times a week. But in the case of BIM models, it is used 34% daily and there are 36% of professionals who almost never use BIM models for taking out information. Other 30% uses BIM models several times a week.

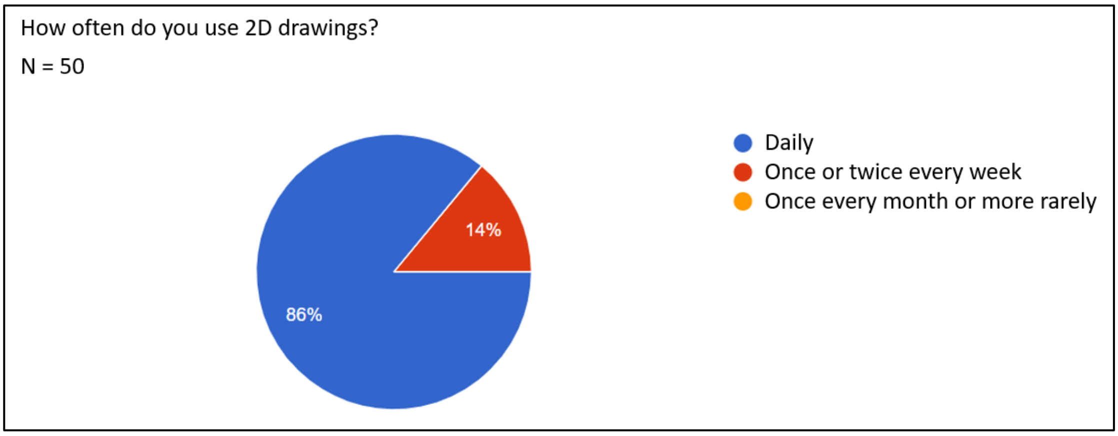


Figure 14 - The frequentness of using 2D drawings (Authors' own figure)

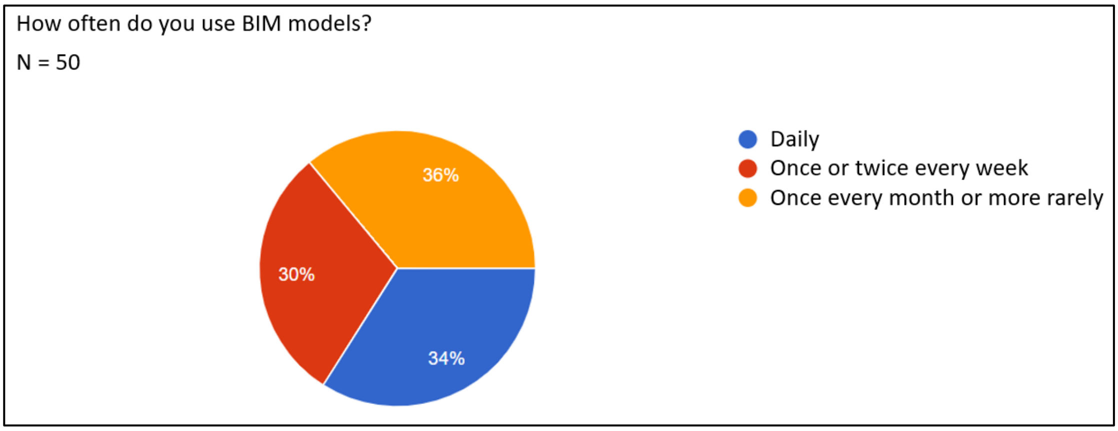


Figure 15 - The frequentness of using BIM models (Authors' own figure)

4.1.3 Different Drawings Format in Use

Almost 100% of the sample group use drawings in digital format and 46% use drawings in paper format at the same time. The ones who use paper format are mostly construction labors or site supervisors. Thus, we can draw conclusion that all of professionals in the branch are already familiar with digital usage of drawings and use digital devices on site. It shows the possibility to introduce BIM as the main information source on site.

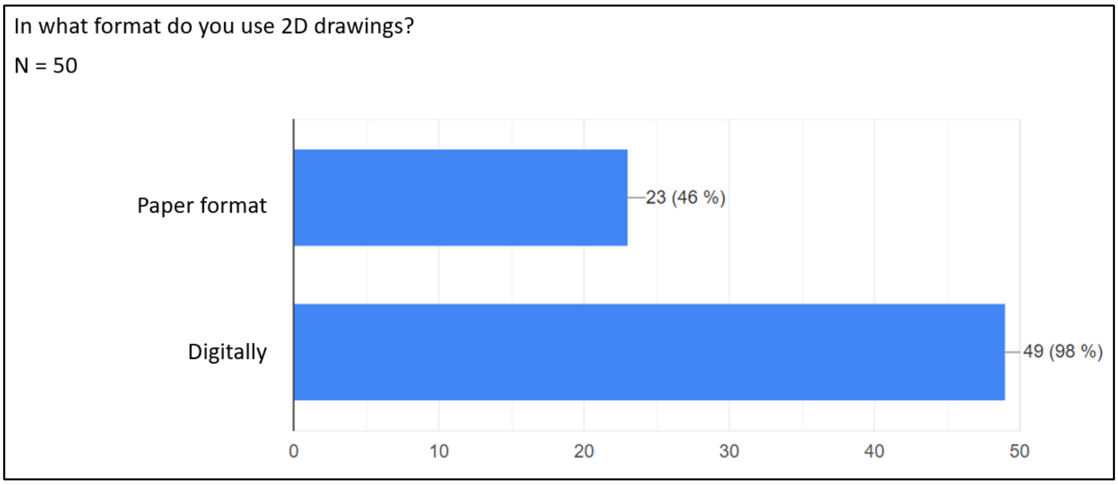


Figure 16 - Comparison of different formats in which respondents use 2D drawings (Authors' own figure)

4.1.4 Different BIM Software Used by Respondents

On the other hand, all the respondents have used one of the BIM interfacing computer programs. The conclusion can be that all of disciplines are already familiar more and less with BIM models. Even though some use it once a month or less. They use BIM 360 the most (76%). Solibri is the next most used program (56%). It is because of the fact that the investigated company has implemented BIM 360 and Solibri as the main BIM programs for on-site usage.

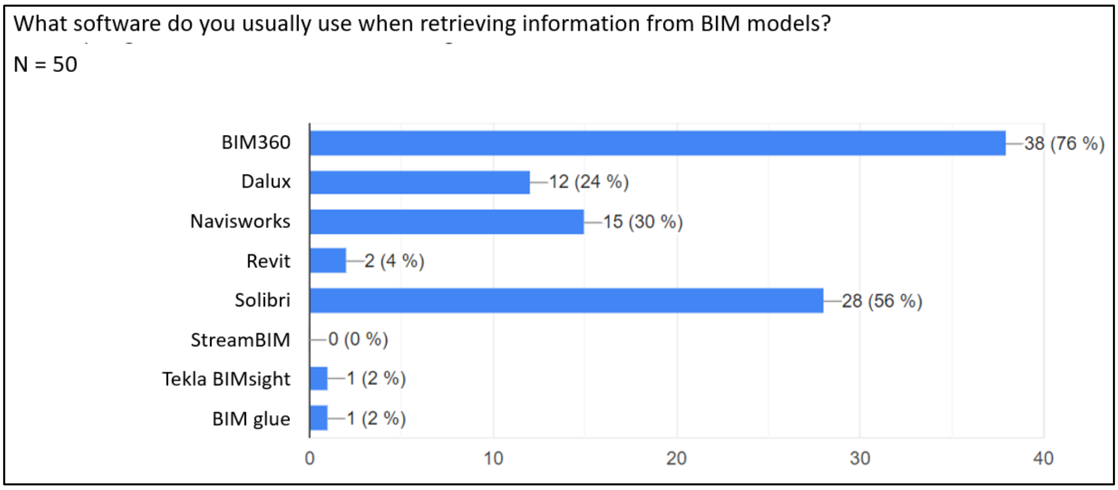


Figure 17 - Comparison of how much each BIM software is used by respondents (Authors' own figure)

4.1.5 Frequency of Information Take Off from Various Information Sources

Dimensions and distances are the information types which are taken out from drawings the most often while the Specifications (fire safety class, standard codes, sound requirements, etc.) and building elements are taken from drawings the least often. Dimensions and distances are also the information types which are taken from BIM models the most often and also Specifications are taken from BIM models the least often.

In comparison between BIM and drawings, construction details are significantly less often taken from BIM models. Littera is also taken a lot less often from BIM models which shows its importance in the drawings.

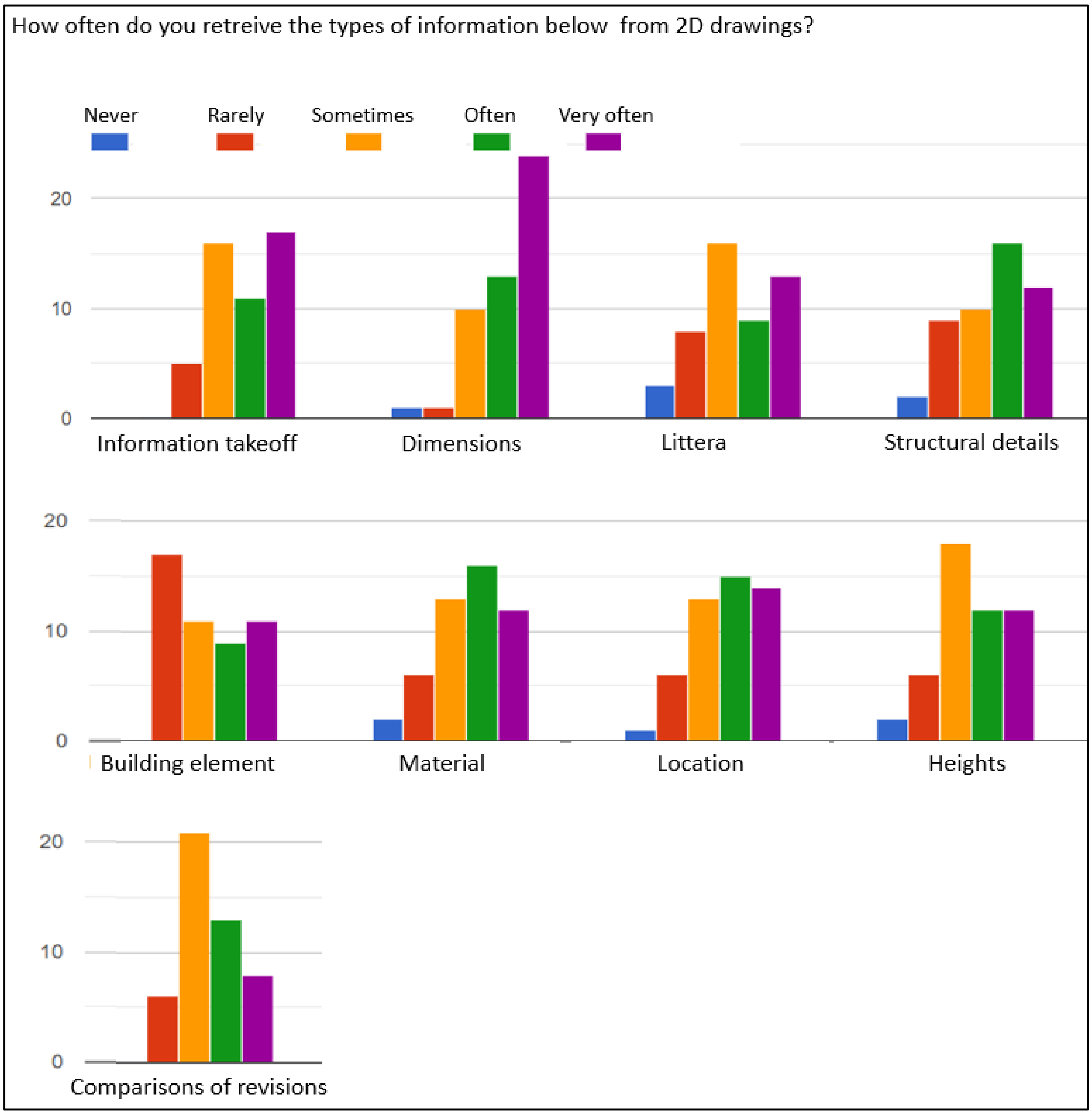


Figure 18 - Comparison of frequentness of retrieving each type of information from 2D drawings by respondents (Authors' own figure)

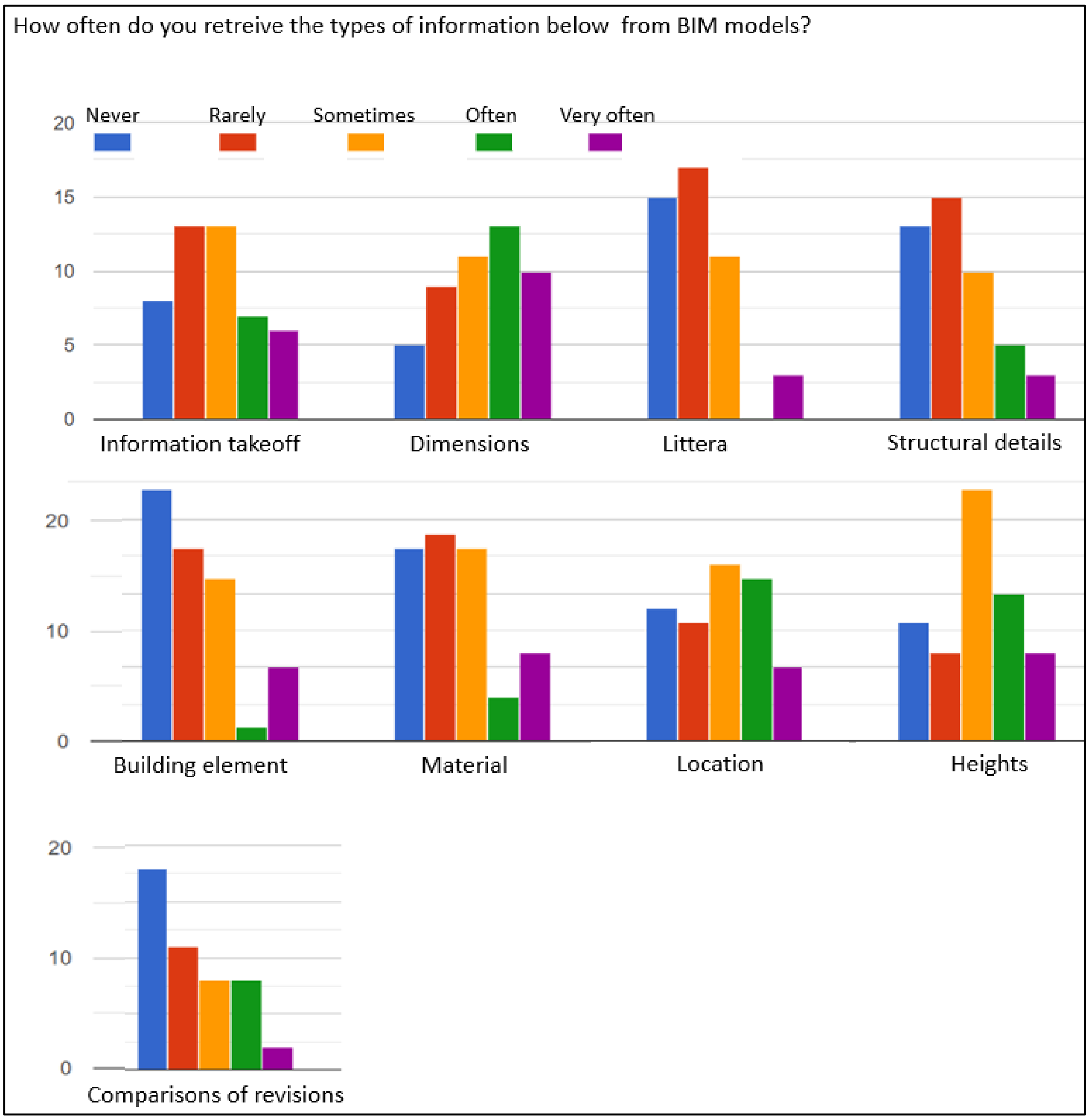


Figure 19 - Comparison of frequentness of retrieving each type of information from BIM models by respondents (Authors' own figure)

4.1.6 Reliability in Various Information Sources

78% of the respondents graded the reliability of the drawings 4 and 5, while almost the same amount (76%) graded reliability of BIM models 3 and 4. At the same time 18% of the respondents think drawings are completely reliable (5 of 5), while this number for BIM models is 12%. The value described for grading system is considered 1to 5. It means grade 3 is considered as a neutral answer. Following this grading system, average value of the reliability among respondents is 3.9 for the drawings and 3.5 for BIM models. It demonstrates that most construction professionals believe that BIM models are not yet reliable enough.

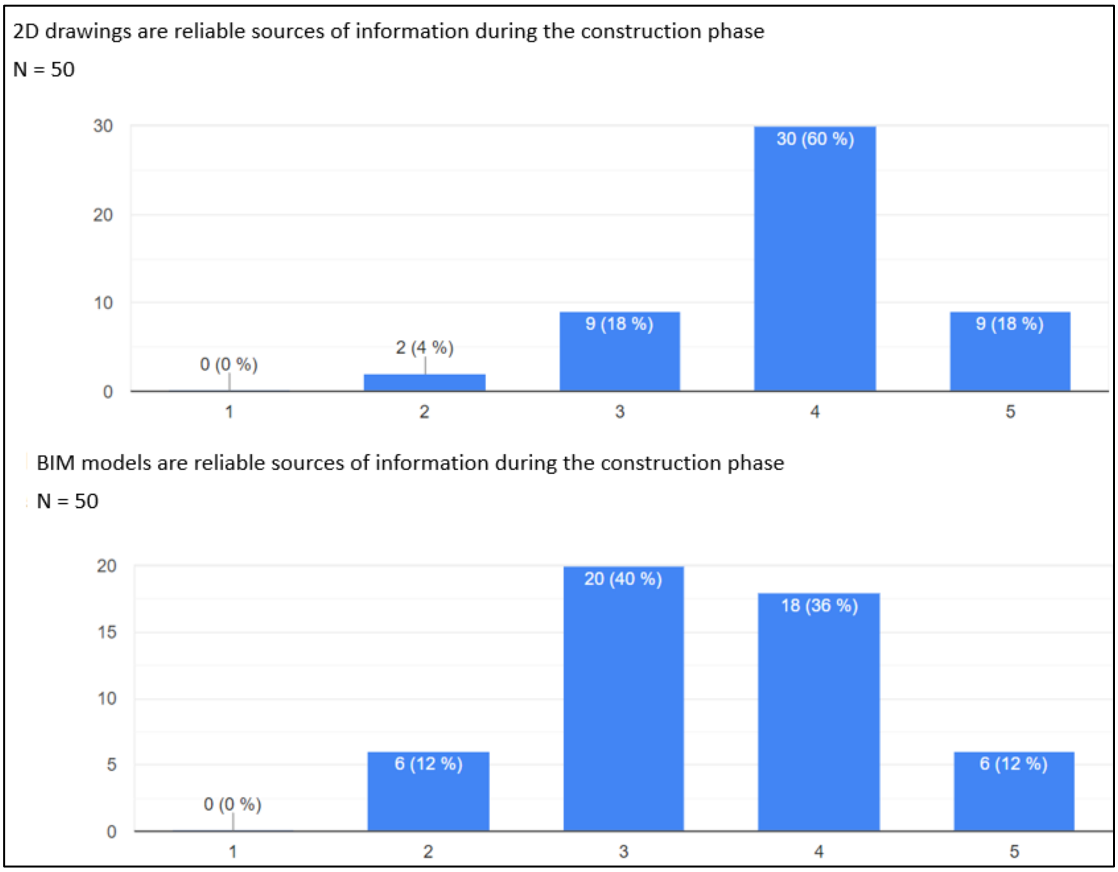


Figure 20 - The level of reliability of different information sources graded by respondents (Authors' own figure)

Some respondents provided short answers in the case of unreliable drawings and BIM models. Most of the respondents of written answers emphasized that drawings consist small errors, are not updated on time, lacking information and not linked in the right way. They also pointed out that BIM models are not updated usually as much as 2D drawings, so it is necessary to double check them with 2D drawings. It is also emphasized that some information is lacking in BIM models such as amounts and dimensions. In one of the respondents' point of view BIM models are only a compliment to the 2D drawing. It is also mentioned that the quality of BIM models is different in different projects, they consist a lot of collisions and they are depended on the design team's way of workings, which makes BIM models not as reliable as 2D drawings.

4.1.7 Easiness of Navigation in Various Information Sources

Most of the respondents (56%) graded the easiness of navigating between different drawings 4 of 5 and 18% find it totally easy to navigate between different drawings. Also 22% of the respondents was neutral towards this question. The average value of the responses is 3.9 in the grading system. In the case of easiness of navigating in BIM models, 40% of the respondents graded it 4, 30% were neutral and 16% find it totally easy. It is necessary to consider that 6% of the respondents graded it 1, it means they experience it very difficult to navigate in BIM models. Nobody graded easiness of navigating between drawings 1. The average value of easiness of navigating in BIM models is 3.5 based on the grading system mentioned earlier.

Since there are 36% of the respondents who don't use BIM at all, it is not surprising to see that easiness of navigating in the BIM model is graded lower than easiness of navigating between drawings. This can be categorized in different aspects of BIM models such as lack of knowledge, lack of total implementation of BIM models among the organizations etc. But in the case of navigating between drawings, the responds clarify that despite of new methods of linking the drawings to each other, navigating between drawings is still not totally easy for many individuals.

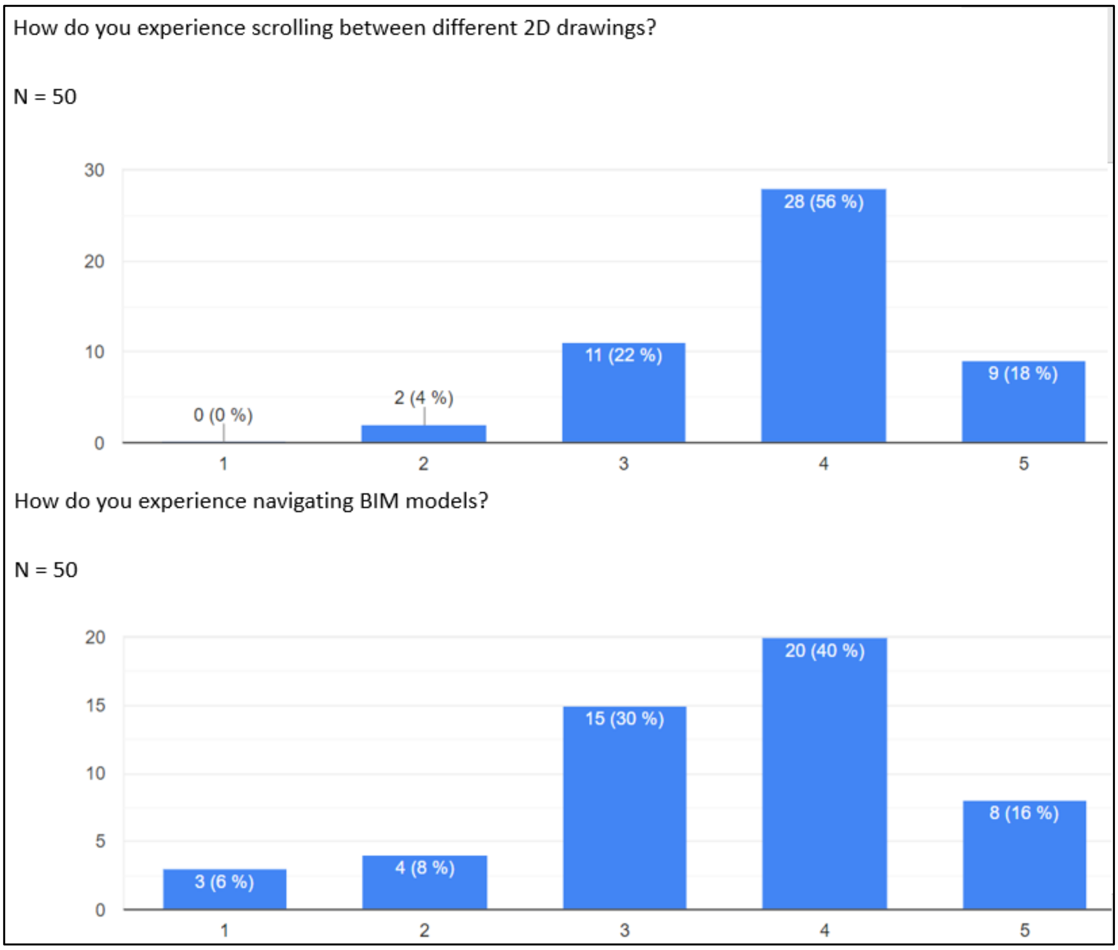


Figure 21 - The level of easiness of navigating in different information sources graded by respondents (Authors' own figure)

Some respondents provided short answers in the case of navigating between drawings and in BIM models. Most of respondents pointed out that linking between drawings are not easy because they mostly lack linking codes, and they are not oriented well.

Some of the respondents also think the reason they have difficulties with linking between drawings is a software-based problem. Some pointed out that BIM360 does not have a searching function and some emphasized that Bluebeam can make it easier. In the case of navigating in BIM models some of them emphasized that models are mostly massive and hard to navigate, but most of the respondents emphasized that lack of knowledge in how to use BIM programs and the shortcuts make it harder to navigate in BIM models.

4.1.8 Importance of Different Construction Documents

Most of the respondents graded the importance of construction drawings 5 of 5 and its average value based on the mentioned grading system is 4.4, construction drawings is considered the most important drawing. The second important drawings in respondents' point of view are architecture drawings. Site managers answered mostly that all the drawings are as important. Construction labors naturally answer this based on their discipline.

On the other hand, construction model and architecture model are graded as the most important ones in the case of BIM models, even though dispersal of the responses are more in BIM models and naturally average values are lower. Prefab construction drawings are not graded high while prefab construction model is graded almost as high as construction model. Ventilation models and plumbing models are graded as high as their drawing which can demonstrate they can be combined, or drawings can be substituted by their models in this case. On the other hand, landscape drawings and control drawings are considered as the least important drawings and exactly the same models are considered as the least important ones.

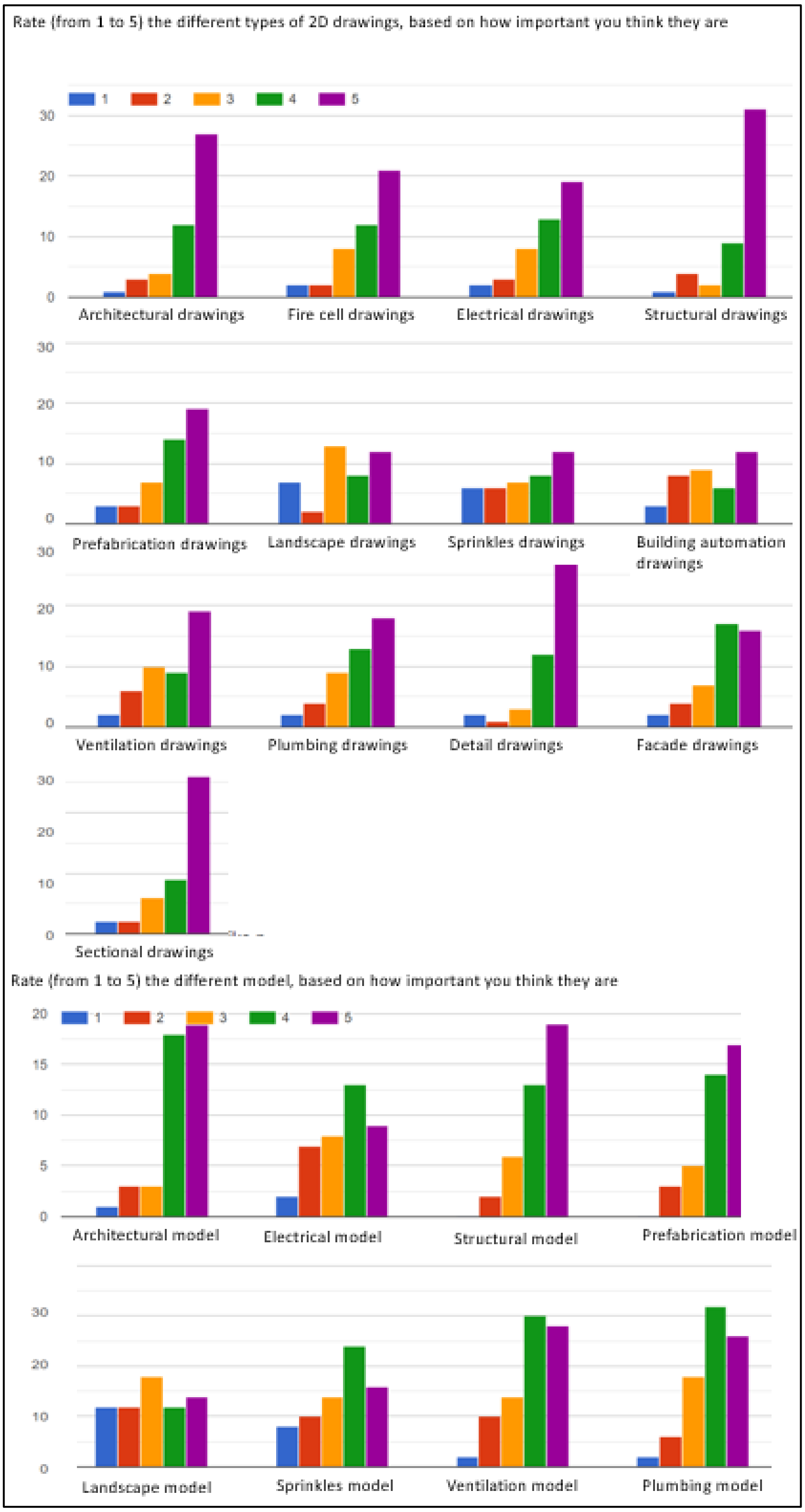


Figure 22 - The level of importance of different information sources graded by respondents (Authors' own figure)

4.1.9 User Friendliness of Different Construction Documents

Architecture drawings (average value of 3.9) and Construction drawings (average value of 3.8) got the highest grade among drawings in the case of how easy it is to use them and among them, section drawing (3.9) is graded the most user-friendly piece of drawing. On the other hand, building automation drawings got the least grade and can be translated as the hardest drawing to use. Among the BIM models, architecture model (3.6) and construction models (3.6) are graded to be the easiest model to read and landscape model is the hardest.

But It can be also translated that the landscape models are used the least and considered the least important in previous question, so they got the least grade here. What is used less is harder to use. This is confirmed also in the case of most important ones. Construction drawings and architecture drawings are the most important ones in respondents' opinion. It means they are more depended to these drawings and models. As a result, they are used more, developed more and became easier to find information from. This obviously shows that both drawings and models in this case are important almost in the same level. So, it also demonstrates the possibility to keep one of them as the main source of information and remove the other one.

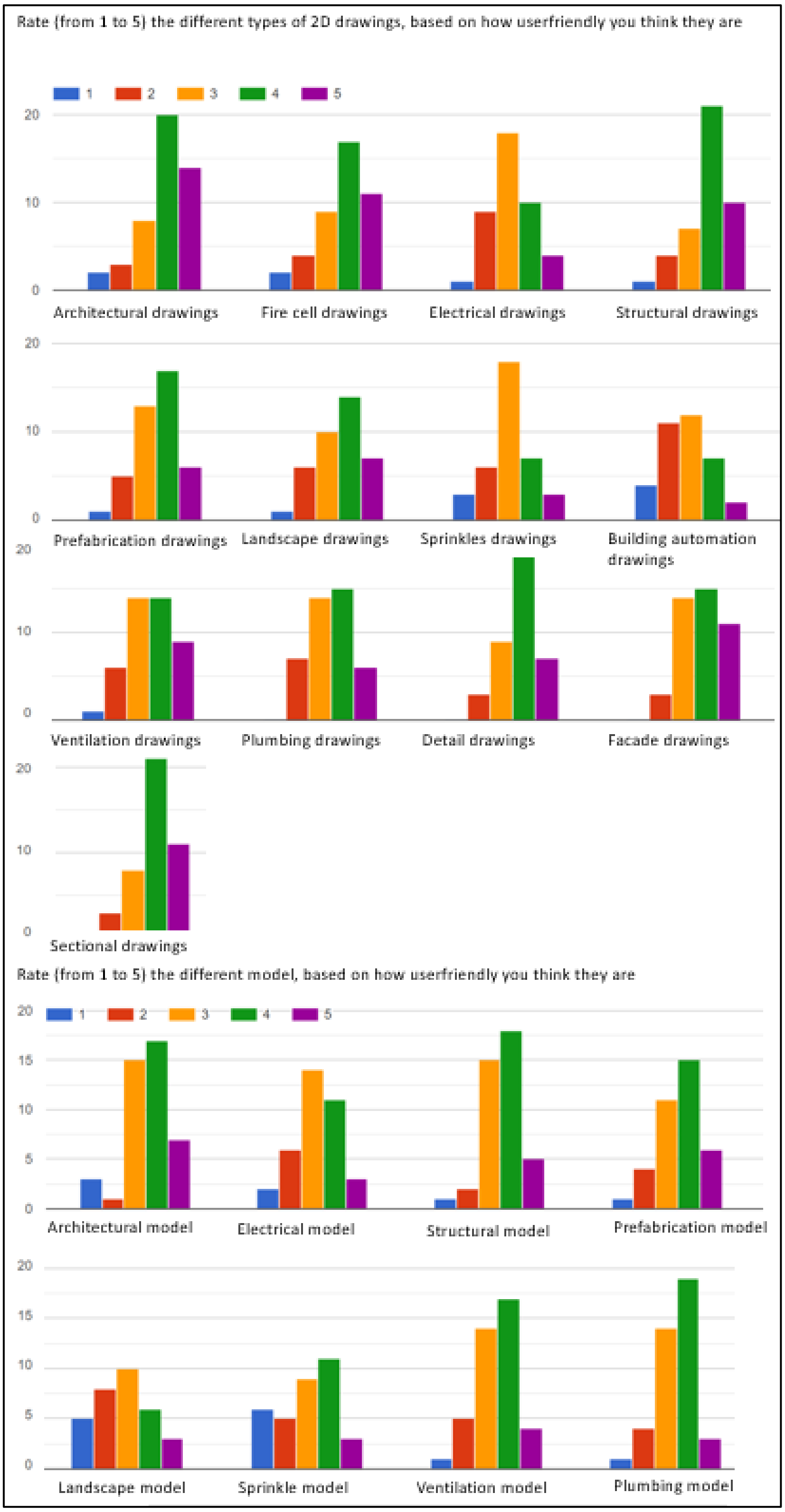


Figure 23 - The level of user-friendliness of different construction information in various sources graded by respondents (Authors' own figure)

Some of the respondents provided short written answers in the case of difficulties of finding necessary information in drawings and BIM models. Most of them pointed out that user friendliness of drawings differs between different disciplines. Some of them also emphasized that lacking necessary information, too many rules, too many layers and not completed drawings which can make it harder to find information in 2D drawings. In the case of BIM models, they emphasized that BIM models are not always linked to each other perfectly and they lack details, which make them not to be full-standing information sources.

4.1.10 Time Consumption for Different Construction Documents

Architect drawings (3.8) and architect model (3.4) are graded to be the least time-consuming information sources. Construction drawings (3.7) and construction models (3.4) are also considered as the least time-consuming sources. On the other hand, control drawings, electrical models and electrical drawings are considered as the most time-consuming sources. There is a direct relation between drawings and models in the results of this question. It is also demonstrated that ventilation models, plumbing models and electrical models are less time consuming to use than their drawings.

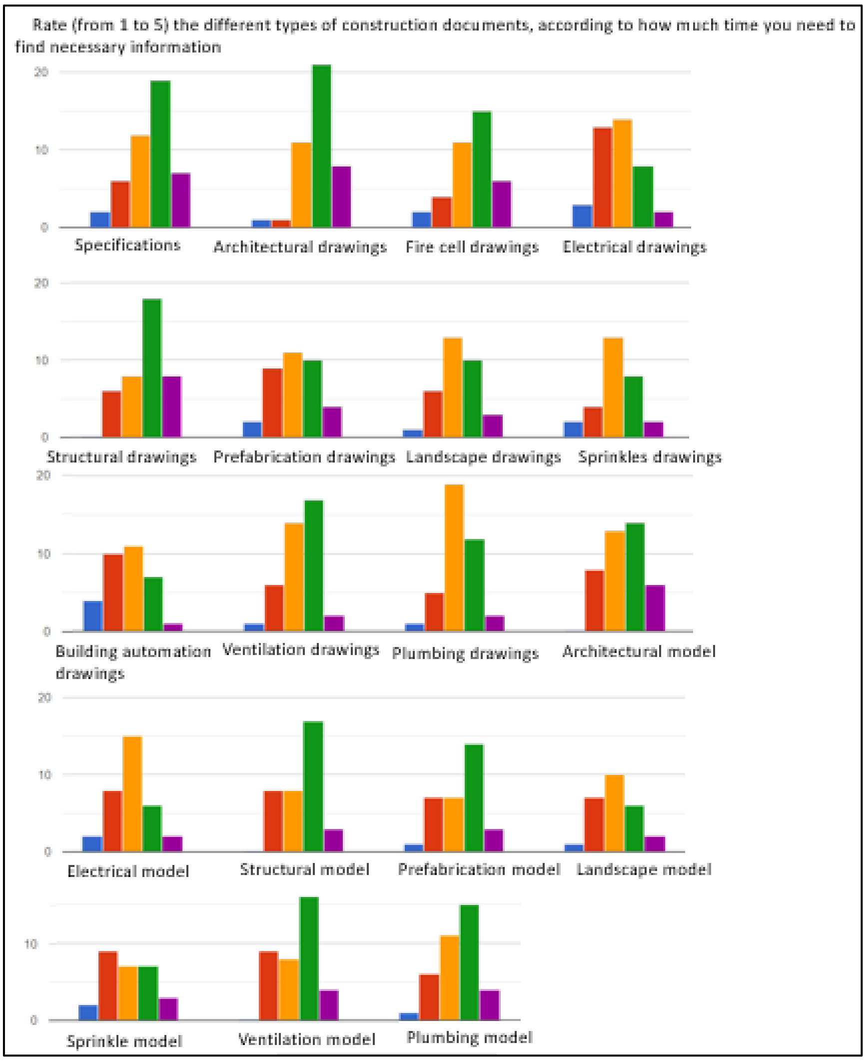


Figure 24 - The level of how time-consuming is to use different construction information in different sources (Authors' own figure)

4.1.11 The Holistic Vision Given by Various Information Sources

Respondents believe that the combination of drawings and BIM models give them better understanding of the finished product. After combination, BIM models stand on the second place and drawings are considered to be the worst to give the holistic vision of the project.

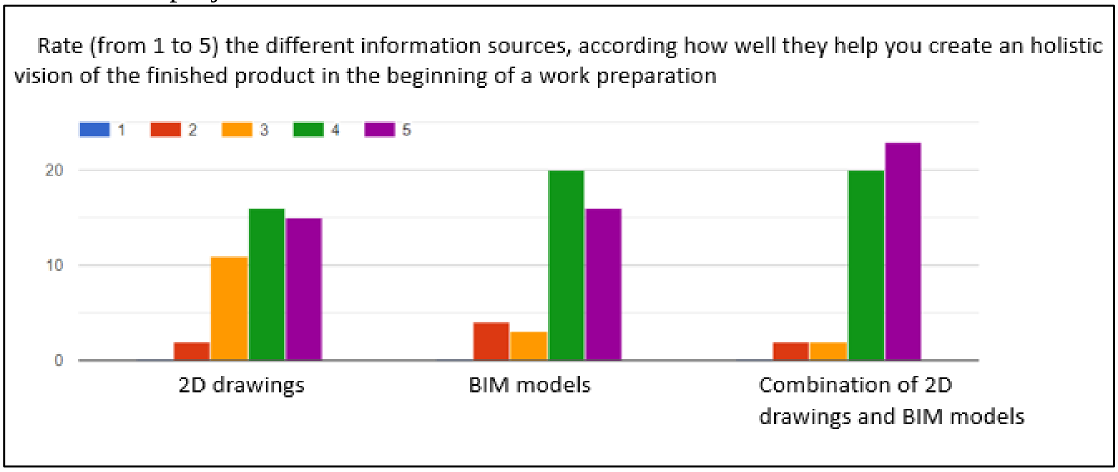


Figure 25 - The level of how different construction information sources provide holistic vision of final building graded by respondents (Authors' own figure)

4.1.12 Correlations of Variables in the Questionnaire

The analysis of the questionnaire survey demonstrates correlation between different aspects in the construction industry. One of the powerful correlations addresses the relationship between the level of education and perceiving specifications. In this case, it is demonstrated that perceiving information from specification documents is faster among professionals with higher educations in the investigated projects (see Table 1). On the other hand, the number of years within the industry correlate negatively with level of education. The professionals who are working in the investigated projects for longer years have lower education level which shows that they might not have been under any form of new educations during their working life and naturally, they do not have any form of education related to new methods of information management such as BIM.

Table 1: Correlation between level of education and related variables

Variable	R (*p*-Value)
How many years have you worked in the industry?	**-0.417****
How long it takes for you to find needed information from specifications? (grading scale 1-5)	**0.429****

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed)

Based on the correlation analysis, the more one uses BIM, the easier it becomes to navigate in BIM models (see Table 2), more reliable it feels to take information from BIM models and more information take-off takes place by the help of BIM models (see Table 3). Based on this analysis, having more experience in using BIM models can improve its performance. On the other hand, there is not a correlation between using the drawings more often and they become more user-friendly. It can demonstrate that using drawings more often have not made them become easier to be used after all these years that they are the legal source of construction documents. This is opposite in the case of BIM models.

Table 2: Correlation between frequentness of using BIM models and related variables

Variable	R (*p*-Value)
How easy it is for you to navigate in BIM models? (grading scale 1-5)	**0.630****

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed)

Table 3: Correlation between How easy it is to navigate in BIM model related variables

Variable	R (*p*-Value)
How reliable BIM models are as information sources?	**0.292***
How often you take dimensions from BIM models?	**0.604****
How often do take material information from BIM models?	**0.359***
How often do take information about heights from BIM models?	**0.507****
How often do take information about types of building elements from BIM models?	**0.333***

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed)

On the other hand, the results of the survey showed that professionals within the investigated projects take more information from 2D drawings and use the drawings mostly every day. But only 34% of the respondents use BIM models daily and 36% of them almost never use BIM models, while there is no one between the respondents who never uses drawings. It can show that by making the BIM models be used more often, it can get a lot easier to use BIM and consequently more information be taken from BIM models. In addition, user friendliness of BIM models and 2D drawings have got almost the same average grade among the respondents such as construction, ventilation, plumbing etc. As a result, by more experience in using BIM, taking information from BIM models can naturally increase and become easier for the users. The other observation in the questionnaire is that professionals who can get a holistic vision from 2D drawings can have the same vision from BIM models and a combination of those two sources of information.

This analysis shapes the basis of the test as the second part of the empirical data. Some specific types of information, including dimensions, specifications, distances etc. are all taken from drawings more often today. Through the test, same types of information are asked to be taken from very simplified BIM model and regular drawings. Through the correlation analysis it was demonstrated that the main reason of shortcoming in BIM models and less usage of them is lack of experience and naturally lack of Knowledge. By simplifying the BIM model, the lack of knowledge is excluded from the test. In this methodology, all the questions are defined in both drawings and BIM models clearly and the user needs very few and simple actions within the models to get the answers.

4.2 The Cognitive Test

Based on the questionnaire and literature study, a cognitive test is developed in order to firstly compare the perception of different information sources (BIM model, drawings and specifications), secondly to evaluate the answers in questionnaire furthermore and thirdly to find out the weaknesses and strengths of different information mediums of construction industry in real life. The expected outcome of the test was to empirically identify what types of information should stay as 2D representations and what information is better perceived in BIM models in current state of construction projects. So, it can be possible to make guidelines for how the combination of different construction documents should be presented in order to achieve the fastest, easiest and most practical perception of construction information.

The test attendances were having the questions and a count-down timer for each question on one screen and they had the information sources on the other screen. In first chapter of the test participants had access to a simplified BIM model as a Solibri file (See figure 26). In order to exclude lack of knowledge from the test and specifically evaluate the efficiency of the medium in perceiving information from, the BIM model is totally simplified. Specific building elements which are the subjects of the questions are marked in a separated view for each question. Respondents could find the views in “Communication” tab in Solibri file. So, in order for them to answer the questions, only a few very simple actions were needed such as zooming in, zooming out, clicking the elements, clicking the tabs and measuring the distances. The questions differed from the specifications to measurements of different elements (see Appendix 2).

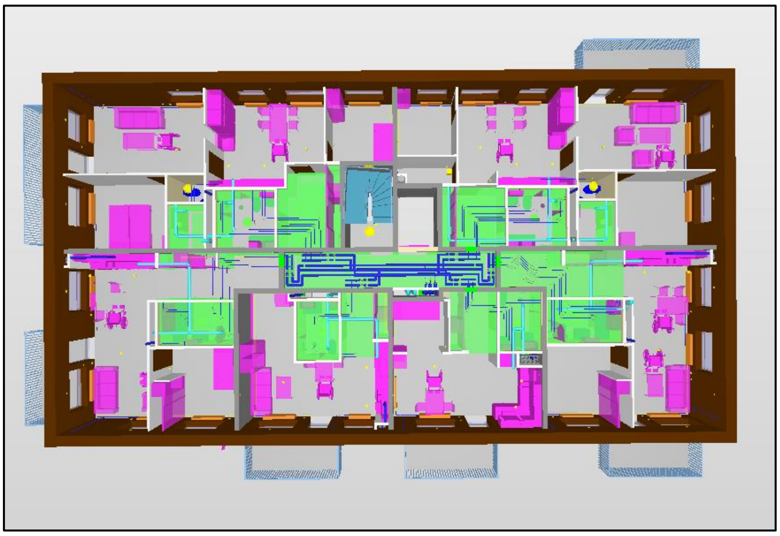


Figure 26 - Planview of the first chapter (Authors' own figure)

In the second chapter of the test, the respondents were provided with all the necessary drawings of another part of the same project as first chapter in order to keep the same quality of information through the whole test (See Figure 27). The questions and time limit for each question was exactly the same as first chapter. The attendants needed to navigate between drawings and find the related drawing to each question. In other words, a situation same as their everyday work-life was simulated for them with time limit. The related building element for each question was marked in the related drawing.

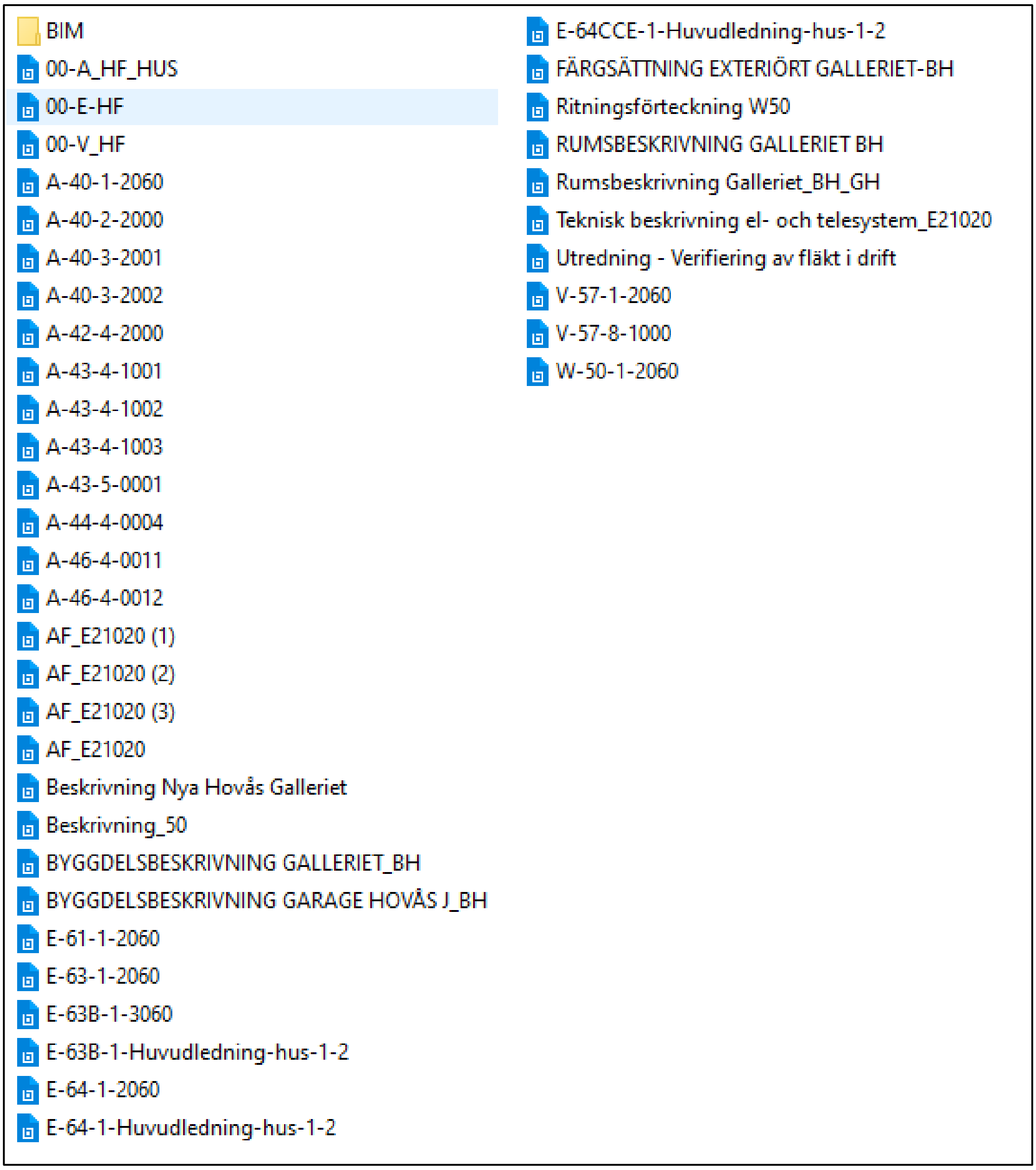


Figure 27- Drawings and specifications used in the second chapter (Authors' own image)

In the third and last chapter of the test, a combination of BIM model and 2D plan drawing in a Solibri file was provided for the respondents (See Figure 28). This combination was representing another part of the same project and was working the same as first chapter of the test, the difference was that the respondents could see the plan drawing on the floor as a layer in the model (see Appendix 2). So, they could also access to measurements and information in the drawings by seeing the model from top view.

Figure 28 - Planview of the third chapter (Authors' own image)

Using Solibri, was because it is the main BIM software which is used by the researched company. In all of test sessions one or both authors of this research were present with the respondent. In some cases that was not possible to be with the respondent physically, the authors joined the respondents on Teams application. They presented the test, described the software features which the respondents were not aware of and also observed the respondents during the test. The observations were a part of the test and are included in the analysis. There was also a preparation question in the beginning of the session which was not considered in the results and authors and respondents went through it together. This sample question was only a preparation for the respondents to understand the layout and procedure of the test (See Figure 29).

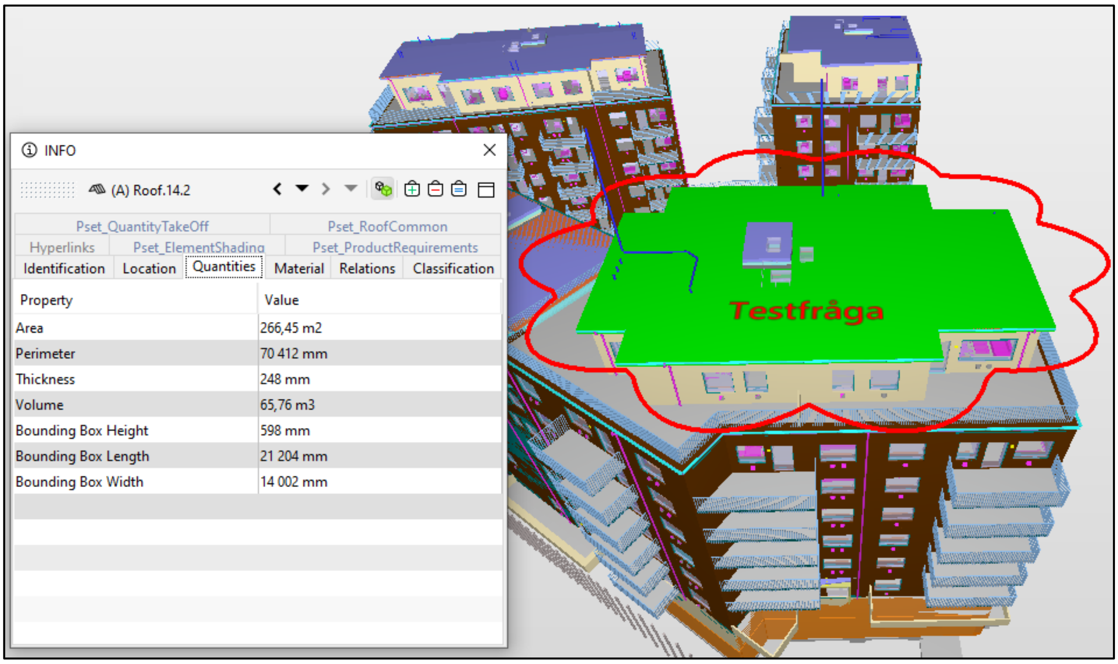


Figure 29 - Test question to prepare participants (Authors own image)

4.2.1 Results of the Cognitive Test

The first question is about information take off from a specified wall of a residential project. Information such as wall type, dimensions, material, layers and thickness (see Appendix 2). The defined wall is from different parts of the project in different chapters of the test. In first chapter participants need to click on the marked wall in the BIM model presented in the Solibri software. After the click, information window opens up and the participants need to go through different tabs in the information window such as identification, quantities, location, material, etc to find the needed information (See figure 30). On the other hand, for answering first question in chapter two of the test, which is the same question but different wall, the participants find the related wall in the architecture drawings. Then they need to go through different drawings to find specifications of the wall and also measure the dimensions of the wall (See figure 31). They do it through Bluebeam software which is used by the investigated company as the main PDF reader software. All of the participants except one, had at least basic knowledge of Bluebeam which was covering the needed functions for the test. In the third chapter of the test, the defined wall is marked in the combination model. The participants can click on the related wall and find all the information in the information window, the same as BIM model. But the difference is that they could see the length of the wall in the drawing attached to the floor (See figure 32).

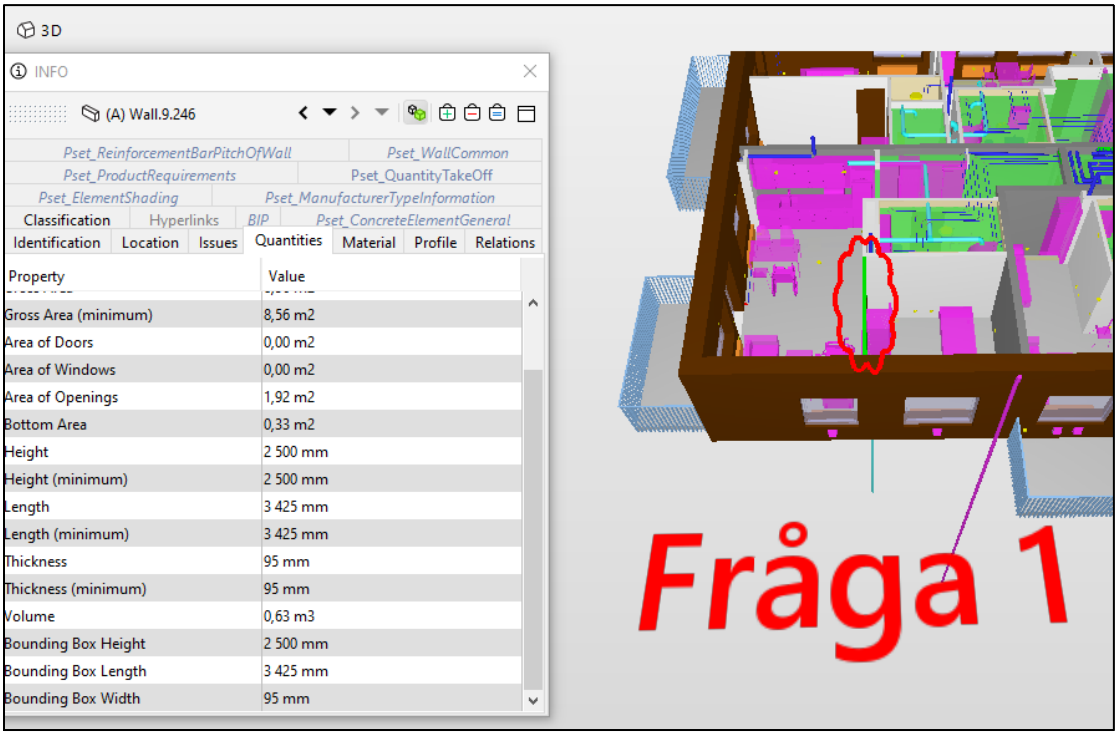


Figure 30 - Chapter 1, question 1 (Authors' own image)

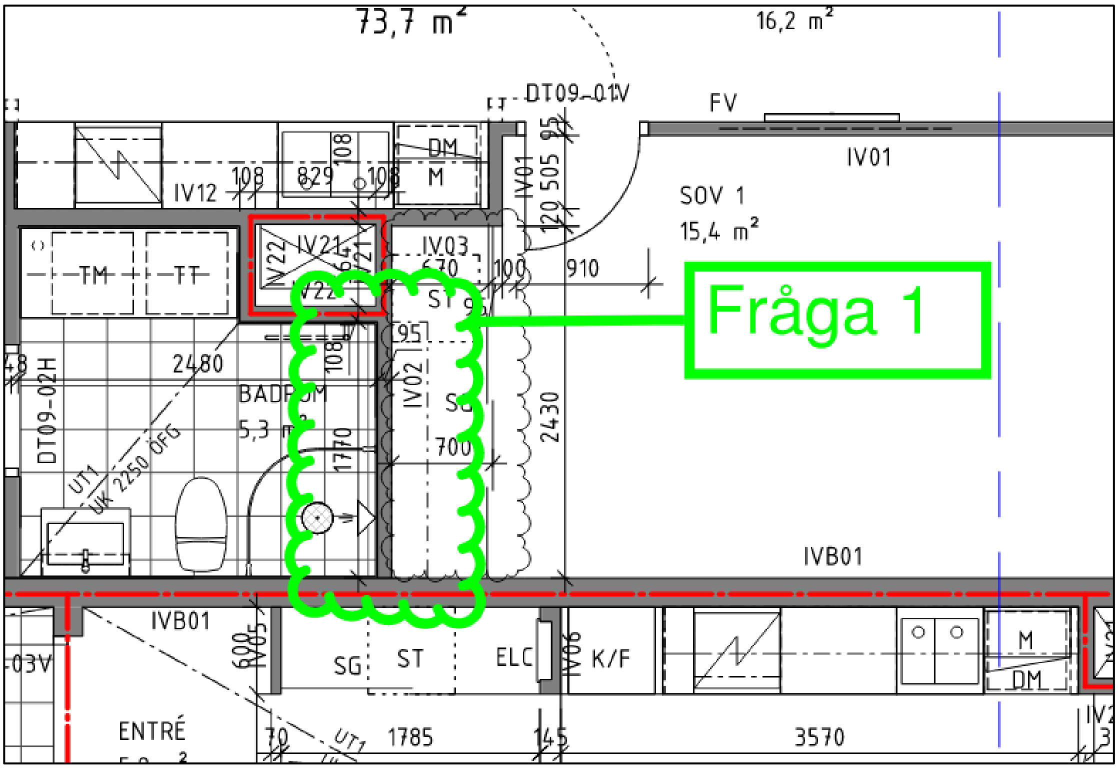


Figure 31 - Chapter 2, question 1 (Authors' own image)

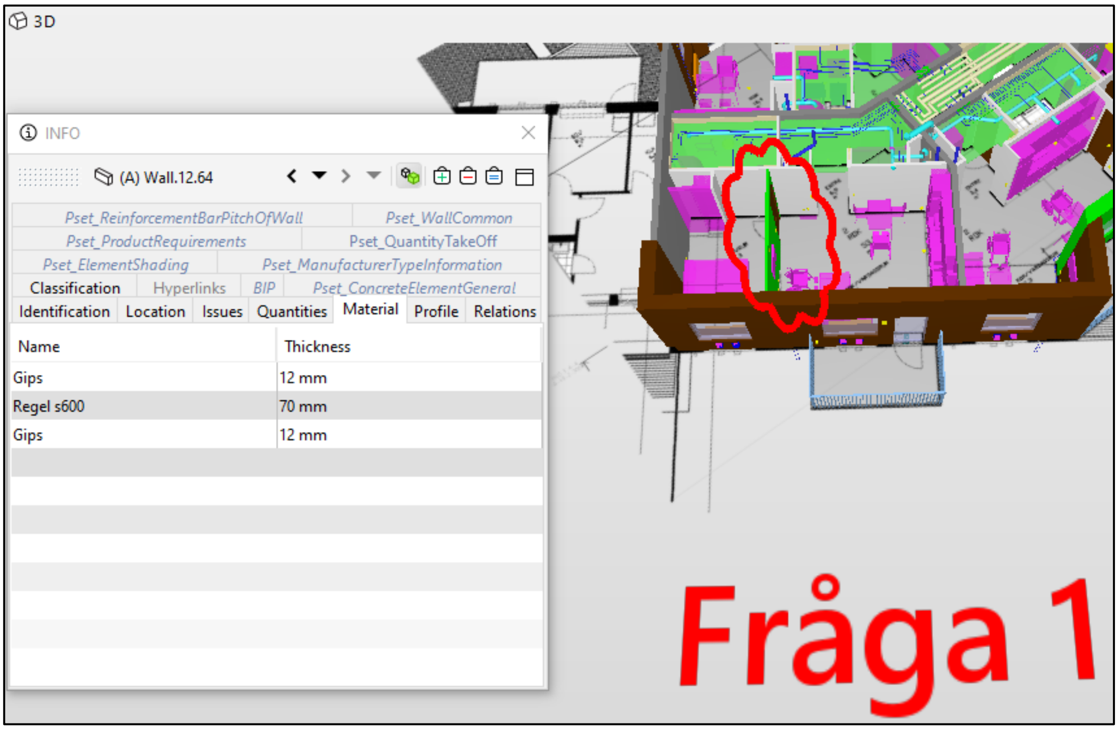


Figure 32 - Chapter 3, question 1 (Authors' own image)

The result of the first question shows that respondents do the information take off from BIM models easier, faster and more accurate in comparison with drawings. The average point (means) of the first question taken by the respondents from BIM model is 4.26/5 and 2.47/5 from 2D drawings. The results also show that respondents have found information from the combined model even easier than BIM model with the average point of 4.53/5 (see Table 4).

One of the sub questions of this task is asking for the height of the wall and it made it necessary for the respondents to start searching for other drawings and also measure the height of the wall. It was where they start to perform slower. Only 3 respondents out of total 19 answered this question correctly in the drawing chapter, while 17 respondents answered this question in the chapter of BIM model and 18 respondents in the chapter of combination of BIM model and 2D drawings (see Table 4). After this question in the chapter of 2D drawings, there was not much time left for answering other 2 sub questions of this task where they needed again to navigate between drawings.

Table 4: The results of question #1 of the cognitive test

	Number of correct answers		
Questions	**BIM model**	**2D drawing s**	**Combination of BIM model and 2D drawing**
What is the type-code of the wall?	17	19	19
What is the length of the wall?	18	18	18
What is the height of the wall?	17	3	18
How many layers of gypsum does the wall have?	16	4	16
What is the thickness of the wall?	16	2	15
Average point of question1 (from 5 points)	4.26	2.47	4.53

In the second question a window was subject of the information take off. The procedure of the questions was the same as first question and the differences were that there was no measurement in this question and that there was a smaller number of drawings needed (See figure 33, 34 & 35). So, the results of this question show the efficiency differences of finding specifications between drawings, BIM models and combination of those two. The results of this question were better in the 2D drawings (average point of 2.58/5) than the BIM model (average point of 2.37/5). But still the combination of BIM model and drawing worked better for this question with an average point of 3.74/5. The fact that the respondents were more comfortable with the test in last chapter, especially for the respondents with less experience in models, cannot be denied. It made it easier for them to navigate in the model or find information from right tabs or even measurements. It demonstrates that only a small experience of working with BIM models can develop needed skills for simple tasks very fast.

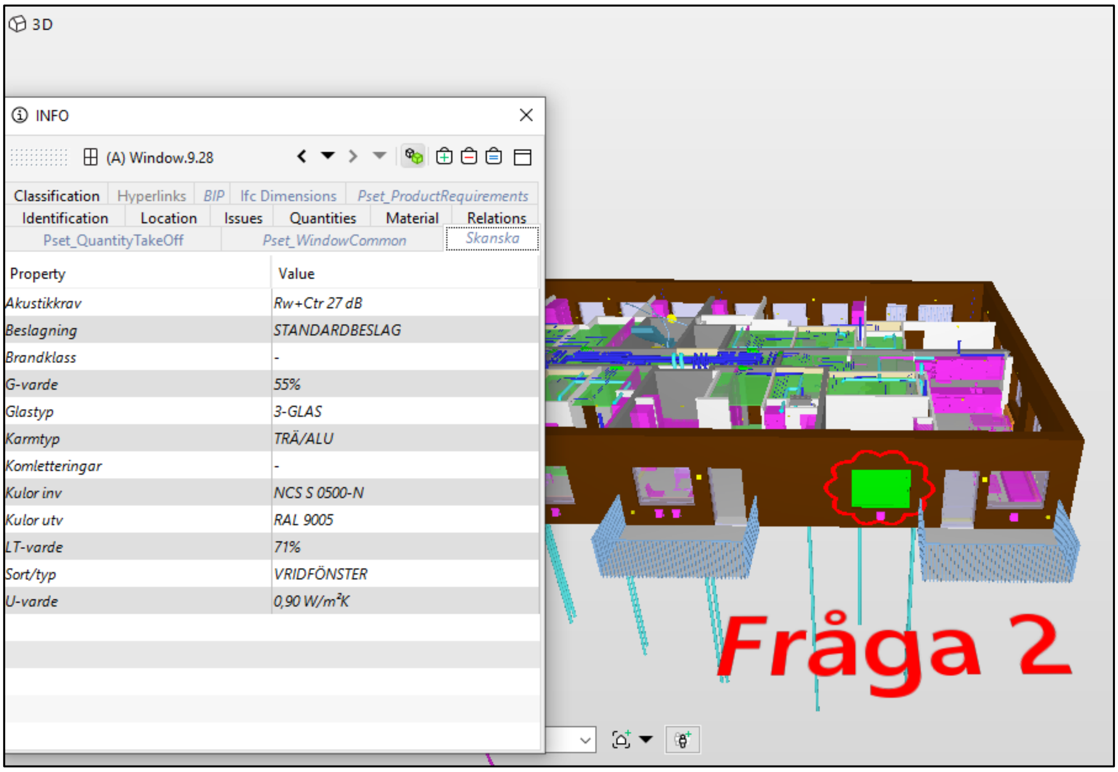


Figure 33 - Chapter 1, question 2 (Authors' own image)

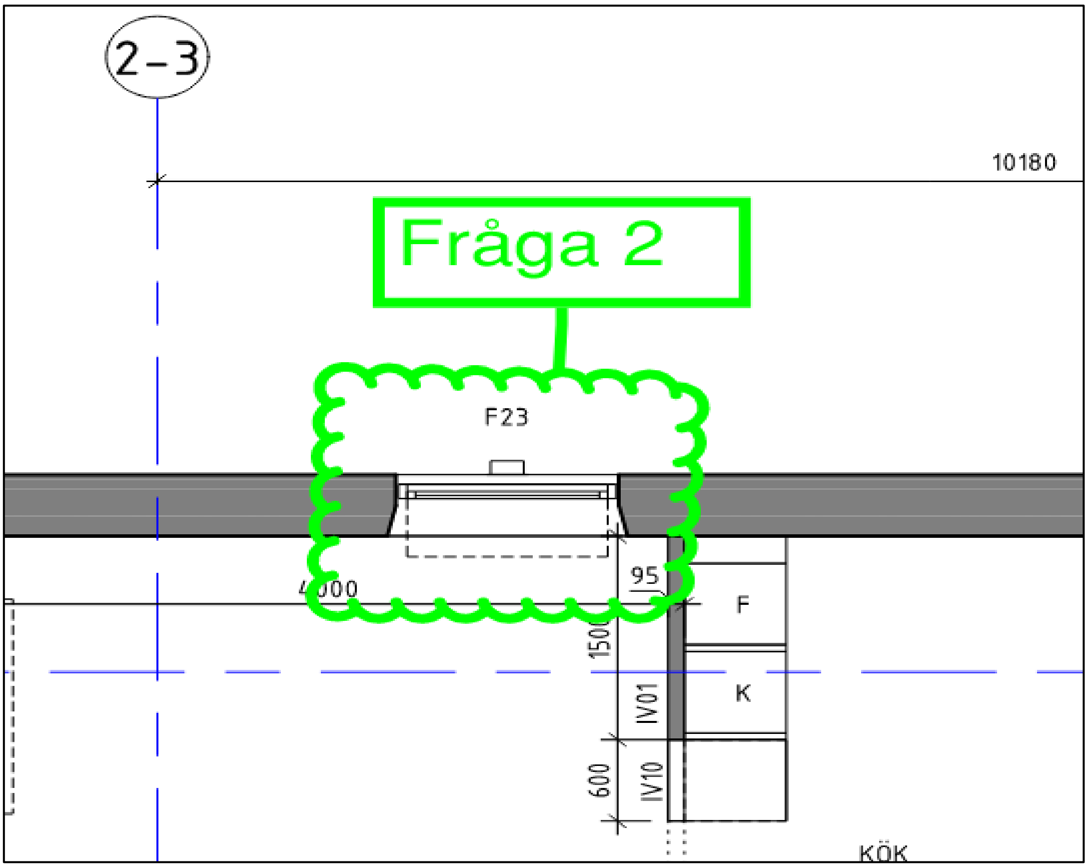


Figure 34 - Chapter 2, question 2 (Authors' own image)

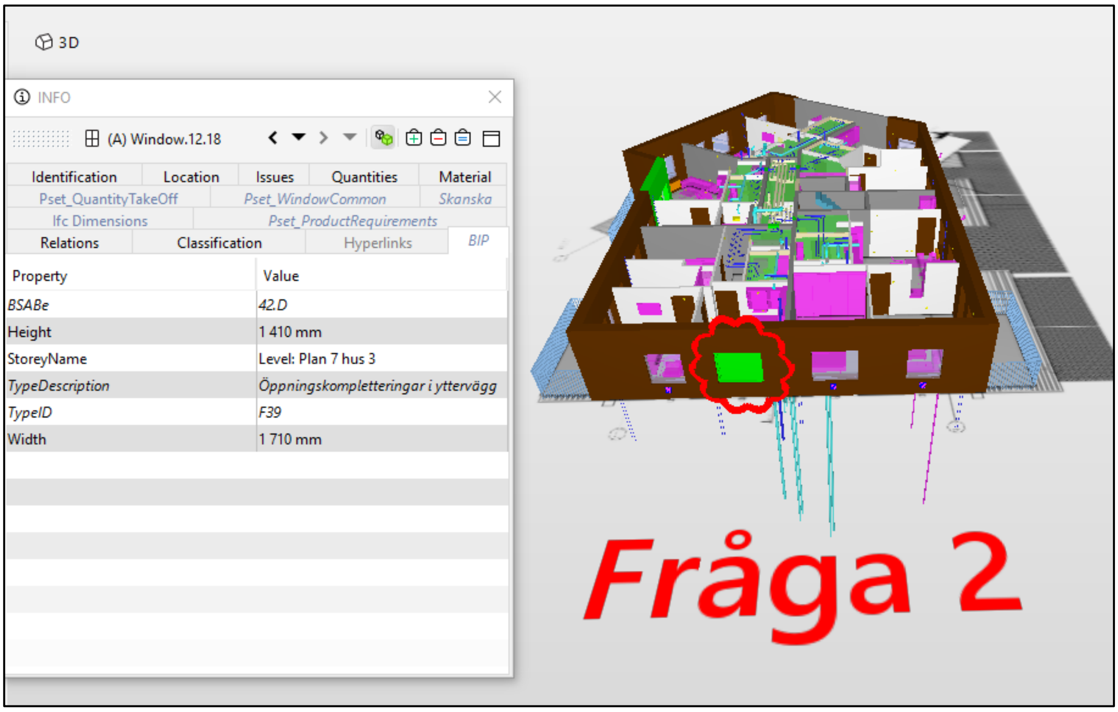


Figure 35 - Chapter 3, question 2 (Authors' own image)

It was observed during the test that the slow performance in BIM model took place since the code of window type was not written clearly in BIM model. So, it became a reason for confusion which resulted in that only 6 respondents answered the question about *window type* and *color code* of the window in BIM chapter and only one respondent answered the last sub-question of this task which was asking for *opening type* of the window, While the number of correct answers for the same sub-question in drawing were respectively 17, 7 and 4 and in combination chapter they were 11, 17 and 11 (See Table 5). The needed information for this task in BIM model chapter was in different tabs of the information window and it made it more time consuming for the respondents to find the information by searching in different tabs.

Table 5: The results of question #2 of the cognitive test

	Number of correct answers		
Questions	**BIM model**	**2D drawings**	**Combination of BIM model and 2D drawing**
What type name of window?	6	17	11
What are the dimensions of the window?	16	11	17
What is the material of the window?	14	9	17
What is the color code of the window?	6	7	17
What is the opening type of the window?	1	4	11
Average point of question 2 (from 5 points)	2.37	2.58	3.74

The third question was about dimensions of a room in the building. The goal with this question is to analyze which information source can work more efficient with measurements. In the first chapter of the test the attendances needed to measure the room in BIM model using ‘’Dimensions” function in Solibri. It was explained to the attendances who did not know how to use this function. In the second chapter (2D drawings) and third chapter (combination of 2D drawings and BIM model) the dimensions of the room and area are both written in the drawing (See figure 36,37 & 38). Respondents got the worst result from BIM model in this question (average point of 0.92/2) and it was observed that measuring straight distance between two walls is difficult in 3D environment (see Table 6). Even though respondents got better results for this question (average points of 1.84/2) from 2D drawings, it was observed that due to several layers of information in the drawings, all the respondents except one, missed the measurements written in the drawings. They measured the dimensions manually using measurement tool in Bluebeam software. On the other hand, the respondents got the best result from this question in combination chapter (average point of 1.87/2). The drawings used in the combined model in third chapter is cleaned up and only needed information that couldn’t be found in the BIM model is included, e.g., dimensions, areas and functions of the rooms. It had made it easier for the respondents to not miss the information written in the drawing due to time limit and mental workload.

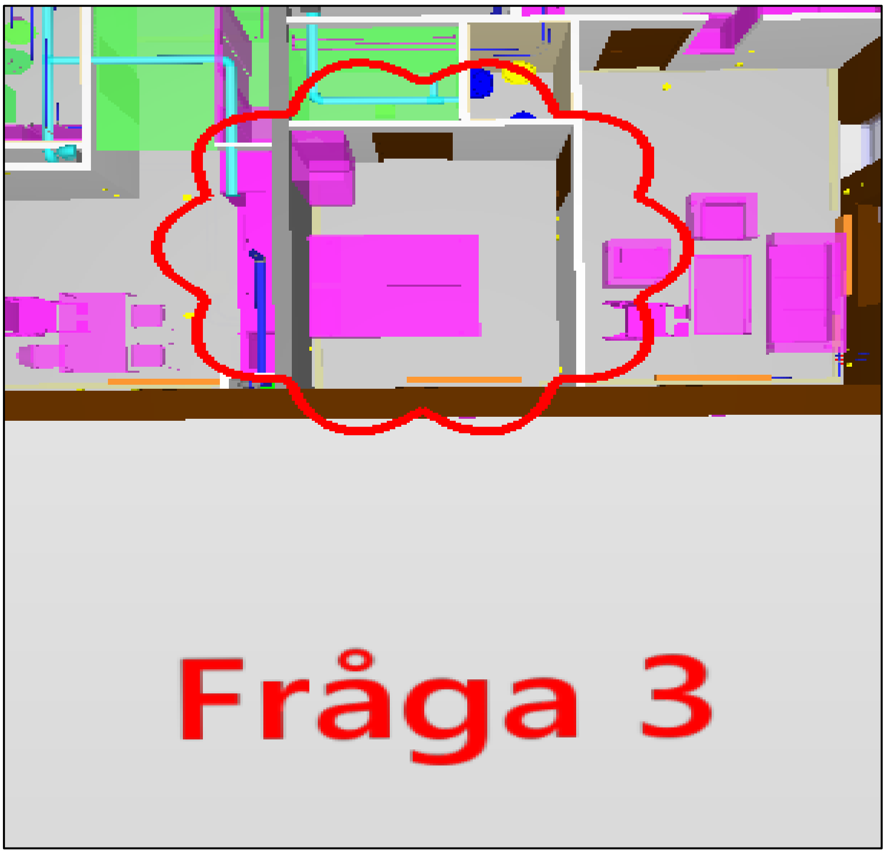


Figure 36 - Chapter 1, question 3 (Authors’ own image)

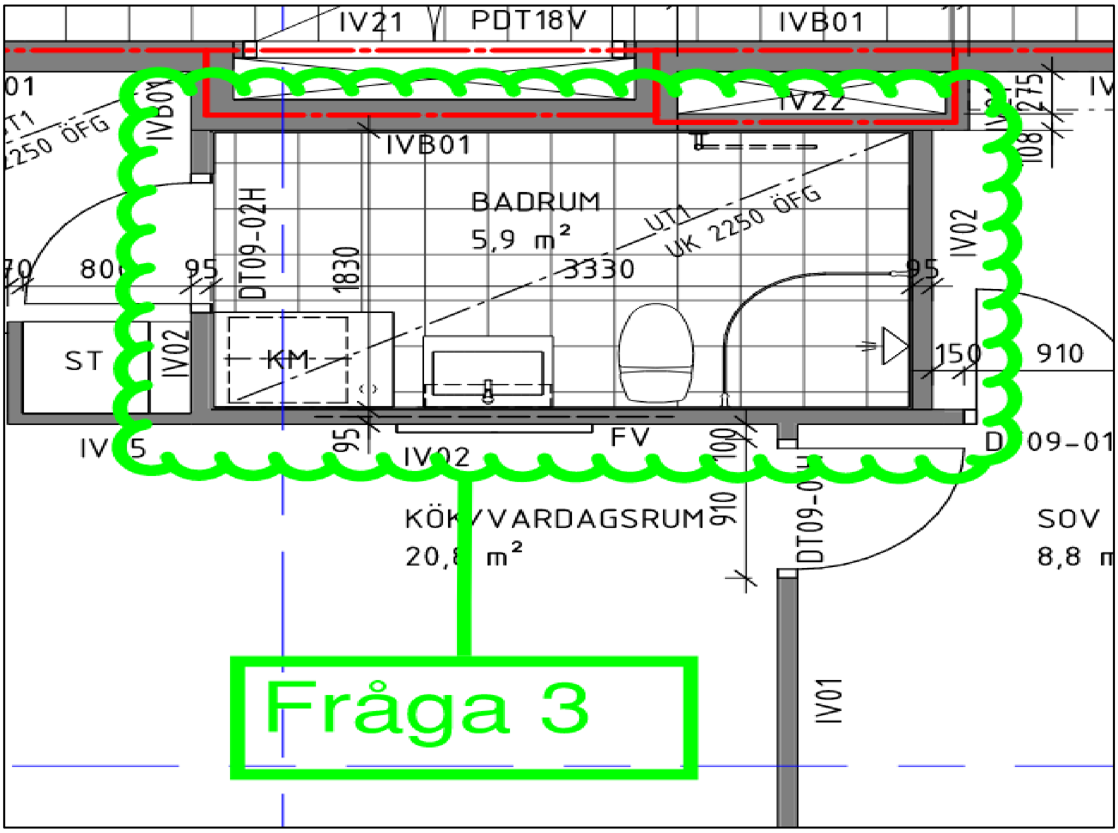


Figure 37 - Chapter 2, question 3 (Authors' own image)

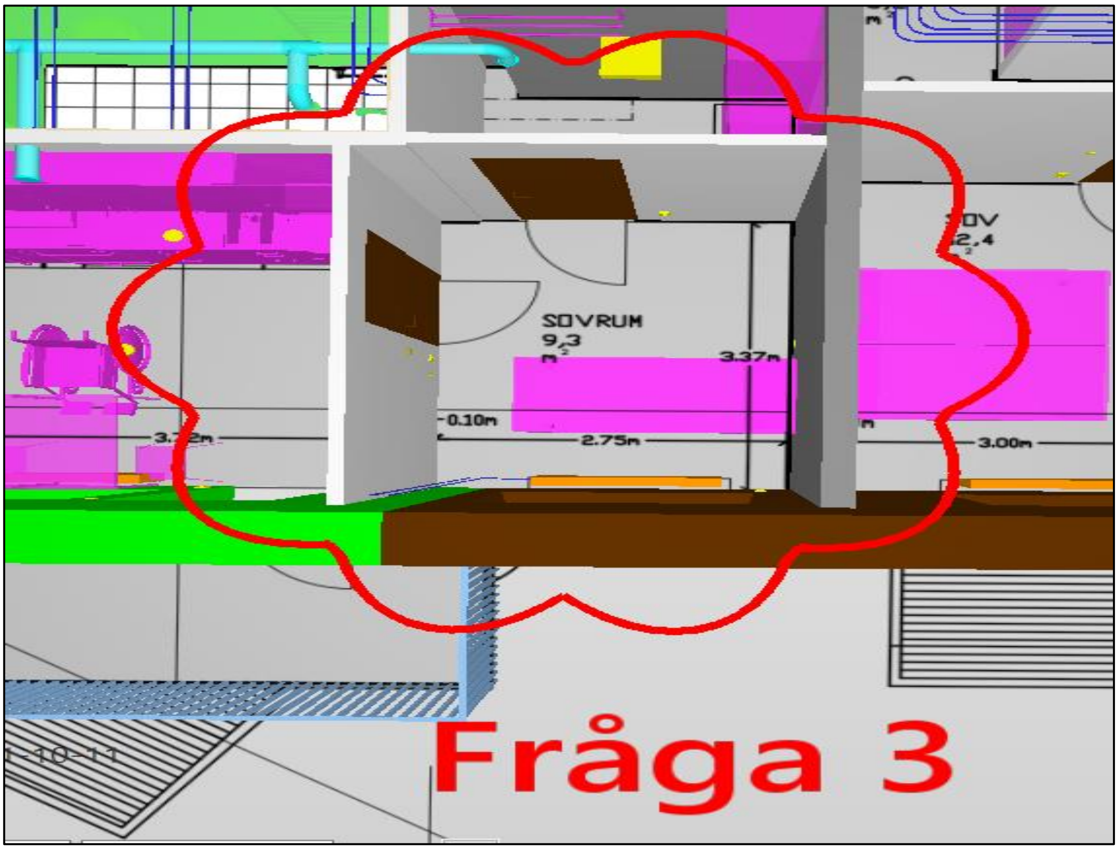


Figure 38 - Chapter 3, question 3 (Authors' own image)

Table 6: The results of question #3 of the cognitive test

Questions	Number of correct answers		
	BIM model	**2D drawings**	**Combination of BIM model and 2D drawing**
What are the dimensions of the room?	13	19	19
What is the area of the bedroom?	6	16	17
Question 3 (2 points)	0.92	1.84	1.87

The fourth question was specifically about finding information related to plumbing and ventilations. Information including the distances, dimensions and collisions. In BIM model finding the information seemed easy by clicking on each pipe or ventilation channel (See figure 39, 40, 41, 42 & 43). Even collision was clearly visible by navigating through the model. The results were better in the BIM chapter (average point of 3.05/5) in comparison with drawings chapter (2.26/5). In this question, the same as other questions, respondents got the best results from third chapter (combination of BIM model and 2D drawing) with the average point of 4.05/5 (see Table 7). The observation demonstrated that in the 2D drawing chapter, finding out the collision was very difficult and needed a series of calculations and spatial abilities while it was visually obvious in BIM model and the combined model. It led to only 2 correct responses for sub-question about collision in the chapter of 2D drawings, which was observed that the respondents just guessed it, while 7 correct answers in BIM model and 9 correct answers in combination of BIM model and 2D drawings (see Table 7).

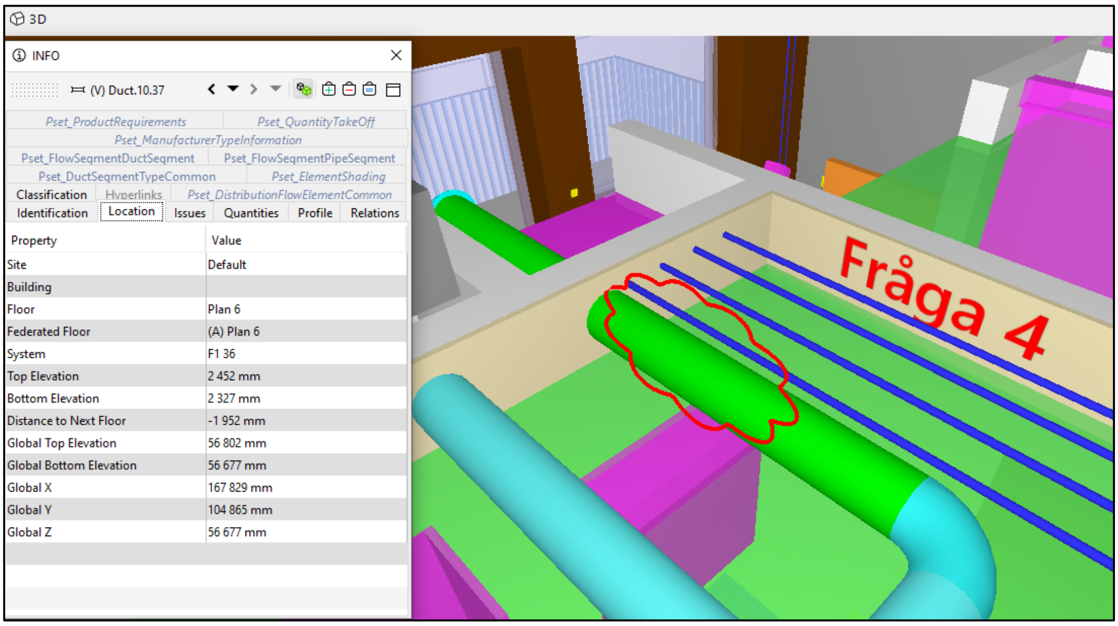


Figure 39 - Chapter 1, question 4 (Authors' own image)

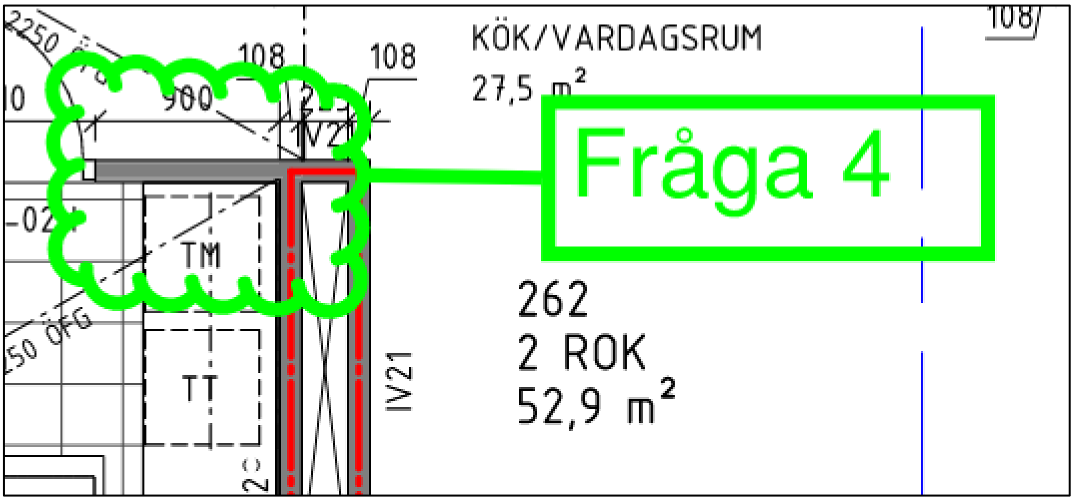


Figure 40 - Architectural drawing of chapter 2, question 4 (Authors' own image)

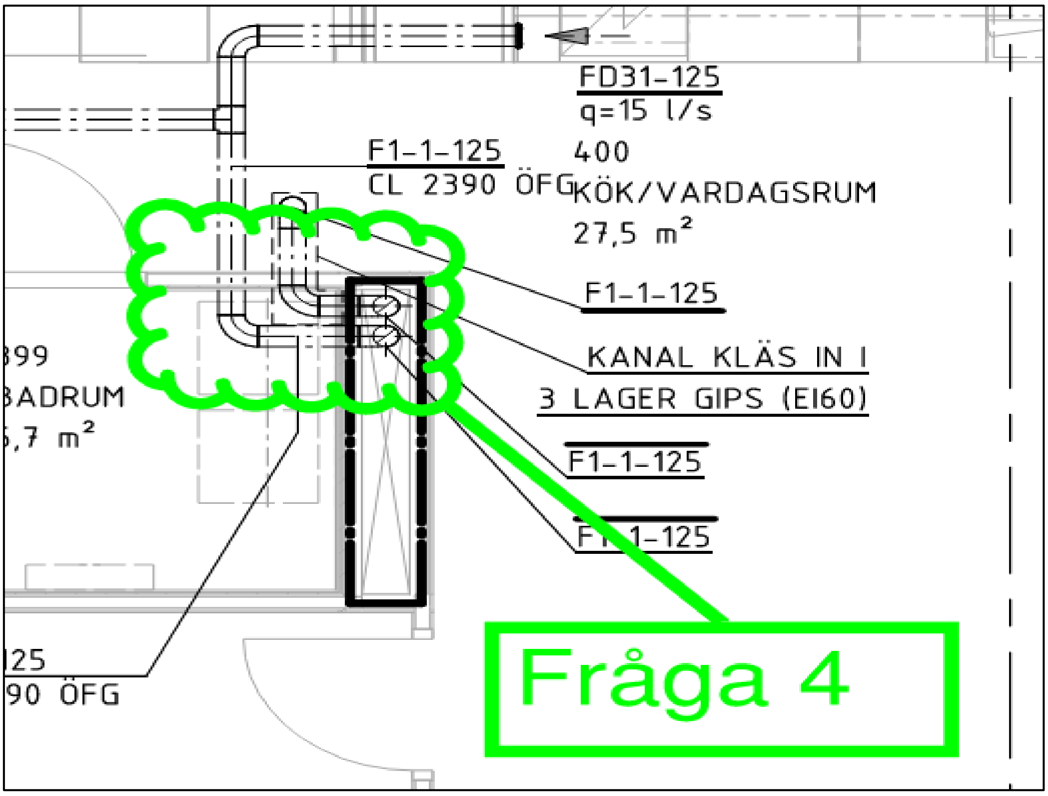


Figure 41 - Ventilation drawing of chapter 2, question 4 (Authors' own image)

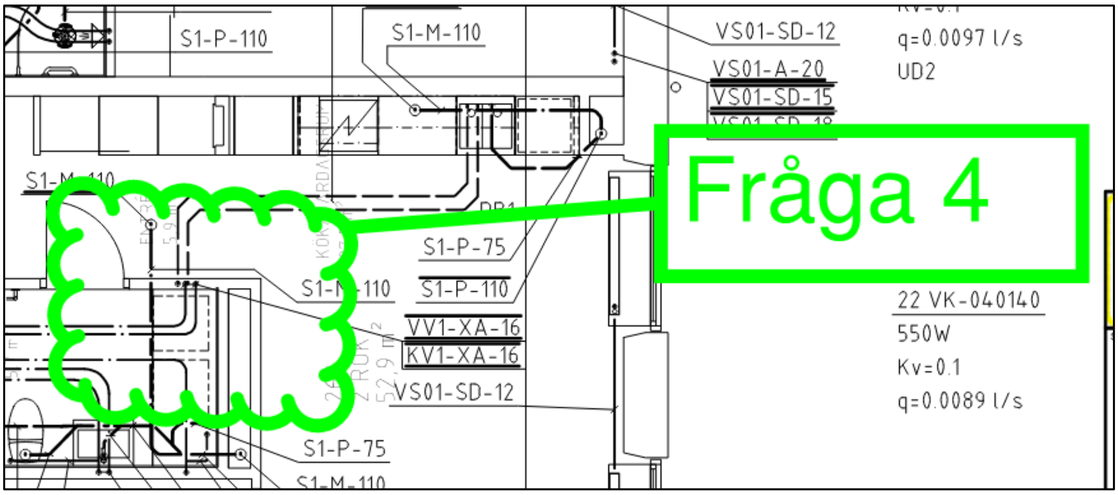


Figure 42 - Plumbers drawing of chapter 2, question 4 (Authors' own image)

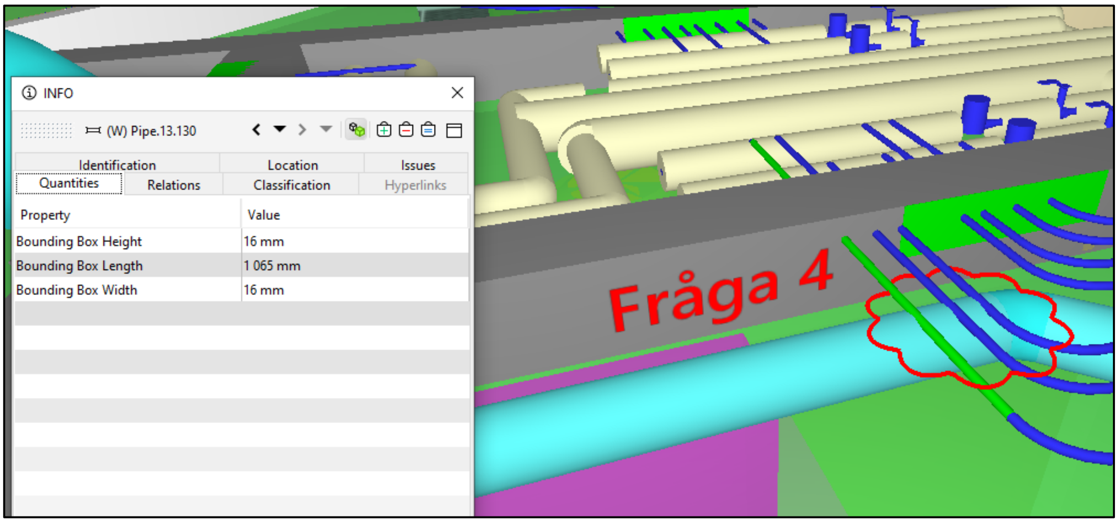


Figure 43 - Chapter 3, question 4 (Authors' own image)

Table 7: The results of question #4 of the cognitive test

	Number of correct answers		
Questions	**BIM model**	**2D drawings**	**Combination of BIM model and 2D drawing**
How high over the finished floor the ventilation channel will be installed?	14	15	12
What are the dimensions of ventilation channel?	14	14	13
How high over the finished floor warm water pipes will be installed?	12	2	11
What are the dimensions of warm water pipes?	9	11	10
Is there any collision between ventilation channel and warm water pipes?	7	2	9
Average point of question4 (5 points)	3.05	2.26	4.05

In total, respondents got significantly better points from the last chapter. After the combination of BIM model and 2D drawings, they did better in BIM model and the worst result belong to drawings chapter in total (see Table 8).

Table 8: The results of the cognitive test

	BIM model	2D drawings	Combination of BIM model and 2D drawing
Question #1 (5 Points)	4.26	2.47	4.53
Question #2 (5 Points)	2.37	2.58	3.74
Question #3 (2 Points)	0.92	1.84	1.87
Question #4 (5 Points)	3.05	2.26	4.05
Total score (17 points)	10.61	9.16	14.18
Mental demand (1-10)	5.84	4.42	6.95
Performance (1-10)	4.84	4.37	5.74
Frustration (1-10)	5.68	5.32	6.84

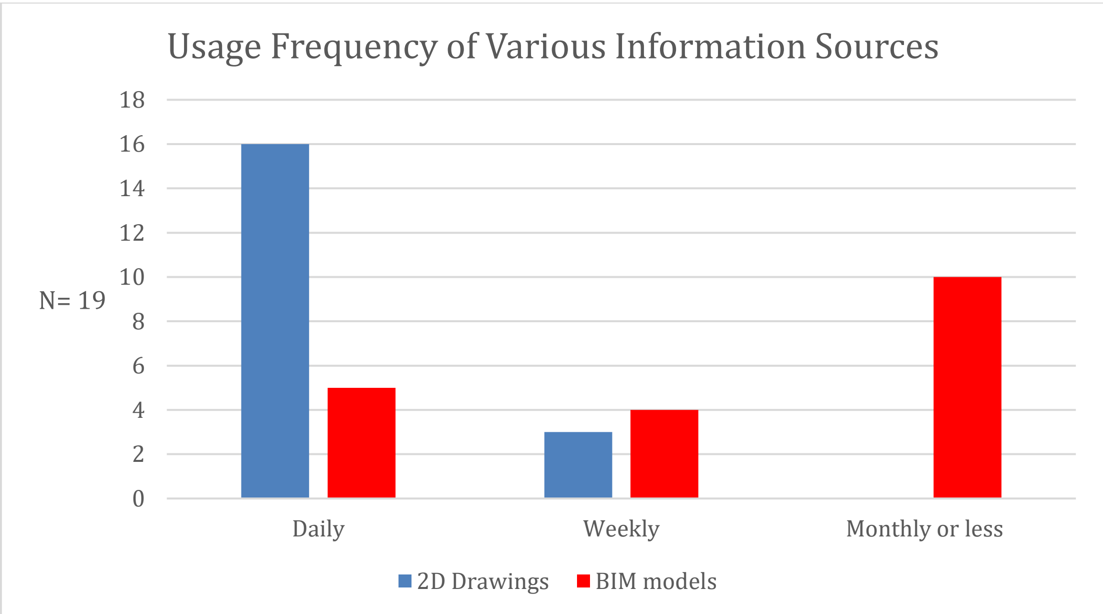


Figure 44 - Test respondents usage frequency of various information sources (Authors' own image)

4.2.2 Analysis of the Cognitive Test

After each test, a series of questions was asked from the attendances about their experience of the test. They also gave score to each chapter of the test in the scale of 1 to 10 related to how heavy the workload was, how did they perform and how frustrated they became. In their opinion, based on the average points of complimentary questions, the workload was the lightest and they were the least frustrated in the third chapter (combination of BIM model and 2D drawings). They also believed that they performed better in the combination chapter. The total scores that they took from different chapters also confirms this belief. Some of the respondents did not have experience with BIM models or working with Solibri and before taking the test they believed that they will perform better in drawings. But in most cases the opposite was proven. The test results clearly show that in the same time limit, using BIM models for finding information in construction phase is faster, easier and more efficient. It is also proven that if we use 2D drawings for presenting some information that BIM model cannot show them proper enough, or it is time consuming to use BIM models for taking out that information, we can optimize the performance of information flow significantly.

It was asked from the respondents about any comments they had in relation to the test. After doing the test, most of the respondents believed that they are certain that using BIM models as the construction information source is faster and easier than the drawings. About the last chapter of the test, some of attendances pointed out clearly that by doing the test they realized that information missed in BIM models can be completed by drawings as a combination and the combination is a good material for being the main information source. Some of the attendances which did not believe in the BIM models before, changed their mind about that after they saw how much faster and easier it went with the models and specially with combination.

There were also some negative comments about the BIM model. Some participants believed that measuring distances and dimensions is very hard in the BIM models. But most of the respondents believed that the main problem with BIM models is lack of experience and education. Some also pointed out that BIM models are not always like the model used in the test including all the information needed in the project. On the other hand, after the test there were a lot more negative comments about the drawings. E.g., some commented that it is very time consuming to find information from drawings, plumbing and ventilation drawings are very difficult to read, information in drawings can be missed under time pressure etc.

19 people attended in the test and all of them are professionals and labors from different disciplines, but all working with construction phase within the investigated projects. 6 of the respondents are project engineers, 4 of them are site managers, 4 of them are installation engineers and 5 of them supervisors and labors. In total, all the attendances performed the best in combination of BIM model and 2D drawings. On the other hand, all the attendances except site managers performed better in BIM models in comparison with 2D drawings. In this case, site manages perform the same in both drawings and BIM model in total.

There are some contradictions in what the respondents think of their performance and how they really performed. Installation engineers believed that they were more frustrated in BIM models and they also believed that they performed better in drawings. But actual results show that they did better in BIM model significantly. Installation engineers were the people who worked only with drawings and they had resisted towards BIM model by scoring the drawings as the part they did the best in.

4.3 Correlations Between Questionnaire and Cognitive Test

The correlations analysis shows that respondents who answered in the questionnaire that BIM architectural models are less time consuming to use, were more frustrated with the drawings in cognitive test. In addition, respondents who take information on materials and also do the measurements more often from BIM models, had perceived that they had better performance with BIM models during the cognitive test.

On the other hand, the workload that the respondents experienced with the drawings during the cognitive test correlate negatively with the holistic view that BIM models provide for them based on their responds in questionnaire. It means that the respondents of questionnaire who believed that they take a better holistic picture from BIM models experienced more frustration with 2D drawings in the test.

On the other hand, correlation analysis demonstrates the influence of different questions in the test. By this analysis it can be interpreted that what information is more efficient to taken from BIM models and what information can be perceived better from drawings. The results from the chapter of BIM models in the cognitive test have a strong positive correlation with first question and fourth question (see Table 9). It means that information take-off from different building elements and also collision control were the tasks that affected the results in BIM models significantly positive. So, it is very efficient to do these tasks in BIM models during construction works. In addition, the mental workload that the respondents experienced during the test in BIM chapter correlate positively with the results of question 4 in BIM chapter (see Table 10). It means that clash controls and information take-off from ventilation and plumbing models requires significantly lower mental workload.

Table 9: Correlations between Results of cognitive test in BIM chapter and related variables

Variable	R (*p*-Value)
BIM, question 1: Information take-off from a specified wall.	**0.824****
BIM, question 4: Information take-off and clash control of plumbing and ventilation installation.	**0,842****

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed)

Table 10: Correlation; How the mental workload did you experienced during the test in BIM chapter?

Variable	R (*p*-Value)
BIM, question 4: Information take-off and clash control of plumbing and ventilation installation.	**0.583***

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed)

The frequentness of using BIM based on survey, has positive correlation with the frequentness of measuring in BIM models and negative correlation with the results of question number 3 in BIM chapter (see Table 11). It means as much as BIM models are used more, the result of measuring in BIM models were low. It shows that it is not very efficient to use BIM models for measurements. The experience of performance in the cognitive test based on the respondents' opinion correlate negatively with question number 3 in 2D drawings' chapter, which was about measuring in drawings. The performance interpretation was proportionally low in 2D drawings but the results of this question was significantly good (see Table 13). It shows that during the cognitive test using dimensions and measurements in 2D drawings seem to be efficient in comparison with other questions.
Regarding the correlation analysis and the results from tests it can be concluded that information take-off and clash controls work better in BIM models but taking out dimensions and measuring in 2D drawings are the strength of 2D drawings.

Table 11: Correlation; How often do you use BIM models?

Variable	R (*p*-Value)
Cognitive test - BIM, question 3: Dimensions and area of a specified room	-0.638*
Survey: How often do you take out dimensions from BIM models?	0,531*

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed)

Table 12: Correlation; Results of cognitive test in drawing chapter

Variable	R (*p*-Value)
Cognitive test – 2D drawings, question 1: Information take-off from a specified wall.	0,553*
Cognitive test – 2D drawings, question 2: Information take-off from a specified window.	0,808**
Cognitive test – 2D drawings, question 4: Information take-off and clash control of plumbing and ventilation installation.	0,680**

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed)

Table 13: Correlation; How did you performed during the cognitive test in the chapter of 2D drawing?

Variable	R (*p*-Value)
Cognitive test – 2D drawings, question 3: Dimensions and area of a specified room	-0,616**

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed)

5 Discussion of Findings

This chapter is a discussion on the literature review and empirical study and also conducts a comparison between theoretical findings and empirical results. The discussions take place in order to prepare an overall analysis to draw the conclusion in the next chapter.

5.1.1 Human Perception of Construction Information

Based on the systematic literature review conducted through this thesis, two specific parameters affect humans in perceiving information; Cognitive workload demands and contiguity principals. Based on studies done by Groen and Baker (2019) and Snow et al. (2014), human brain perceives the information presented in 3-dimensional representations the same as real-life experience. It means that cognitive perception of 3D representations is faster, easier and more practical. On the other hand, by emerging BIM in construction industry, it is possible to gather all the information needed for construction phase from all the disciplines in one 3D model as the main information source (Czmoch & Pękala, 2014). But it is still not accepted by the construction industry that the long working hours for educating the employees are worth the benefits of BIM within the organizations (Czmoch & Pękala, 2014). It was demonstrated by the survey in this thesis that 36 % of professionals within the investigated projects almost never use BIM models and 30% of them only use the models a few times a week. On the other hand, results of the test pointed out that using BIM models for information take-off and clash controls in construction phase can be significantly easier and faster than 2D drawings. It applies even to users who do not have any previous experience with BIM models. It demonstrates that BIM models are not yet taken serious enough among professionals.

By taking one more step into the details, the specification documents are complimentary information sources for 2D drawings which are presented separately (Bröchner and Silfwerbrand, 2019). But Holsanova et al. (2009) indicates that if text is presented separated from graphics, the contiguity principals are not followed dedicatedly and the whole information will be hard to grasp. In cognitive test conducted in this thesis, in terms of contiguity principles, searching for information from different drawings or finding information related to a drawing from another document (specifications) proved to be distracting and time consuming. This matter is already solved in BIM models and it was demonstrated in the test that having written information in the same environment in the model helps the users stay focused and make less mistakes. On the other hand, in the third chapter of the test, BIM model combined with 2D drawings provided high degree of contiguity which resulted in significantly better outcome.

Literature review revealed that precisely after finishing a task, questioning the person who did the task about the difficulty of the task can define the needed mental workload for the task (Hart, 2006; Dadi, Goodrum, et al., 2014). This self-evaluating method is called NASAs' Task load index. This method is used after each session of the cognitive test and participants were asked about the mental workload they experienced and also their opinion about how they performed in different chapters of the test. Based on results of cognitive test and participants' opinions, in terms of mental workload, too much information in the drawings and also navigating between several drawings to find information related to one building element, make users frustrated and waste a lot of time. This matter is solved in BIM models by the help of information windows attached to all building elements. On the other hand, there is a difficulty in BIM models for measuring in 3D environment. By preparing 2D drawings which include only information that is missed in BIM models and adding them as layers to the BIM model, the models can be completed, and the flaws can be covered.

It was also demonstrated within this paper that in construction industry, the performance of professionals with 2D drawings is not going to improve through experience in a holistic approach in the whole industry in general. These 2D representations of construction information are being around for thousands of years and they've been legal construction documents since the beginning of construction regulations (Babic & Rebolj, 2016). As a result, almost all the professionals in construction industry are familiar with the construction documents and most of them are using 2D drawings regularly every working day. Through the results of survey conducted within this thesis, it was revealed that 86% of professionals in the investigated projects use the 2D drawings every workday and the rest use it at least a few times a week. But only 34% of the respondents use BIM models every day and 36% never use them. But during the test it was demonstrated that respondents with almost no experience in BIM models are able to use it by a very brief presentation of some basic features. They also got better results in the combination of BIM and 2D drawings, based on their opinion and observations, by experiencing the BIM model for a few minutes in first chapter. It can demonstrate that professionals' performance in BIM models can be improved through experience. But this improvement is proved that does not apply on 2D drawings. It is clearly proven by analysis of the survey that the frequentness of using BIM models correlate positively with how easy it is to navigate in BIM models. In other words, as much as one use BIM more often, it becomes easier to use BIM models and take information from them. This correlation does not apply to 2D drawings on the individual level in investigated projects.

Based on the results of the test, respondents' comments and observations, even some respondents with more experience in working with BIM models predicted that they would perform better in the drawings. It is also demonstrated that more often using the BIM models does not correlate directly with how reliable BIM models are. All these mentioned findings can point out the bias in confirming the fact that BIM models can provide faster, easier and more reliable information take-off and mental workload among professionals in investigated projects. This is also supported with literature review, that while BIM models are being around for at least one decade, still companies and also individuals cannot see benefits in putting BIM models in use (Gustavsson and Vass, 2017). This resistance to change can be solved by making professionals more aware of the benefits they can have from using BIM models as main information sources.

5.1.2 Utilization of Construction Information

Selected literature emphasized that by using BIM models a lot of benefits will be provided for the professionals individually and also in an organizational level. E.g., BIM models provides the possibility to gather all the information from different disciplines in one 3D model and turn the 3D model into the main source of information (Jongeling, 2008). As a result, communication between different teams becomes more efficient. Clash detections and information take-off also become faster and more accurate (Azhar, 2011). BIM also opens up new possibilities for applying new technologies to the construction projects such as implementing 4D and 5D simulations (Jongeling, 2008; Leon, van Berlo, Mathijs Natrop, 2015). The empirical study also revealed that information take-off, clash detection and the holistic view that BIM models provide are significantly more efficient from the drawings. It is also demonstrated in the field of neuroscience that using 3D models provide a real-life experience in perceiving information and having both graphical and written information in one place help the user to perceive information better which provides proper mental workload (Groen and Baker, 2019; Holsanova et al. 2009; Dadi, Goodrum, *et al.,* 2014). In the case of 2D drawings and specifications, it is also revealed through selected literature that these representations of construction information benefitting from being used for so long, are very familiar among the professionals and it makes 2D drawings easy to use. Using them for a long time have made them developed a lot (Babic & Rebolj, 2016). The level of accuracy in explanation that 2D drawings provide is so high and it makes it possible to search for all needed information from different disciplines (Bergenudd, 2003; Jongeling, 2008). Empirical study disclosed that existing information within the drawings, such as accurate dimensions, support the accuracy of the construction work.

Although that the flow of information enhances using BIM models, it sets a high demand on how the information is set in the BIM models (Jongeling, 2008). Furthermore, there are some shortcomings in all mentioned documents. BIM models are affected a lot by human errors and a small defect in the model or in how to use different features within the model can cause large-scale problems (Czmoch & Pękala, 2014). In addition, models due to not being legal documents and proportionally new in the industry, effects the projects with lack of knowledge and experience in their usage (Czmoch & Pękala, 2014). Empirical study also demonstrated that measuring distances are difficult in 3D nature of BIM models and classifications of information are not quite well-done even in high quality models which can also cause misunderstandings and time waste. Drawings and specifications also have lots of shortcomings within their nature. They're mostly separated from each other and come in different pages and in large numbers of documents (Babic & Rebolj, 2016). It makes the drawing difficult to perceive in terms of contiguity principals, which causes heavy mental workload for the reader (Dadi, Goodrum, *et al.*, 2014;). 2D drawings are also hard to interpret by all of professionals because of many layers of information and large amounts of used symbols (Jongeling, 2008; Lam, Kumarswamy and Ng,2001). Empirical study also demonstrated that navigating between drawings and specifications causes significantly much time waste and errors. It also admitted that different layers of information cause the reader to miss some information which already exists in the drawings. Some kinds of information quality check such as clash control is almost impossible in some cases like installations and plumbing because of lacking the real-life 3D views in drawings.

In general, the problems that the medium of drawings and specifications cause in construction projects were proved to be more damaging and time wasting. This leads larger problems such as cost waste and rework. In addition, drawings have taken their full potential already and it is not expected that they will develop further. On the other hand, BIM models are still developing and a way far from their full potential. The empirical study showed that the lack of experience and confirmation bias could be the main reasons that the industry is still doubting in BIM models to become the main source of information. In the last chapter of cognitive test conducted in this thesis, it is demonstrated that for today's state of BIM models and professionals' skills, a combination of BIM models and 2D drawings can provide an information source with the best results. In this method 2D drawing is added as a visible layer to BIM model. Shortcomings of BIM models such as measurements and information classifications, can be fulfilled by written dimensions and information of 2D drawings. Shortcomings of 2D drawings such as being consisted of too much different materials and layers, can also be fulfilled by contiguity and real-life experience of perceiving information that BIM models provide.

6 Conclusion and Suggestions

In today's construction industry 2D drawings and specification documents are considered as legal construction documents and important parts in procurement of the projects. The investigated projects is not an exception in this case. BIM models are mostly used for supporting 2D drawings in construction projects. As a result, professionals in construction sector are mostly not experienced with using BIM models as a regular source of information. Following that, BIM models are not developing well enough to be efficient sources of information. The results are unexperienced professionals in using BIM models, inefficient BIM models and dependency on 2D drawings as the main and legal sources of information.

6.1 Human Perception of Construction Information

On the other hand, both empirical and literature studies in this thesis have demonstrated that BIM models can be faster and easier to use and even more accurate sources of information. The cognitive perception that BIM models provide for the users is significantly higher than 2D drawings. But lack of experience and education in using BIM models among the professionals in construction sector results in resistance towards changing the main source of information from 2D drawings to BIM models. This resistance is a product of confirmation bias in individual level and not specified BIM models' benefits in business models in organizational levels. Both these reasons of resistance towards change comes from not enough information about efficiency of BIM models. This thesis and especially the cognitive test demonstrated practically that benefits of BIM models in an individual levels, which are higher cognitive perception and lower mental workload, can result in organizational benefits, such as less error, time waste and rework.

6.2 Structure of Construction Information Sources for Improving Cognitive Workload

2D drawings are more familiar for professionals within the construction industry and they provide a lot of accurate information. But it is time consuming and difficult to grasp this information because of being presented in many separated documents. BIM models are not familiar to use among all professional but very easy and fast to take the information from. They also provide fast holistic view of the final outcomes. The only problem is lack of experience which discourages the organizations to spend the time and money for having more developed BIM models and educate their employees. A solution presented in this thesis for promoting BIM models and also making them even easier to use is having specific 2D drawings as additional layers in BIM models which are visible as a part of the models. Through this method, the information that needs more experience to be taken from BIM models including measurements and unit numbers, can be provided by 2D drawings simultaneously and instantly in BIM models. In addition, it encourages the professionals to use BIM models. The cognitive test conducted in this thesis clearly demonstrated that by having 2D drawings in BIM models, using BIM models feels a lot easier especially for the users with less experience in BIM models. It can result in more frequently usage of BIM models, faster and more accurate information take-offs, and moving towards a BIM-based industry. In this case, 2D drawings will be produced to support

BIM models instead of producing low quality BIM models for supporting only the holistic vision of massive number of 2D drawings. It also reduces the need of having too much information in 2D drawings that are even difficult to read them. 2D drawings can only include specific information for complementing the BIM models such as dimensions and measurements, area of the spaces, apartment numbers, construction details etc.

Having BIM models as the main source of information requires also solving improper information classifications. The information exported by IFC files should be classified based on proper BIM manuals accurately in order to not cause the same experience of information take-off in 2D drawings. Having too many information tabs can provide the same experience of having too many separated 2D documents. This thesis emphasizes that it is definitely easier to use BIM models than 2D drawings, it is fast to learn how to use BIM models and the resistance towards changing to BIM-based industry is due to confirmation bias. This thesis also shows ways of simplifying BIM models even more for unexperienced professionals. Following these conclusions, how to design organizational change plans towards total BIM-based industry and different IT methods to develop BIM models supported by 2D drawings can consist further studies in this topic.

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8 Appendices

8.1 Appendix 1: Questionnaire

Nulägesanalys utav användande och upplevelser av bygghandlingar

Vi är två studenter från Chalmers och skriver just nu på vårat examensarbete, detta gör vi ihop med Skanska Region Hus Göteborg och det är också därför som vi frågar er om ni kan delta i vårat formulär.

Formuläret undersöker hur dagens bygghandlingar används och upplevs. Från resultatet av detta formulär kommer det efteråt att ske en analys kring vilka bygghandlingar som upplevs lättare respektive svårare att ta till sig nödvändig information. Formuläret förväntas ta cirka 10-15 minuter att fylla i och sista datumet för att svara på formuläret är satt till den 26:e september.

Deltagande i detta webbformulär är helt frivilligt och alla svar kommer att redovisas anonymt.

Ett tips om ni använder er utav en surfplatta eller smartphone för att svara på detta formulär, är att rotera på eran enhet till horisontellt läge för att enklast kunna se alla svarsalternativ.

Vi hade varit jättetacksamma om ni kan ställa upp och svara på vårat formulär!

Vid frågor eller funderingar, vänligen kontakta oss på:
bjorn.engman.otreus@skanska.se
eller
sam.nemati@skanska.se

Tack på förhand!
Björn Engman Otréus & Sam Nemati

otreus.b@gmail.com Byt konto

*Obligatorisk

E-post *

Din e-post

Nästa   Sidan 1 av 6   Rensa formuläret

Generell information

Vad har du för jobbtitel? *

- ◯ Projektchef
- ◯ Produktionschef
- ◯ Projektingenjör
- ◯ Arbetsledare
- ◯ Yrkesarbetare
- ◯ Övrigt: ______

Vilken disciplin tillhör du / vilka ansvarsområden har du? *

- ☐ Betongarbetare
- ☐ Brand (ex. Fogning)
- ☐ El
- ☐ Fasad (ex. Murare)
- ☐ Golv (ex. Plattsättare / Parketläggare)
- ☐ Inköp
- ☐ Mark
- ☐ Prefab / Stomme
- ☐ Styrinstallationer
- ☐ Tak (ex. Plåtslagare / Tätskiktsmontör)
- ☐ Träarbetare (ex. Inrede / stomkomplettering)
- ☐ Ventilation
- ☐ VVS
- ☐ Övergripande ansvar (ex. Produktionschef)
- ☐ Övrigt: ______

Inom vilket produktområde jobbar du? *

- [ ] Kommersiella fastigheter
- [ ] Bostäder

Vilken är din högsta genomförda utbildningsnivå? *

- ○ Grundskola
- ○ Gymnasiet
- ○ Yrkeshögskola
- ○ Högskola

Vad var det för inriktning på din utbildning? (ex. Byggnadssnickare, Väg och vatten, etc.) *

Ditt svar

Antal år som du arbetat inom byggbranschen? *

- ○ 0-1 år
- ○ 1-5 år
- ○ 5-10 år
- ○ +10 år

Bakåt Nästa Sidan 2 av 6 Rensa formuläret

Ritningar

Med "ritningar" avses i detta formulär både 2D-Ritningar och uppställningsritningar

Hur ofta använder du ritningar?

- ○ Dagligen
- ○ Någon gång i veckan
- ○ En gång i månaden eller mer sällan

På vilket sätt läser du ritningar?

- ☐ Pappersformat
- ☐ Digitalt

Hur ofta hämtar du informationstyperna nedan från ritningar?

OBS! Om du använder surfplatta eller smartphone, rotera på eran enhet till horisontellt läge för att enklare kunna se alla svarsalternativ.

	Aldrig	Sällan	Ibland	Ofta	Väldigt ofta
Mängder (Antal, storlek, volym)	○	○	○	○	○
Mått / Avstånd	○	○	○	○	○
Littera (ex. slagning, ljudkrav, beslagskod, brandklass etc.)	○	○	○	○	○
Konstruktionsdetaljer	○	○	○	○	○
Byggdelstyp (ex. väggtyp)	○	○	○	○	○
Material	○	○	○	○	○
Läge (ex. trapphus och plan)	○	○	○	○	○
Höjder (ex. installationshöjd)	○	○	○	○	○
Jämförelser utav ändringar	○	○	○	○	○

Ritningar är pålitliga informationskällor under bygghandlingsskedet

	1	2	3	4	5	
Instämmer inte alls	○	○	○	○	○	Instämmer i hög grad

Om du INTE tycker att ritningar är pålitliga, ge ett exempel / kort kommentar på varför du tycker så

Ditt svar

Hur upplever du det att bläddra mellan olika ritningar? (Ex. Från planritning till specifik detaljritning)

	1	2	3	4	5	
Väldigt svårt	○	○	○	○	○	Väldigt enkelt

Om du INTE tycker det är enkelt att bläddra mellan olika ritningar, ge ett exempel / kort kommentar på varför du tycker så

Ditt svar

Betygsätt (från 1 till 5) de olika ritningstyperna utifrån hur viktiga du anser att de är

1= Inte viktig och 5= Väldigt viktig. Om det finns någon ritningstyp som du aldrig använt dig utav, lämna denna blank.

	1	2	3	4	5
Arkitektritningar	○	○	○	○	○
Brandritningar	○	○	○	○	○
Elritningar	○	○	○	○	○
Konstruktionsritningar	○	○	○	○	○
Konstruktionsritningar Prefab	○	○	○	○	○
Landskapsritningar	○	○	○	○	○
Sprinklerritningar	○	○	○	○	○
Styrritningar	○	○	○	○	○
Ventilationsritningar	○	○	○	○	○
VS-ritningar	○	○	○	○	○
Detaljritningar	○	○	○	○	○
Fasadritningar	○	○	○	○	○
Sektionsritningar	○	○	○	○	○

Betygsätt (från 1 till 5) de olika ritningstyperna utefter hur väl du upplever användarvänligheten för att hitta nödvändig information

1= Väldigt svårt och 5= Väldigt enkelt. Om det finns någon ritningstyp som du aldrig använt dig utav, lämna denna blank.

	1	2	3	4	5
Arkitektritningar	○	○	○	○	○
Brandritningar	○	○	○	○	○
Elritningar	○	○	○	○	○
Konstruktionsritningar	○	○	○	○	○
Konstruktionsritningar Prefab	○	○	○	○	○
Landskapsritningar	○	○	○	○	○
Sprinklerritningar	○	○	○	○	○
Styrritningar	○	○	○	○	○
Ventilationsritningar	○	○	○	○	○
VS-ritningar	○	○	○	○	○
Detaljritningar	○	○	○	○	○
Fasadritningar	○	○	○	○	○
Sektionsritningar	○	○	○	○	○

Om du INTE upplever det enkelt att hitta nödvändig information på någon utav ritningstyperna, ge ett exempel / en kort kommentar på varför du upplever det så

Ditt svar

Bakåt | Nästa | Sidan 3 av 6 | Rensa formuläret

BIM-modell

Med "BIM-modell" avses i detta formulär en sammanslagen modell av alla discipliner

Hur ofta använder du BIM-modeller?

- ◯ Dagligen
- ◯ Några gånger i veckan
- ◯ Några gånger i månaden eller mer sällan

Vilka programvaror använder du vanligtvis när du hämtar information från BIM-modeller?

- ☐ BIM360
- ☐ Dalux
- ☐ Navisworks
- ☐ Revit
- ☐ Solibri
- ☐ StreamBIM
- ☐ Övrigt:

Hur ofta hämtar du informationstyperna nedan från BIM-modeller?

	Aldrig	Sällan	Ibland	Ofta	Väldigt ofta
Mängder (Antal, storlek, volym)	○	○	○	○	○
Mått / Avstånd	○	○	○	○	○
Littera (ex. slagning, ljudkrav, beslagskod, brandklass etc.)	○	○	○	○	○
Konstruktionsdetaljer	○	○	○	○	○
Byggdels typ (ex. väggtyp)	○	○	○	○	○
Material	○	○	○	○	○
Läge (ex. trapphus och plan)	○	○	○	○	○
Höjder (ex. installationshöjd)	○	○	○	○	○
Jämförelser utav ändringar	○	○	○	○	○

BIM-modeller är pålitliga informationskällor under bygghandlingsskedet

	1	2	3	4	5	
Instämmer inte alls	○	○	○	○	○	Instämmer i hög grad

Om du INTE tycker att BIM-modeller är pålitliga, ge ett exempel / kort kommentar på varför du tycker så

Ditt svar

Hur upplever du det att navigera i BIM-modeller?

	1	2	3	4	5	
Väldigt svårt	○	○	○	○	○	Väldigt enkelt

Om du INTE upplever det enkelt att navigera i BIM-modeller, ge ett exempel / kort kommentar på varför du tycker så

Ditt svar

Betygsätt (från 1 till 5) de olika modellerna utefter hur viktiga du anser att de är

1= Inte viktig och 5= Väldigt viktig. Om det finns någon modelltyp som du aldrig använt dig utav, lämna denna blank.

	1	2	3	4	5
Arkitektmodellen	○	○	○	○	○
Elmodellen	○	○	○	○	○
Konstruktionsmodellen	○	○	○	○	○
Konstruktionsmodell Prefab	○	○	○	○	○
Landskapsmodellen	○	○	○	○	○
Sprinklermodellen	○	○	○	○	○
Ventilationsmodellen	○	○	○	○	○
VS-modellen	○	○	○	○	○

Betygsätt (från 1 till 5) de olika modellerna utefter hur väl du upplever användarvänligheten för att hitta nödvändig information

1= Väldigt svårt och 5= Väldigt enkelt. Om det finns någon modelltyp som du aldrig använt dig utav, lämna denna blank.

	1	2	3	4	5
Arkitektmodellen	◯	◯	◯	◯	◯
Elmodellen	◯	◯	◯	◯	◯
Konstruktionsmodellen	◯	◯	◯	◯	◯
Konstruktionsmodellen Prefab	◯	◯	◯	◯	◯
Landskapsmodellen	◯	◯	◯	◯	◯
Sprinklermodellen	◯	◯	◯	◯	◯
Ventilationsmodellen	◯	◯	◯	◯	◯
VS-modellen	◯	◯	◯	◯	◯

Om du INTE upplever det enkelt att hitta nödvändig information i någon utav BIM-modellerna, ge ett exempel / kort kommentar på varför du tycker så

Ditt svar

Bakåt   Nästa   Sidan 4 av 6   Rensa formuläret

Bygghandlingar

Med "Bygghandlingar" avses både ritningar och BIM-modeller

Betygsätt (från 1 till 5) de olika bygghandlingarna utefter hur mycket tid du behöver för att hitta nödvändig information

1= Mycket tidskrävande och 5= Inte tidskrävande. Om det finns någon bygghandling som du aldrig använt dig utav, lämna denna blank.

	1	2	3	4	5
Beskrivningar (ex. Ram- och typrumsbeskrivningar)					
Arkitektritningar					
Brandritningar					
Elritningar					
Konstruktionsritningar					
Konstruktionsritningar Prefab					
Landskapsritningar					
Sprinklerritningar					
Styrritningar					
Ventilationsritningar					
VS-ritningar					

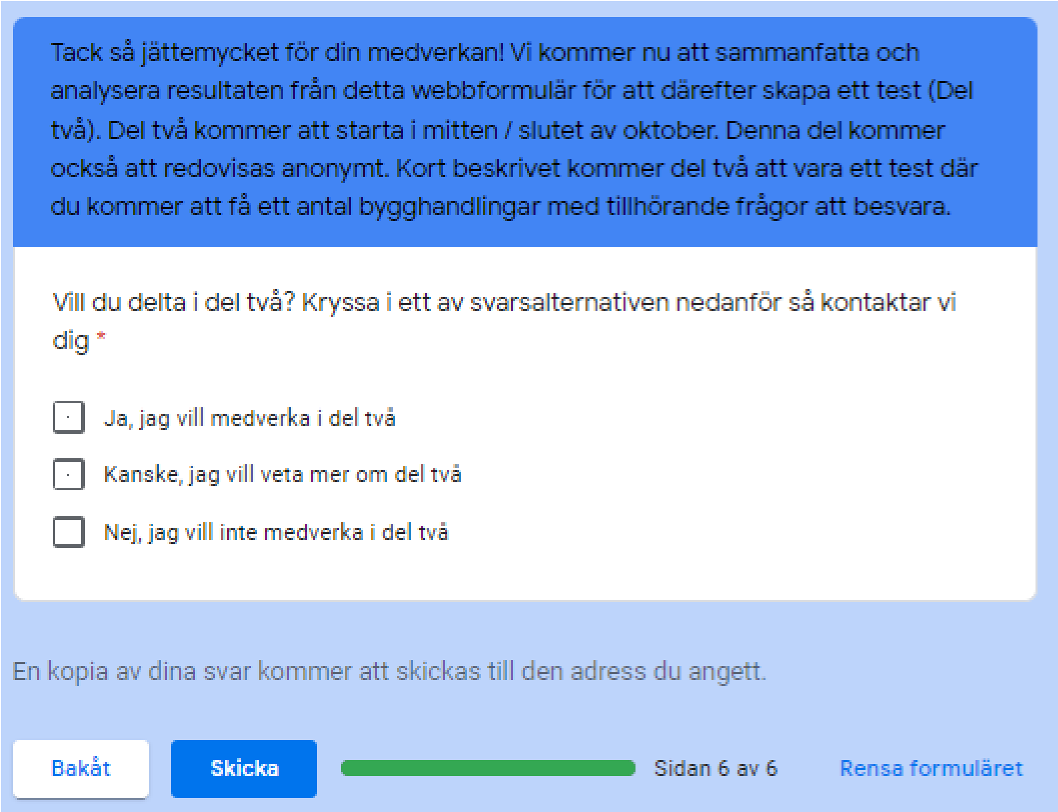
Arkitektmodellen	○	○	○	○	○
Elmodellen	○	○	○	○	○
Konstruktionsmodellen	○	○	○	○	○
Konstruktionsmodell Prefab	○	○	○	○	○
Landskapsmodellen	○	○	○	○	○
Sprinklermodellen	○	○	○	○	○
Ventilationsmodellen	○	○	○	○	○
VS-modellen	○	○	○	○	○

Betygsätt (från 1 till 5) de olika bygghandlingstyperna utefter hur väl de hjälper dig att skapa en helhetsbild utav färdig produkt i början av en arbetsberedning

1= Hjälper inte alls och 5= Väldigt hjälpsam. Om det finns någon bygghandling som du aldrig använt dig utav, lämna denna blank.

	1	2	3	4	5
Ritningar	○	○	○	○	○
BIM-modeller	○	○	○	○	○
Kombination av ritningar och BIM-modeller	○	○	○	○	○

Bakåt Nästa Sidan 5 av 6 Rensa formuläret



Tack så jättemycket för din medverkan! Vi kommer nu att sammanfatta och analysera resultaten från detta webbformulär för att därefter skapa ett test (Del två). Del två kommer att starta i mitten / slutet av oktober. Denna del kommer också att redovisas anonymt. Kort beskrivet kommer del två att vara ett test där du kommer att få ett antal bygghandlingar med tillhörande frågor att besvara.

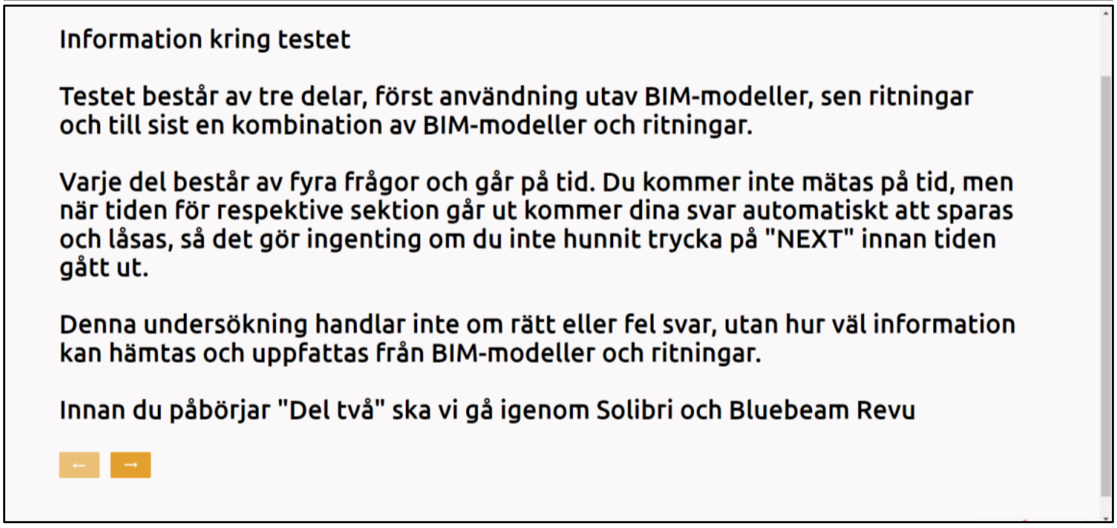
Vill du delta i del två? Kryssa i ett av svarsalternativen nedanför så kontaktar vi dig *

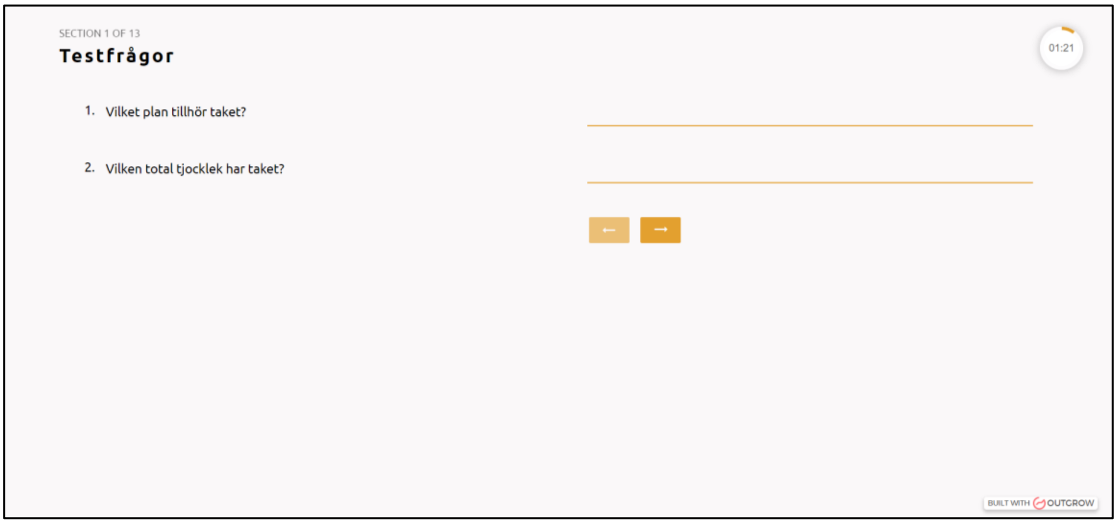
- [ ] Ja, jag vill medverka i del två
- [ ] Kanske, jag vill veta mer om del två
- [ ] Nej, jag vill inte medverka i del två

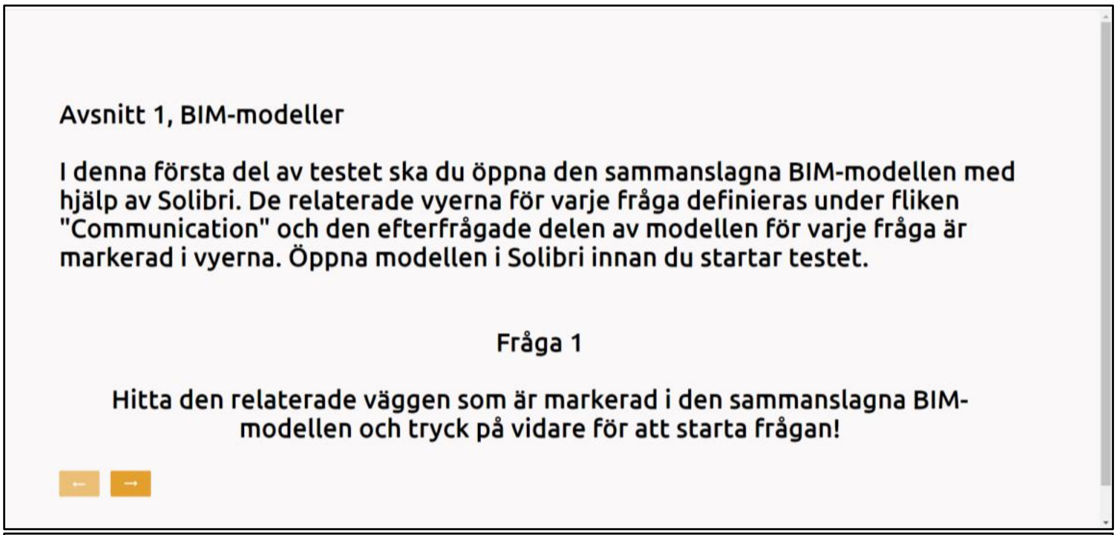
En kopia av dina svar kommer att skickas till den adress du angett.

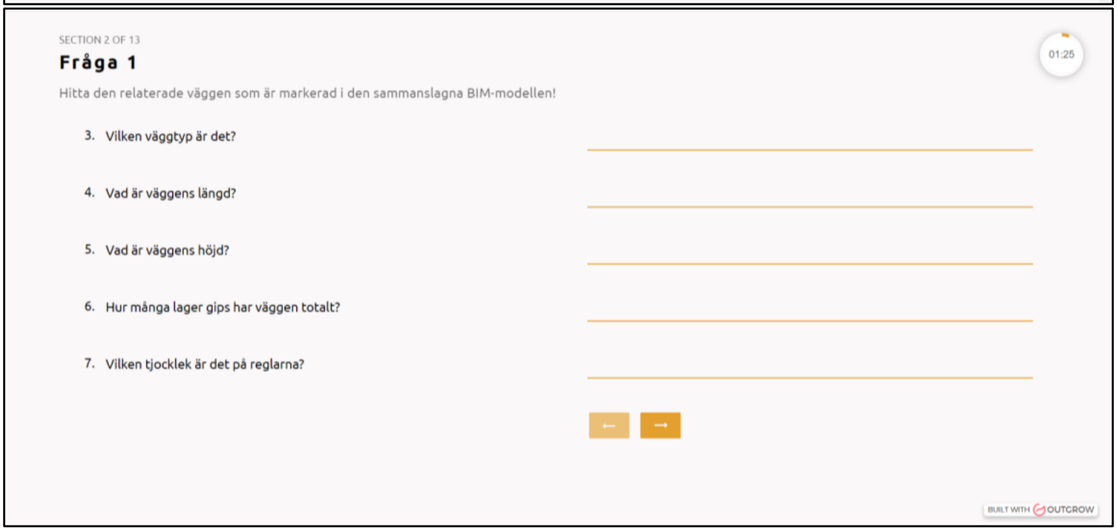
Bakåt | Skicka | Sidan 6 av 6 | Rensa formuläret

8.2 Appendix 2: The Cognitive Test




SECTION 1 OF 13
Testfrågor
01:21
1. Vilket plan tillhör taket?
2. Vilken total tjocklek har taket?
BUILT WITH OUTGROW

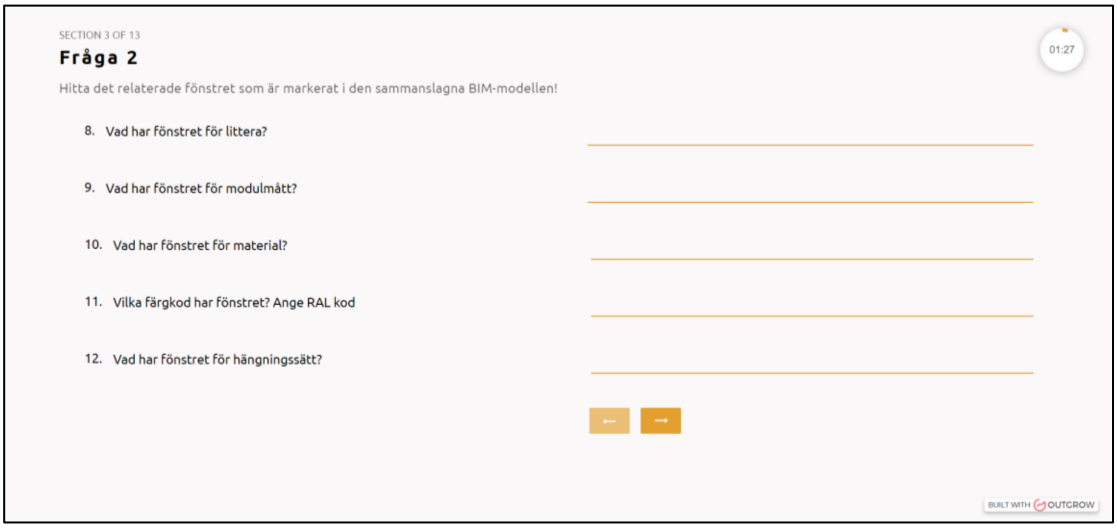

Avsnitt 1, BIM-modeller
I denna första del av testet ska du öppna den sammanslagna BIM-modellen med hjälp av Solibri. De relaterade vyerna för varje fråga definieras under fliken "Communication" och den efterfrågade delen av modellen för varje fråga är markerad i vyerna. Öppna modellen i Solibri innan du startar testet.
Fråga 1
Hitta den relaterade väggen som är markerad i den sammanslagna BIM-modellen och tryck på vidare för att starta frågan!


SECTION 2 OF 13
Fråga 1
01:25
Hitta den relaterade väggen som är markerad i den sammanslagna BIM-modellen!
3. Vilken väggtyp är det?
4. Vad är väggens längd?
5. Vad är väggens höjd?
6. Hur många lager gips har väggen totalt?
7. Vilken tjocklek är det på reglarna?
BUILT WITH OUTGROW

Fråga 2

Hitta det relaterade fönstret som är markerat i den sammanslagna BIM-modellen och tryck på vidare för att starta frågan!

BUILT WITH OUTGROW



SECTION 3 OF 13

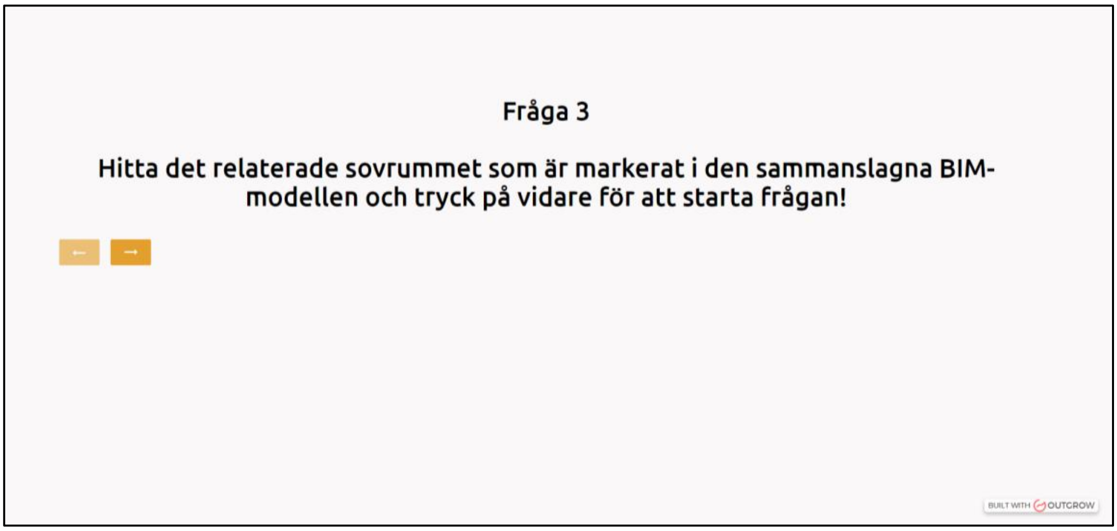
Fråga 2

01:27

Hitta det relaterade fönstret som är markerat i den sammanslagna BIM-modellen!

8. Vad har fönstret för littera?
9. Vad har fönstret för modulmått?
10. Vad har fönstret för material?
11. Vilka färgkod har fönstret? Ange RAL kod
12. Vad har fönstret för hängningssätt?

BUILT WITH OUTGROW



Fråga 3

Hitta det relaterade sovrummet som är markerat i den sammanslagna BIM-modellen och tryck på vidare för att starta frågan!

BUILT WITH OUTGROW

SECTION 4 OF 13

Fråga 3

56

Hitta det relaterade sovrummet som är markerat i den sammanslagna BIM-modellen!

13. Vad har sovrummet för dimensioner (längd * bredd)?

14. Vad har sovrummet för area?

BUILT WITH OUTGROW

Fråga 4

Hitta det markerade området för denna fråga i den sammanslagna BIM-modellen och tryck på vidare för att starta frågan!

BUILT WITH OUTGROW

SECTION 5 OF 13

Fråga 4

01:54

Hitta det markerade området för denna fråga i den sammanslagna BIM-modellen!

15. Hur högt över färdigt golv sitter ventilationskanalen?

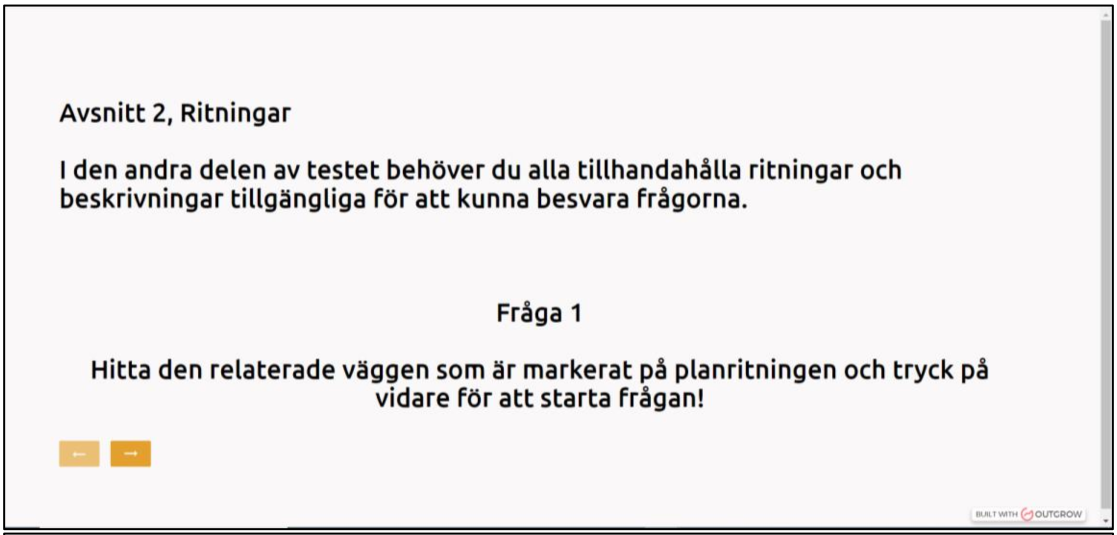
16. Vilken dimension har ventilationskanalen?

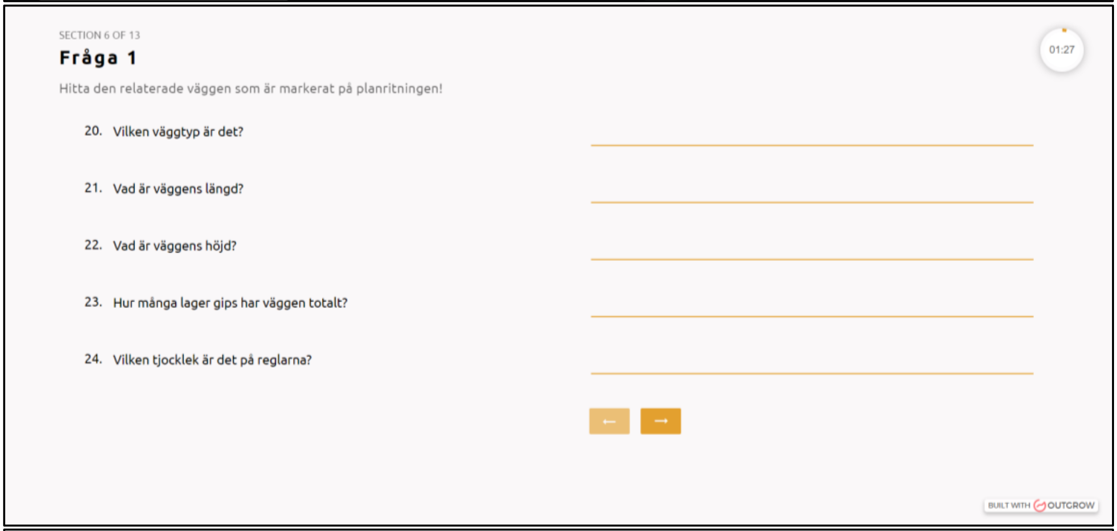
17. Hur högt över färdigt golv sitter varmvattenröret?

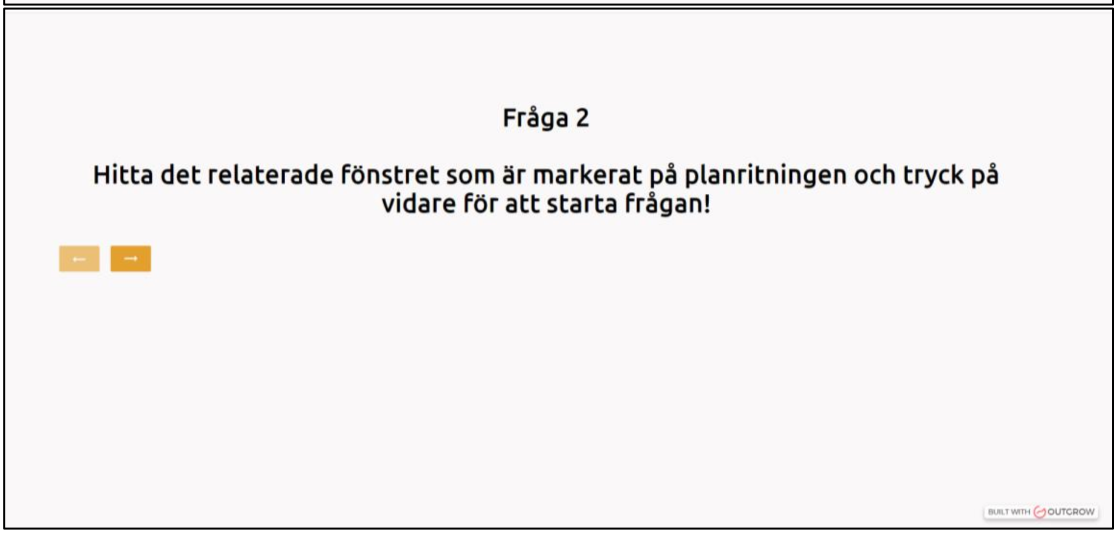
18. Vilken dimension har varmvattenröret?

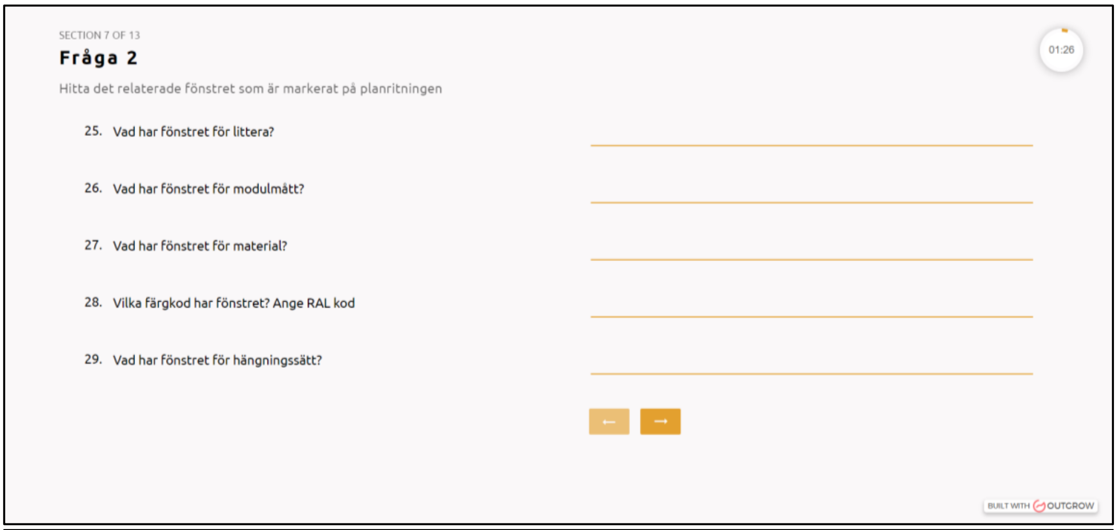
19. Kolliderar ventilationskanalen med varmvattenröret?

BUILT WITH OUTGROW


Avsnitt 2, Ritningar
I den andra delen av testet behöver du alla tillhandahålla ritningar och beskrivningar tillgängliga för att kunna besvara frågorna.
Fråga 1
Hitta den relaterade väggen som är markerat på planritningen och tryck på vidare för att starta frågan!
BUILT WITH OUTGROW


SECTION 6 OF 13
Fråga 1
Hitta den relaterade väggen som är markerat på planritningen!
01:27
20. Vilken väggtyp är det?
21. Vad är väggens längd?
22. Vad är väggens höjd?
23. Hur många lager gips har väggen totalt?
24. Vilken tjocklek är det på reglarna?
BUILT WITH OUTGROW


Fråga 2
Hitta det relaterade fönstret som är markerat på planritningen och tryck på vidare för att starta frågan!
BUILT WITH OUTGROW


SECTION 7 OF 13

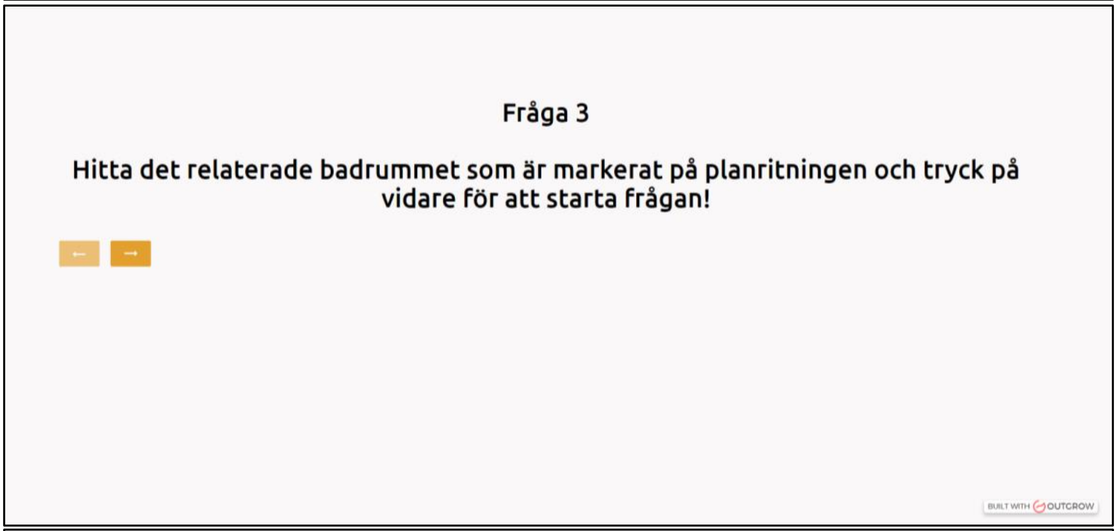
Fråga 2

Hitta det relaterade fönstret som är markerat på planritningen

25. Vad har fönstret för littera?
26. Vad har fönstret för modulmått?
27. Vad har fönstret för material?
28. Vilka färgkod har fönstret? Ange RAL kod
29. Vad har fönstret för hängningssätt?

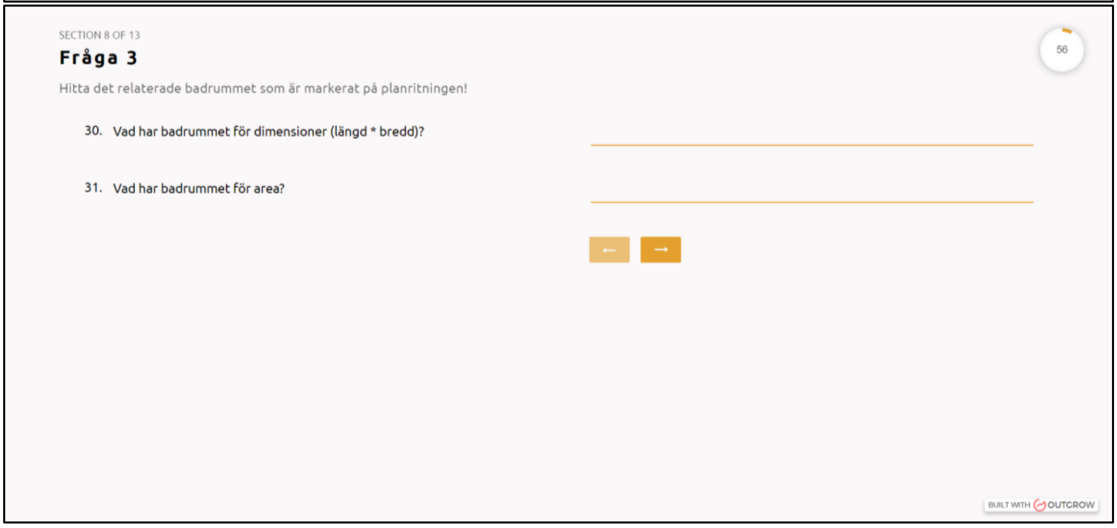
01:26

BUILT WITH OUTGROW


Fråga 3

Hitta det relaterade badrummet som är markerat på planritningen och tryck på vidare för att starta frågan!

BUILT WITH OUTGROW


SECTION 8 OF 13

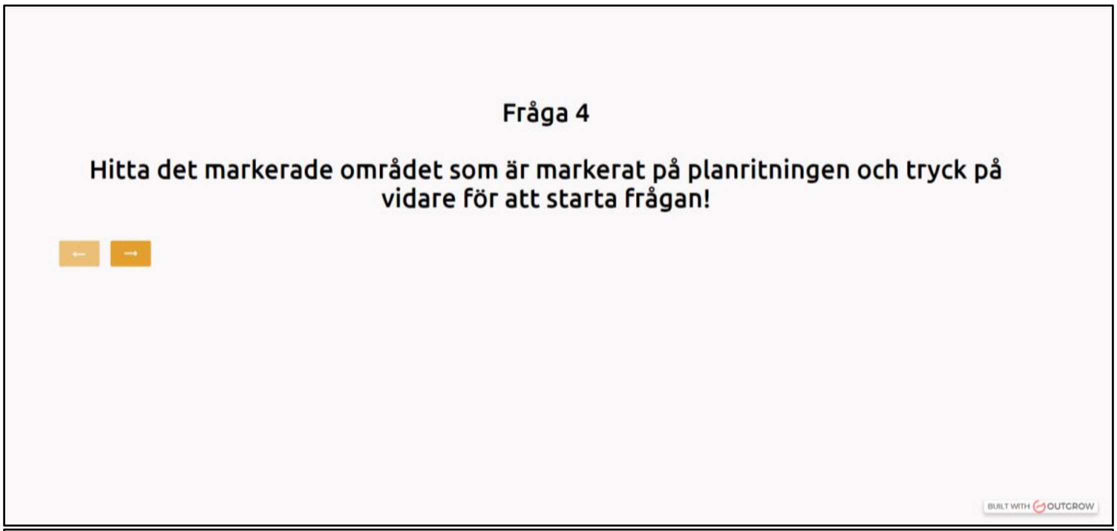
Fråga 3

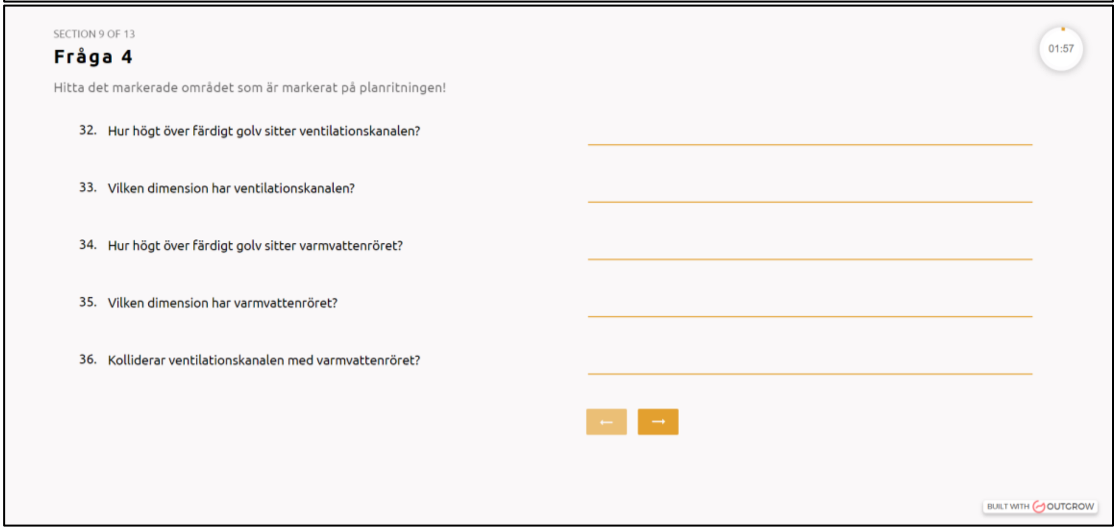
Hitta det relaterade badrummet som är markerat på planritningen!

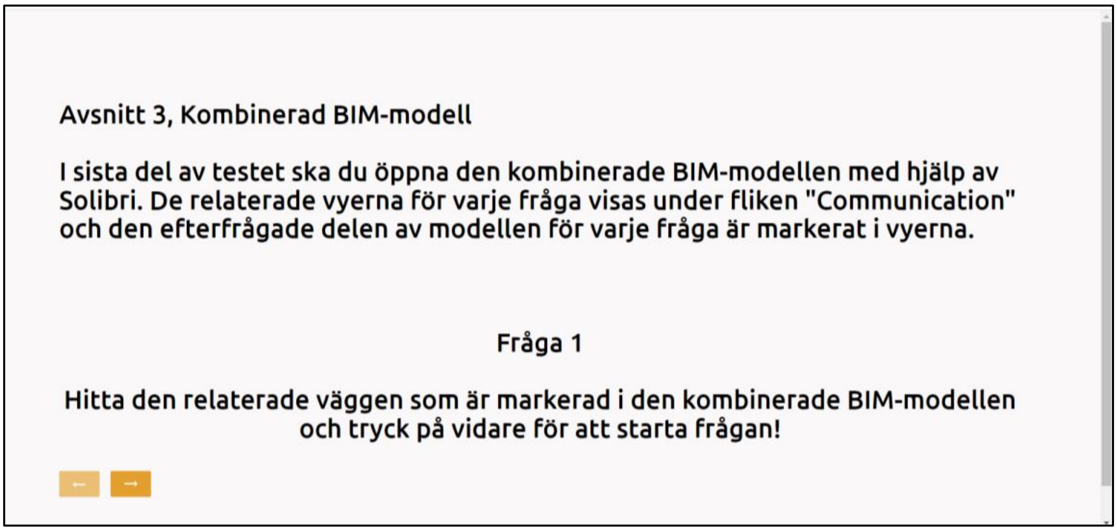
30. Vad har badrummet för dimensioner (längd * bredd)?
31. Vad har badrummet för area?

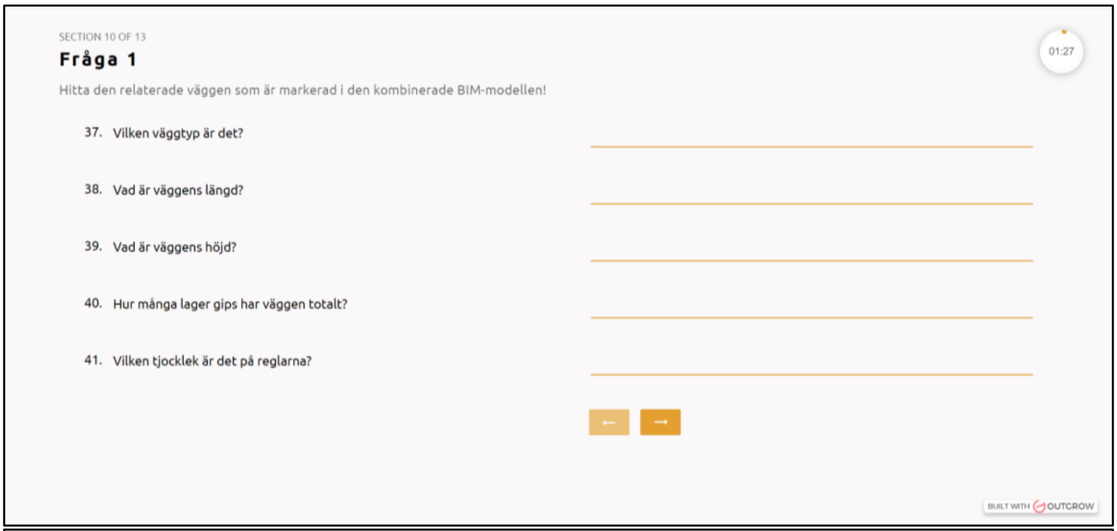
56

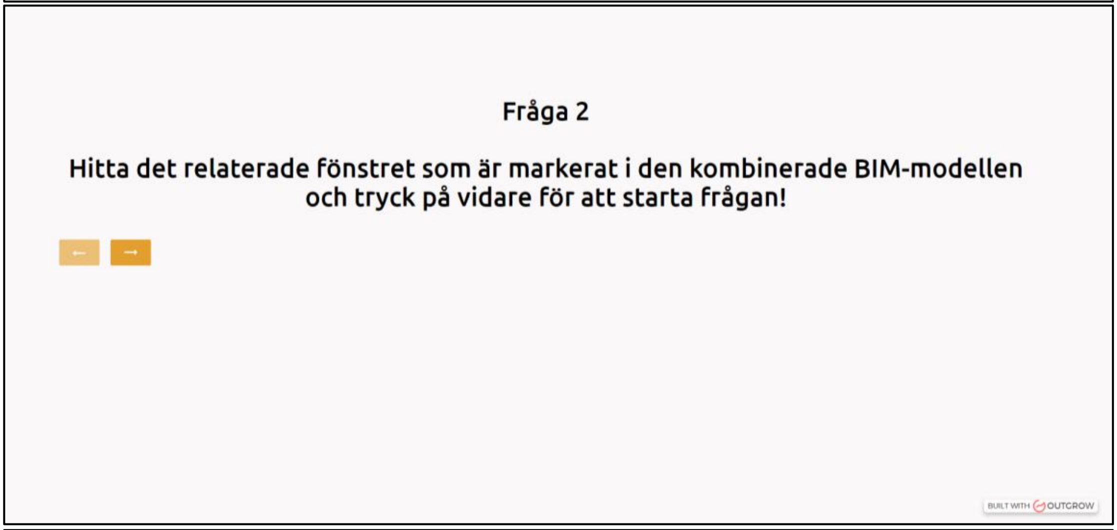
BUILT WITH OUTGROW

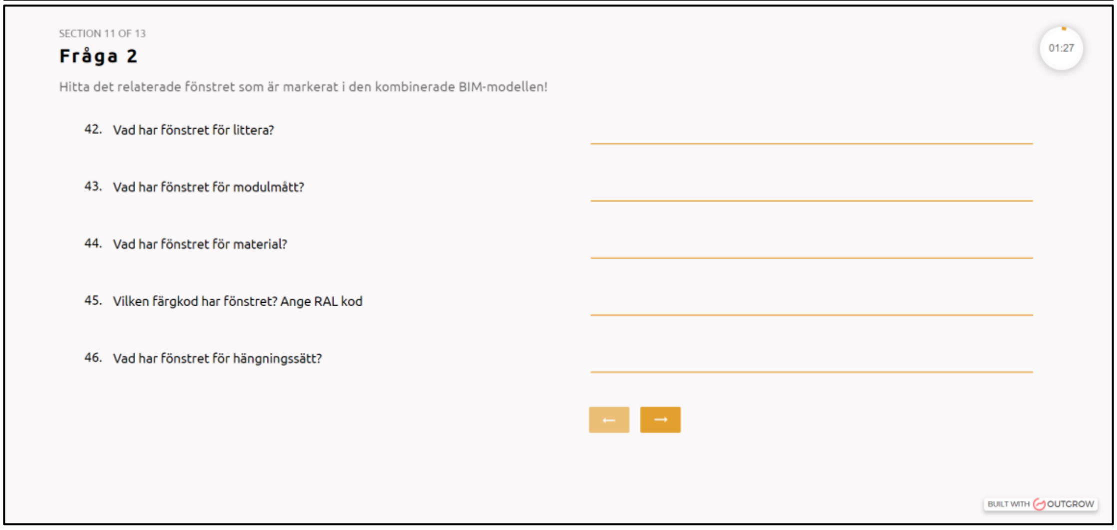

Fråga 4
Hitta det markerade området som är markerat på planritningen och tryck på vidare för att starta frågan!
BUILT WITH OUTGROW

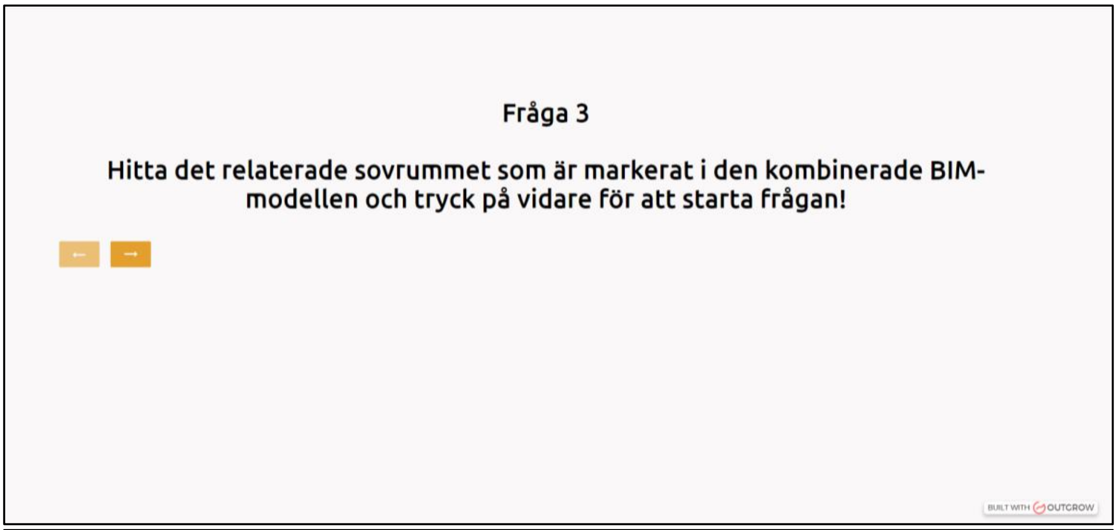

SECTION 9 OF 13
Fråga 4
Hitta det markerade området som är markerat på planritningen!
01:57
32. Hur högt över färdigt golv sitter ventilationskanalen?
33. Vilken dimension har ventilationskanalen?
34. Hur högt över färdigt golv sitter varmvattenröret?
35. Vilken dimension har varmvattenröret?
36. Kolliderar ventilationskanalen med varmvattenröret?
BUILT WITH OUTGROW

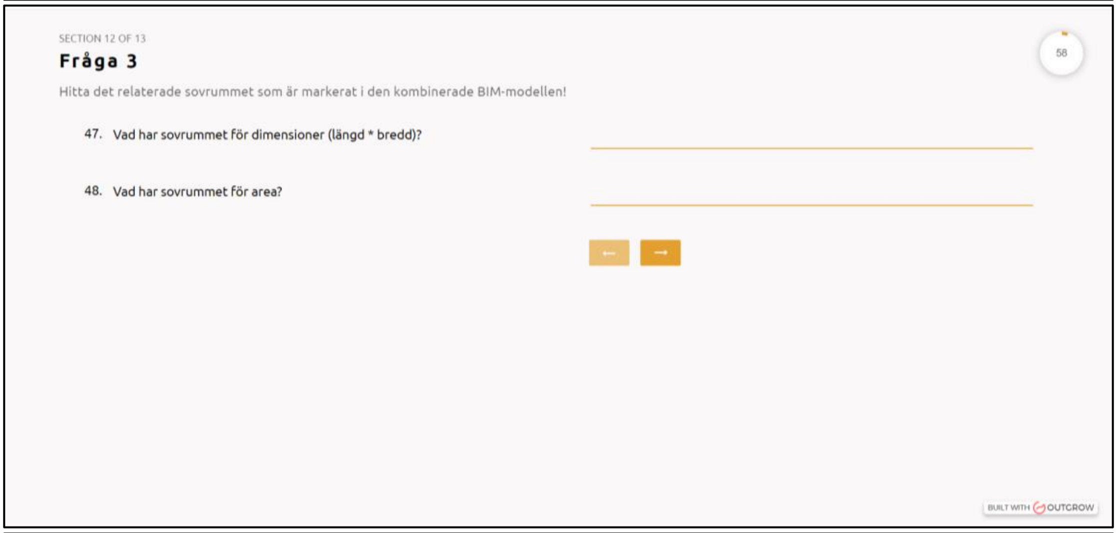

Avsnitt 3, Kombinerad BIM-modell
I sista del av testet ska du öppna den kombinerade BIM-modellen med hjälp av Solibri. De relaterade vyerna för varje fråga visas under fliken "Communication" och den efterfrågade delen av modellen för varje fråga är markerat i vyerna.
Fråga 1
Hitta den relaterade väggen som är markerad i den kombinerade BIM-modellen och tryck på vidare för att starta frågan!

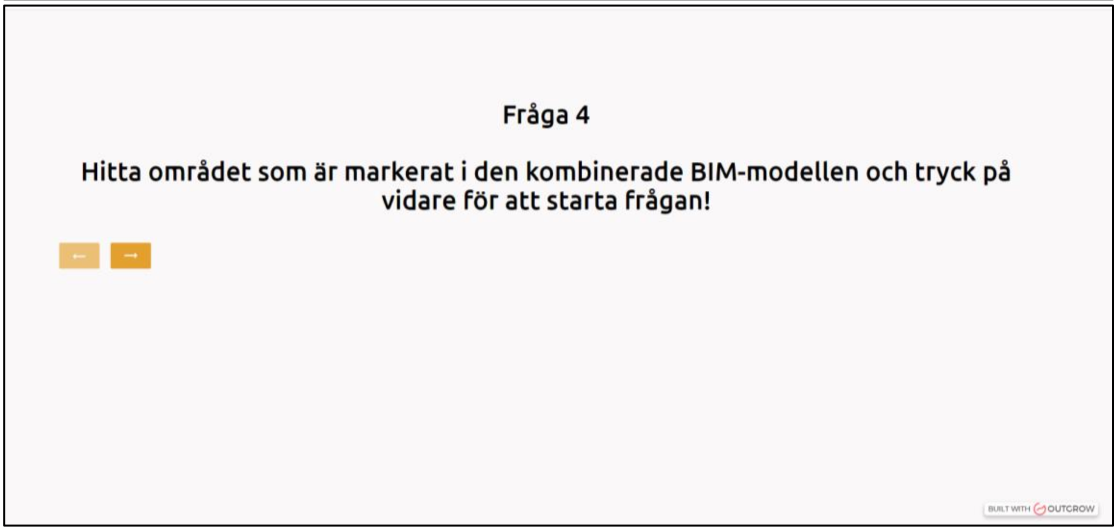

SECTION 10 OF 13
Fråga 1
Hitta den relaterade väggen som är markerad i den kombinerade BIM-modellen!
37. Vilken väggtyp är det?
38. Vad är väggens längd?
39. Vad är väggens höjd?
40. Hur många lager gips har väggen totalt?
41. Vilken tjocklek är det på reglarna?
01:27
BUILT WITH OUTGROW

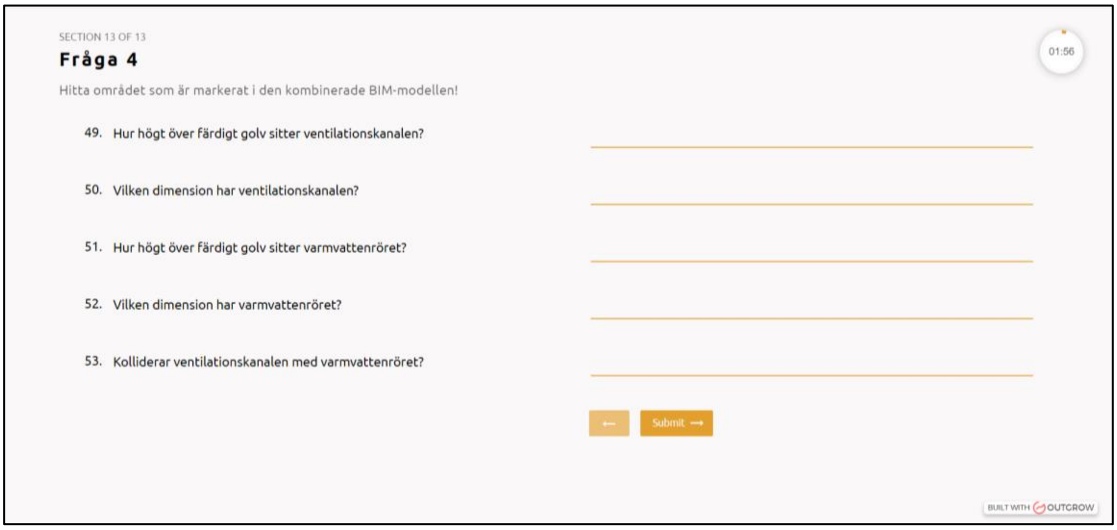

Fråga 2
Hitta det relaterade fönstret som är markerat i den kombinerade BIM-modellen och tryck på vidare för att starta frågan!
BUILT WITH OUTGROW


SECTION 11 OF 13
Fråga 2
Hitta det relaterade fönstret som är markerat i den kombinerade BIM-modellen!
42. Vad har fönstret för littera?
43. Vad har fönstret för modulmått?
44. Vad har fönstret för material?
45. Vilken färgkod har fönstret? Ange RAL kod
46. Vad har fönstret för hängningssätt?
01:27
BUILT WITH OUTGROW


Fråga 3
Hitta det relaterade sovrummet som är markerat i den kombinerade BIM-modellen och tryck på vidare för att starta frågan!
BUILT WITH OUTGROW


SECTION 12 OF 13
Fråga 3
Hitta det relaterade sovrummet som är markerat i den kombinerade BIM-modellen!
47. Vad har sovrummet för dimensioner (längd * bredd)?
48. Vad har sovrummet för area?
58
BUILT WITH OUTGROW


Fråga 4
Hitta området som är markerat i den kombinerade BIM-modellen och tryck på vidare för att starta frågan!
BUILT WITH OUTGROW


SECTION 13 OF 13
Fråga 4
Hitta området som är markerat i den kombinerade BIM-modellen!
49. Hur högt över färdigt golv sitter ventilationskanalen?
50. Vilken dimension har ventilationskanalen?
51. Hur högt över färdigt golv sitter varmvattenröret?
52. Vilken dimension har varmvattenröret?
53. Kolliderar ventilationskanalen med varmvattenröret?
Submit
01:56
BUILT WITH OUTGROW

DEPARTMENT OF ARCHITECTURE AND
CIVIL ENGINEERING
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2021
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